Human Cancer Biology

Large-Scale Analysis of KIT Aberrations in Chinese Patients with Melanoma

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Abstract

Purpose: KIT aberrations were described in acral and mucosal melanomas in largely Caucasian populations. Asian populations are more prone to develop acral and mucosal than cutaneous melanomas, and may harbor a high frequency of KIT aberrations.

Experimental Design: Melanoma subtypes (n = 502) were analyzed histologically to determine melanoma subtype. Tissue samples were analyzed for mutations in exons 9, 11, 13, 17, and 18 of KIT gene in genomic DNA by PCR amplification and Sanger sequencing. The copy numbers of the KIT gene were analyzed by quantitative PCR, and protein expression levels of KIT (CD117) were determined by immunohistochemistry.

Results: The most common melanoma subtypes were acral (38.4%) and mucosal (33.3%) melanomas in this population. The overall incidence of somatic mutations within the KIT gene was 10.8% (54/502), and all subtypes of melanoma contained KIT mutations. Increases in KIT gene copy numbers were correlated to CD117 overexpression. The genetic mutations of KIT were unrelated to the age, gender, stage, thickness, and ulceration of primary melanomas. Importantly, the overall survival of melanoma patients with KIT mutations (P = 0.001) or with KIT aberrations (mutation plus amplification, P = 0.0002) was significantly shorter than that of patients without such alterations.

Conclusion: In China, the prevalent melanomas are acral and mucosal melanomas. KIT mutations are detected in all melanoma subtypes. Our study suggests that increases in KIT gene copy numbers, but not KIT mutations, may be correlated to CD117 overexpression. For the first time, our study suggests that genetic KIT aberration is an adverse prognostic factor for melanoma. Clin Cancer Res; 17(7); 1684–91. ©2011 AACR.

Introduction

The incidence of melanoma is rising globally and this includes an increased prevalence in China (1–3). Based on the anatomic location and the degree of sun exposure, melanomas can be classified into 4 subtypes: (1) melanomas that occur on skin without chronic sun-induced damage (non-CSD); (2) melanomas on skin with chronic sun-induced damage (CSD); (3) mucosal melanomas, and (4) acral melanomas (4, 5). Incidence of these 4 subtypes differs significantly among different races and ethnicities (1–3). For example, acral melanomas account for only 1% to 7% of all cutaneous melanomas in Caucasians, whereas the percentage is significantly higher in Chinese and other populations (1–3, 6, 7). Despite these apparent disparities, few investigations have rigorously evaluated melanoma subtypes in large non-Caucasian cohorts, and no studies have been performed in Chinese patient populations.

The KIT (c-Kit, CD117, stem cell factor receptor) proto-oncogene encodes a 145 kDa transmembrane tyrosine kinase protein (8). The dysregulation of KIT has been reported in certain neoplastic disorders (9, 10). Signal transduction pathways, such as the PI3K/Akt and mitogen-activated protein (MAP) kinase pathways, have been implicated in mediation of KIT-induced mitogenesis and differentiated functions (11). Sequencing of the KIT gene has revealed mutations in the majority of gastrointestinal stromal cell tumors (GIST). Recently, Curtin and colleagues, who examined 102 primary melanomas excised from...
various anatomical sites, found mutations and/or copy number increases of KIT in 39% of mucosal melanomas, 36% of acral melanomas, and 28% of melanomas on chronically sun-damaged skin, but not in any (0%) melanomas on nonglabrous skin without CSD (5). Other recent studies also identified oncogenic KIT mutations in several melanoma cohorts (4, 12–15). These findings indicate that KIT is an important oncogene in melanomas of mucosa, acral skin, and skin with CSD.

Imatinib (formerly known as STI571) is a tyrosine kinase inhibitor with activity against Abelson tyrosine kinase (ABL), KIT, and platelet-derived growth factor receptors (11). This drug is approved for the treatment of chronic myelogenous leukemia and GIST, and is being evaluated in clinical trials for the treatment of melanomas harboring KIT mutations (16–22). KIT is a validated therapeutic target in GIST, with a large percentage of patients bearing KIT mutant tumors benefiting from imatinib and second-generation KIT inhibitors (16, 17). Prior trials have shown that kinase inhibitors such as imatinib have little or no activity in histologically or genetically unselected melanoma patients (18–20). Therefore, ongoing trials require that a KIT gene mutation be documented in the tumor before a patient is treated (21, 22). However, published series on the frequency of KIT aberrations in melanoma are relatively small, and there are almost no data available on Chinese patients, with potentially the largest population of such patients.

We collected 502 melanoma tissue samples from patients, evaluated incidence of melanoma subtypes and examined all samples for alterations in the KIT gene. This study represents the first systematic analysis of melanoma subtypes and somatic KIT mutations of melanoma in a Chinese patient cohort.

Patients and Methods

Patients and tumor tissue samples

This study involved samples from 502 melanoma patients, hospitalized during January 2006 and January 2010 at the Peking Cancer Hospital & Institute. These samples were analyzed by hematoxylin and eosin (H&E) staining and by immunohistochemistry for melanoma markers (S-100, HMB-45, or MART-1) to confirm the diagnosis of melanoma. Sun-induced damage was defined microscopically by the presence or absence of marked solar elastosis on H&E-stained sections, and was determined by at least 2 individual pathologists as previously described (4, 5). Clinical data, including age, sex, TNM (tumor-node-metastases) stage, thickness (Breslow), ulceration, and survival (follow-up persisted until the missing of follow-up or the death of patients) were collected. A representative formalin-fixed, paraffin-embedded block was selected and used for immunohistochemical (IHC) analysis of CD117 as well as for the molecular studies. Samples were sequentially subjected to molecular analysis of KIT mutations and KIT gene copy numbers (the process for collection and analysis of the samples is illustrated in Supplementary Fig. S1, and detailed information for these 502 cases is listed in Supplementary Table S1). To ensure the accuracy of analysis for KIT mutations, results for the first 20 melanoma samples were independently confirmed in Dr. Corless’ laboratory, Department of Pathology, Oregon Health and Science University, Portland, USA. This study was approved by the medical ethics committee of the Beijing Cancer Hospital & Institute and was conducted according to the Declaration of Helsinki Principles.

DNA preparation and mutation screening

Genomic DNA was extracted from formalin-fixed, paraffin-embedded sections using a QIAamp DNA FFPE Tissue Kit (Qiagen). To detect hotspot mutations, we amplified exons 9, 11, 13, 17, and 18 of the KIT gene by PCR in at least 2 separate preparations of genomic DNA. The primer sequences are listed in Supplementary Table S2. PCR conditions have been described previously (5, 13, 15, 23–25). We purified PCR products with QIAquick (Qiagen), and directly sequenced them using Big Dye Terminator sequencing chemistry on an ABI 3130 automated sequencer (Applied Biosystems). All mutations were confirmed by repeat bidirectional sequencing on the ABI sequencer.

KIT gene amplification analysis by real-time PCR

Quantitative real-time PCR was performed as described previously (15, 23), using ribonuclease P (RNase P) as a control gene. Relative copy numbers were calculated using the ΔΔCt method (as detailed in Supplementary Table S2).

CD117 immunohistochemistry

IHC analysis for CD117 (KIT protein) was done using the Dako polyclonal rabbit antibody (Dako) at 1:400 dilution, followed by a standard avidin–biotin detection protocol using diaminobenzidine. Hematoxylin–counterstained slides were cover-slipped and examined for the intensity of staining. The staining intensity was scored as 0, 1, 2, and 3 (“0” as negative, and “3” as the strongest) by 3 pathologists independently, and examples of the scores were shown in Supplementary Fig. S2.
Statistical analysis
All the statistical analyses were performed using SPSS 13.0 software. Categorical data are described using frequencies and percentages. Continuous data such as age are described using means ± SD for normally distributed data. \( \chi^2 \) test or Fisher’s exact test or Kruskal–Wallis test was used to differentiate the rates of different groups, and differences in measurement data of 2 groups were evaluated by unpaired \( t \) test or \( t’ \) test. Survival curves were established using the Kaplan–Meier method and compared by the log-rank test. All statistical analyses were 2 sided, and significance was assigned at \( P < 0.05 \).

Results

Melanoma subtypes in a Chinese population
Using the classification scheme developed by Bastian and colleagues (4, 5), we found that, in our Chinese patient cohort, the most prevalent melanoma subtypes were acral (38.4%) and mucosal (33.3%) melanomas (Table 1). The CSD melanomas were relatively rare (5.8%) in Chinese. Non-CSD melanomas, by far the most common subtype in Caucasians, accounted for 12.4% of all melanomas in Chinese population. Additionally, 51 patients with melanomas (e.g., melanomas found in lymph nodes, liver, lung, and brain upon hospitalization) of unknown primary (UP), accounted for 10.2% of all melanomas.

Genetic aberrations of KIT gene in melanoma subtypes
To investigate mutations within KIT in Chinese patients, we amplified mutation hotspot regions (exons 9, 11, 13, 17, and 18) of KIT gene and analyzed the PCR products by Sanger sequencing. To ensure accurate results, we performed identical experimental processes (DNA extraction, PCR amplification and bidirectional sequencing) at least twice on each sample. Typical sequencing results for mutations in KIT are shown in Supplementary Figures. S3 to S8.

Among the 502 samples screened for KIT mutations, the overall mutation frequency was 10.8% (54/502), with the highest mutation frequency within the CSD subgroup (20.7%). In the acral and mucosal melanoma subtypes, the frequency of KIT mutations was 11.9% (23/193) and 9.6% (16/167), respectively (Table 2), which are lower than the mutation frequency reported in Caucasian patients (5, 13). We also examined KIT gene copy number in these samples and found that it was increased in 37 (7.4%) of the 502 samples. Increased KIT gene copy number was comparatively more frequent in acral (7.3%) and mucosal (10.2%) melanomas than in CSD (3.4%) and Non-CSD (3.2%) melanomas (Table 2). In the entire cohort of 502 patients, genetic aberrations (mutation plus amplification) of KIT were detected in 86 (17.1%) cases (5 of them harboring both KIT mutation and increased KIT copy number). KIT aberrations were detected in 17.6%

### Table 1. Patient characteristics and melanoma subtypes in Chinese patients

<table>
<thead>
<tr>
<th>Group</th>
<th>Patients</th>
<th>Sex</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
<td>Male</td>
</tr>
<tr>
<td>Acral</td>
<td>193</td>
<td>38.4</td>
<td>105</td>
</tr>
<tr>
<td>Mucosal</td>
<td>167</td>
<td>33.3</td>
<td>71</td>
</tr>
<tr>
<td>CSD</td>
<td>29</td>
<td>5.8</td>
<td>14</td>
</tr>
<tr>
<td>Non-CSD</td>
<td>62</td>
<td>12.4</td>
<td>24</td>
</tr>
<tr>
<td>UP</td>
<td>51</td>
<td>10.2</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>502</td>
<td>/</td>
<td>240</td>
</tr>
</tbody>
</table>

Abbreviations: M, male; F, Female.

### Table 2. Genetic aberrations of KIT in Chinese melanoma subtypes

<table>
<thead>
<tr>
<th>Subtype</th>
<th>KIT mutation</th>
<th>Increased KIT copy number</th>
<th>Genetic KIT aberration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Positive</td>
<td>%</td>
</tr>
<tr>
<td>Acral</td>
<td>193</td>
<td>23</td>
<td>11.9</td>
</tr>
<tr>
<td>Mucosal</td>
<td>167</td>
<td>16</td>
<td>9.6</td>
</tr>
<tr>
<td>CSD</td>
<td>29</td>
<td>6</td>
<td>20.7</td>
</tr>
<tr>
<td>Non-CSD</td>
<td>62</td>
<td>5</td>
<td>8.1</td>
</tr>
<tr>
<td>UP</td>
<td>51</td>
<td>4</td>
<td>7.8</td>
</tr>
<tr>
<td>Total</td>
<td>502</td>
<td>54</td>
<td>10.8</td>
</tr>
</tbody>
</table>
(34/193) of acral melanomas, 19.2% (32/167) of mucosal melanomas, 20.7% (6/29) of CSD melanomas, 11.3% (7/62) of Non-CSD melanomas, and 13.7% (7/51) of melanomas of UP.

Next, we analyzed the correlation of KIT mutations and increased KIT gene copy number to CD117 expression levels. Among the 54 cases with KIT mutations, the IHC detection rate for CD117 was 44.4% (24/54), which was not significantly higher ($P = 0.55$) than that (39.1%) in cases (175/448) without KIT mutations (Table 4). For the 37 cases showing increased KIT gene copy number, the detection rate for CD117 was 59.5% (22/37), which was significantly higher ($P = 0.02$) than that (38.1%) in cases (177/465) with normal KIT gene copy number (Table 4). However, when the data for KIT gene mutation were combined with the data for KIT gene amplification (regarded as KIT genetic aberrations), we found that the

Table 3. CD117 expression in melanoma subtypes

<table>
<thead>
<tr>
<th>Subtype</th>
<th>IHC scores</th>
<th>NES</th>
<th>NPS</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Acral</td>
<td>121</td>
<td>57</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Mucosal</td>
<td>93</td>
<td>51</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>CSD</td>
<td>20</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Non-CSD</td>
<td>35</td>
<td>18</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>UP</td>
<td>34</td>
<td>11</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>303</td>
<td>145</td>
<td>29</td>
<td>25</td>
</tr>
</tbody>
</table>

Abbreviations: NES, number of examined samples; NPS, number of positive samples.

*The signal intensity of immunohistochemistry results were determined by 3 individual pathologists and scored as 0, 1, 2, and 3, with score “0” as negative and score “3” as the strongest.

*Samples with signal intensity of scores 1, 2 or 3 were regarded as CD117 positive.

Table 4. Correlation of KIT genetic aberrations to CD117 expression

<table>
<thead>
<tr>
<th>Subtype</th>
<th>KIT mutation</th>
<th>Gene copy number</th>
<th>Genetic aberration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mutation</td>
<td>WT</td>
<td>Increased</td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>273</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>129</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>24</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>Positive/total</td>
<td>24/54</td>
<td>175/448</td>
<td>22/37</td>
</tr>
<tr>
<td>Positive rate (%)</td>
<td>44.4</td>
<td>39.1</td>
<td>59.5</td>
</tr>
<tr>
<td>$P^c$</td>
<td>0.55$^d$</td>
<td>–</td>
<td>0.02$^a$</td>
</tr>
</tbody>
</table>

Abbreviations: WT, wild type.

*Genetic aberration includes KIT mutation and increased gene copy number. Five cases show both genetic mutation and increased gene copy number of KIT.

*The signal intensity of immunohistochemistry results were determined by 3 individual pathologists and scored as 0, 1, 2, and 3 with score “0” as negative and score “3” as the strongest.

*Significance evaluated by chi-square tests.

*Positive rate of CD117 in cases with KIT mutation versus that in cases without KIT mutation.

*Positive rate of CD117 in cases with increased KIT gene copy number versus that in cases with normal KIT gene copy number.

*Positive rate of CD117 in cases with KIT genetic aberrations versus that in cases without KIT aberrations.
positivity rate of CD117 IHC (50.0%) in cases (43/86) with genetic KIT aberrations was significantly higher (P = 0.04) than that (37.5%) in cases (156/416) without genetic KIT aberrations. These data indicate that KIT mutation may not necessarily lead to increased CD117 expression, but the amplification of KIT gene does correlate with CD117 over-expression. Importantly, these results suggest that IHC analysis of CD117 expression is an unreliable surrogate for KIT aberration analysis and should not be used as an initial screen to identify KIT genetic aberrations.

Alterations of KIT in melanoma subtypes

KIT aberrations, including KIT gene mutations and increased KIT gene copy number, and the expression of KIT protein have been implicated in the pathogenesis of certain human malignancies (9–11). Of the 54 cases with KIT mutations, 39 different mutations were detected (Table 5 and Supplementary Fig. S3–S8). In addition to 14 known KIT mutations (E490G, P551L, V553N, W557R, V559A, V560D, N566D, L576P, L576F, E583G, K642E, L647F, I789T, D816N, N822K; C844Y; F848L; W853stop; L858R + L865L), we found 25 novel KIT mutations. In our cohort, the most frequent KIT mutations were L576P (9 cases), K642E (5 cases), I571-L576 in-frame deletion (2 cases), and N822K (2 cases). 11 mutations resulting in single amino acid substitutions (totaling 33 mutations detected in 47 patients) were the most common type of KIT mutation. Additionally, there were 2 cases with mutations in 2 separate exons (codes No. 146 and No. 334, Supplementary Fig. S8), 4 cases with premature stop codons (cases No. 245, No. 263, No. 338, and No. 447), and 2 cases with in-frame deletions in exon 11 (IDPTQL, amino acids 571–576, cases No. 26 and No. 501). The 39 different types of KIT mutations detected in this study affect the extracellular domain (ECD, 2 cases), the juxtamembrane domain (JMD, 25 cases), or both the JMD and the kinase domain (1 case; code No. 146) of KIT protein. These data suggest that the JMD and the kinase domain are affected most frequently, and more effects are required to document the functional significance of novel KIT mutations.

Among the 54 cases with a KIT mutation, 5 cases (9.3%) showed increased KIT gene copy number and 24 cases (44.4%) were positive for CD117 (Table 5), which was not significantly different to those (7.4% and 39.6% respectively) detected in the overall population. Moreover, we found that 68.8% (11/16) of mucosal melanomas with KIT mutations were positive for CD117, which, however, was not significantly higher than the staining seen in acral melanomas (34.8%), CSD melanomas (16.7%), Non-CSD melanomas (60.0%), or of melanomas of UP (25.0%; P = 0.11). These data suggest that KIT mutation is not necessarily related to increased KIT gene copy number or CD117 expression.

Correlation of KIT aberrations to the clinical features of melanoma

In our cohort, the mean age and the proportion of gender were not significantly different between patients with KIT mutation and those without KIT mutation.

Table 5. KIT aberrations in melanoma subtype

<table>
<thead>
<tr>
<th>Subtype</th>
<th>KIT mutation</th>
<th>Domain affected</th>
<th>Incresed KIT copy number (no./total)</th>
<th>CD117 expression (no./total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acral</td>
<td>V489I; E490G; Y553N; I563V; W582stop; N566D + A829V; L576P; L576F + A636A; E633G; L637L + G648S; K642E; I817T; N822K; C844Y; F848L; W853stop; L859P + L865L</td>
<td>ECD; JMD; kinase; JMD + kinase</td>
<td>3/23</td>
<td>8/23</td>
</tr>
<tr>
<td>Mucosal</td>
<td>Q556R; W557R; V559A; V560D; E561G; I571-L576del; L576P; E583G; K642E; L647F; I789T; D816N; N822K; N822Y; W853stop</td>
<td>JMD; kinase</td>
<td>1/16</td>
<td>11/16</td>
</tr>
<tr>
<td>CSD</td>
<td>V555I; I571M; K642E; L566R; Y846H; E849stop</td>
<td>JMD; kinase</td>
<td>1/6</td>
<td>1/6</td>
</tr>
<tr>
<td>Non-CSD</td>
<td>P551L; I571-L576del; T632I-L637F; K642E; L831P</td>
<td>JMD; kinase</td>
<td>0/5</td>
<td>3/5</td>
</tr>
<tr>
<td>UP</td>
<td>L576P; L576F; P577H; S645N</td>
<td>JMD; kinase</td>
<td>0/4</td>
<td>1/4</td>
</tr>
</tbody>
</table>

The threshold for KIT gene copy number increase was 3.40 copies of KIT relative to RNase P. "No/total" indicates for number of cases with increased KIT copy number to that of cases with KIT mutation. The signal intensity of immunohistochemistry results were determined by 3 individual pathologists and scored as 0, 1, 2, and 3. Samples with signal intensity of scores 1, 2, or 3 were regarded as CD117 positive. "No/total" indicates for number of cases positive for CD117 to that of cases with KIT mutation.

![Table 5. KIT aberrations in melanoma subtype](https://example.com/table5.png)
(Supplementary Table S3). The age and gender proportion were also similar between groups with or without increased KIT copy number, KIT genetic aberrations (mutation plus amplification) or CD117 positive expression (Supplementary Table S3).

Stage, thickness and ulceration of melanoma lesions are important clinical features of melanoma, and these factors have been implicated in the prognosis of melanoma (1, 26). The data for stage (450 cases), thickness (438 cases) and ulceration (439 cases) were available for further analysis in our study (detailed in Supplementary Table S1).

Among the 51 patients with KIT mutations and with the clinical stage data available, the percentages of patients with stage I, II, III, and IV were 3.9% (2 cases), 37.3% (19 cases), 21.6% (11 cases), and 37.3% (19 cases), respectively, which were not significantly different from those without a KIT mutation (Supplementary Table S3). For the patients with KIT amplification (32 cases), the percentages of the 4 stages were also not different to those in patients showing normal KIT gene copy number (Supplementary Table S3). When KIT mutation plus KIT amplification were regarded as a single factor (KIT genetic aberration), the stage distribution was similar between patients with or without KIT genetic aberrations. The proportion of cases with overexpression of CD117 versus the absence of expression did not vary across the 4 stages of melanoma (Supplementary Table S3). Moreover, in the patients with advanced stage IV melanoma, data were available for 67 patients with M1a/b melanomas and 79 patients with M1c melanomas, respectively. We found that the genetic mutations, amplifications, and aberrations (mutation plus amplification) of KIT were not significantly different between M1a/b and M1c stages ($P = 0.54, 0.78,$ and 0.80, respectively).

The average thickness of all 438 available samples was more than 5 mm, which was much thicker than the previous reports (1, 2) but was the actual status for Chinese patients upon hospitalization. The average thickness of samples without KIT mutations was $4.91 \pm 2.54$ mm, whereas that of samples with KIT mutations was $5.24 \pm 2.63$ mm, the tumor thickness was not significantly different in these 2 groups ($P = 0.46$, chi-square test). Moreover, the average thickness in patients with KIT gene amplification ($5.08 \pm 2.60$ mm), KIT genetic aberrations ($5.24 \pm 2.55$ mm), or CD117 overexpression ($4.92 \pm 2.61$ mm) were not significantly different to those ($P = 0.84, 0.89$ and 0.75, respectively) in patients without such KIT/CD117 alterations (Supplementary Table S3).

Ulceration of a cutaneous melanoma on microscopic sections is an adverse prognostic finding (1, 26). In our cohort, the overall ulceration rate was 59.2% (260/439). Specifically, the ulceration rate in acral, mucosal, CSD and Non-CSD melanomas were 60.4% (113/187), 56.2% (91/162), 69.0% (20/29), and 59.0% (36/61), respectively. Moreover, we found that statistical differences were not found for ulceration rates between melanomas with or without KIT mutations ($P = 0.65$), with or without KIT amplification ($P = 0.46$), with or without genetic KIT aberrations ($P = 0.61$) or with or without CD117 overexpression ($P = 0.22$; Supplementary Table S3).

**Prognostic significance of KIT aberrations for overall survival of melanoma**

The stage, thickness, and ulceration of primary melanoma are known prognostic factors for prediction of outcomes of melanoma (1, 26). Although several studies have investigated KIT gene mutations in melanoma (4, 5, 12–15), their small size precluded meaningful investigation into the relationship of KIT alterations to overall survival. In consistent with previous study (27), we found that the overall survival of patients with ulceration or at advanced stages was significantly shorter than those without ulceration ($P < 0.05$) or at an early stage ($P < 0.001$), respectively. Then we analyzed the prognostic significance of KIT mutation, KIT amplification, KIT genetic aberrations (mutation plus amplification), and CD117 expression for overall survival. The survival data were collected for patients who were diagnosed as primary melanoma or melanoma of UP (Supplementary Table S1). The median follow-up period was 24.00 (3.00 ~ 229.00) months ($n = 473$). We found that the median survival time for patients with KIT mutations (30 months) was significantly shorter than for patients with wild-type tumors (53 months; $P = 0.01$, Fig. 1A). In addition, patients with increased KIT copy number had a worse survival (42 months) than patients with normal KIT copy number (53 months; Fig. 1B). Together, KIT
genetic aberrations were also associated with shorter survival (32.00 months vs. 55.00 months; \( P = 0.0002 \), Fig. 1C), whereas there was no difference in the outcome of cases with CD117 overexpression (52 months) as compared with cases lacking CD117 expression (51 months; Fig. 1D). These data suggest that KIT mutations and genetic KIT aberrations may be of prognostic significance for melanoma patients.

**Discussion**

In the Caucasian population, the major subtype of melanoma is CSD (1, 2, 4, 5). In contrast, acral and mucosal melanoma, which constitute a small proportion of melanomas in Caucasians, are the most prevalent melanoma subtypes in non-Caucasians, especially in Chinese, as evidenced by our study and by the others (1, 2–7). We found that the incidence of KIT mutation was lower in acral and mucosal melanomas, as compared with that in CSD melanomas and to that reported by others (4, 5, 12–15). The discrepancies between our study and previous reports may be attributed to differences in pathogenesis and genetic predisposition to melanoma. Small sample sizes in previous studies and inadvertent patient selection factors may contribute to the difference. For therapeutic purposes, KIT aberrations may be of clinical importance in identifying patients who may benefit from small molecule inhibitors (e.g., imatinib; refs 16, 17, 21, 22). Diverse KIT mutations were detected in Chinese melanoma patients, with only the K642E, L576P, V559A, and W557R mutations having known sensitivity to imatinib (5, 12–15). Although it has been suggested that mutations affecting the JMD domain will lead to gain-of-function of KIT (28, 29), the significance of the other mutations affecting the ECD and kinase domain of KIT discovered in our study awaits further evaluation. There is recent preliminary evidence provided by Carvajal and colleagues that imatinib can induce an overall response rate of 33% in the small proportion of melanomas with mutations in exon 9 and exon 13 of KIT gene (22). However, in our preliminary phase II clinical trial of imatinib (400 mg/day), we could only obtain an overall response rate of 21% (6/28; ref 30). We speculate that the more enrolled patients, the more variable mutations (e.g., mutations in exons other than exon 9 or exon 13) in KIT and the more advanced stages in our cohort may contribute to this difference (22, 30), which may suggest for a more strict selection strategy for enrollment of imatinib-sensitive melanoma patients.

KIT mutations have been screened in various tumors (23, 24, 28) and have been suggested as an adverse prognostic factor for survival (31–34). In GIST, it has been suggested that KIT mutation is an independent prognostic factor for overall and cause-specific survival of patients with GIST (31). In another study, KIT mutation and activation are important in GIST pathogenesis and may provide important prognostic information (32). In acute myeloid leukemia patients, KIT mutations confer higher relapse risk and appear to adversely affect overall survival (33, 34). However, the significance of KIT mutations in melanoma prognosis has not been evaluated in an adequately sized study. In a multivariate analysis of 13,581 patients with localized melanoma, the 2 most powerful independent characteristics of the primary melanoma among all the prognostic variables analyzed were tumor thickness and ulceration (26). Other statistically significant prognostic factors are patient age, site of the primary melanoma, level of invasion, and sex (26). In our study, we found that the ulceration and stages, but not the age, sex, or thickness, were common prognostic factors for Chinese patients. KIT mutations, KIT amplifications, and CD117 expression level appear unrelated to the age, gender, tumor thickness, stage, or ulceration of melanomas. More importantly, we found that KIT mutations and genetic aberrations (mutation plus amplification) of KIT adversely impact survival. This is the first such report of such a relationship and underscores the importance of accelerating the clinical development of KIT inhibitors in this setting.

In conclusion, our study has confirmed that acral and mucosal melanomas are the most prevalent subtypes of melanoma amongst Chinese patients. Our study further suggests that KIT mutations may be unrelated to CD117 overexpression, whereas the increases in KIT gene copy numbers may be responsible for elevated CD117 expression. We found that KIT aberrations are unrelated to the age, gender, stages, thickness, and ulceration of primary melanomas. Most importantly, genetic mutations in KIT may be an independent adverse prognostic factor in melanoma. Our study also highlights that there are numerous types of KIT mutations present in this population, and that the responsiveness to KIT inhibitors will almost certainly vary. Careful screening for KIT mutations in all exons is necessary to identify patients for inclusion in clinical trials of KIT inhibitors.

**Disclosure of Potential Conflicts of Interest**

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Aberrations of KIT Gene in Chinese Melanomas

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