AMPLIFICATION OF c-MYC AND MLL GENES AS A MARKER OF CLONAL CELL PROGRESSION IN PATIENTS WITH MYELOID MALIGNANCY AND TRISOMY OF CHROMOSOMES 8 OR 11

Angelova S1*, Jordanova M2, Spassov B1, Shivarov V1, Simeonova M3, Christov I4, Angelova P1, Alexandrova K3, Stoimenov A1, Nikolova V1, Dimova I6, Ganeva P1, Tzvetkov N4, Hadjiev E3, Toshkov S1

ORIGINAL ARTICLE

ABSTRACT

Gene amplification (amp) is one of the basic mechanisms connected with overexpression of oncogenes. The c-MYC (located in 8q24) and MLL (located in 11q23) are the most often over represented genes that lead to a rapid proliferation of the affected cell clone in patients with myeloid neoplasms. Assessment of the level of amp c-MYC or amp MLL in the cases with trisomy 8 (+8) or trisomy 11 (+11) and myeloid malignances is necessary for a more precise estimation of the disease progression.

A total of 26 patients with acute myeloid leukemia (AML) and myelodysplastic syndromes (MDS) were included in the study: 18 with +8, six with +11 and two with complex karyotypes suspected of the partial trisomy. Routine cytogenetic analysis and fluorescent in situ hybridization (FISH) were applied to indicate the chromosome alterations and genes amp in the bone marrow cells.

Amp c-MYC was observed in 12 from 18 (66.7%) patients with +8. All the patients with +11 demonstrated a different level of amp MLL. In most of the cases with MDS (9/10), the coincidence of the +8 or +11 with amp c-MYC or amp MLL, respectively, leads to transformation to AML and/or short overall survival. Our data suggest that amp c-MYC and amp MLL develop in conformity with +8 and +11, especially in cases with progressive deviations in the karyotype as an aggressive expansion of an aberrant cell clone and appearance of additional chromosome anomalies.

Key words: Gene amplification (amp), c-MYC, MLL genes, Acute myeloid leukemia (AML), Myelodysplastic syndromes (MDS), Myeloid malignancies, Trisomy chromosomes of 8 or 11

INTRODUCTION

The development of cancer is a step-wise accumulation of genetic and epigenetic alterations including chromosome rearrangements that, in most cases, involve proto-oncogenes. Production of multiple copies of particular gene or gene amplification (amp) is one of the basic mechanisms that lead to over expression of oncogenes [1]. It is a frequent event in solid tumors but is rather rare in malignant hemopathies [1,2].

1 Laboratory of Cytogenetics and Molecular Biology, National Specialized Hospital for Active Therapy of Hematological Diseases, Sofia, Bulgaria
2 Children Hospital of Hematological Diseases, Sofia, Bulgaria
3 Department of Medical Genetics, Medical University Hospital, Pleven, Bulgaria
4 Department of Hematology, Medical University Hospital, Pleven, Bulgaria
5 Department of Hematology, Medical University Hospital, Sofia, Bulgaria
6 Department of Medical Genetics, Medical University, Sofia, Bulgaria
Genes with affinity to genomic over representation in myeloid malignancy such as acute myeloid leukemia (AML) and myelodysplastic syndromes (MDS) and others, are c-MYC, MLL and more rarely RUNXI and ETV6 [3-7].

The MLL gene (located in region 11q23) is a transcriptional factor that normally regulates expression of mir-196b, a hematopoietic microRNA located within the HoxA cluster [8]. The MLL over expression resulting from amp of MLL (amp MLL) leads to over expression of the functionally related HOX genes, provoking an increased cell proliferative capacity and survival, as well as a partial block in differentiation [4,8]. The presence of additional MLL copies in the genotype of the patients with MDS increases the transformation potential of the affected cell clones, which results in evolution to AML [4].

The MYC proteins play a well defined role as the components of signal transduction pathways promoting both cell proliferation and apoptosis [9,10]. The c-MYC gene (located in region 8q24) is frequently over expressed in human cancers, but the downstream events contributing to the tumor genesis remain incompletely understood [3,10]. The next step of the disease progression would be if the amp of c-MYC (amp c-MYC) and amp MLL is accompanied by proven over expressions of corresponding genes [4,10].

Total or partial trisomy is an unbalanced karyotypic anomaly which is more frequently a secondary event in the development of a neoplasia [11]. Trisomy 8 (+8) occurs in 10 to 20% of the cases with myeloid malignancies in contrast to the more rare but non random aberration, trisomy 11 (+11) [12-14]. According to the United Kingdom Medical Research Council (MRC) criteria and World Health Organization classification-based prognostic scoring system, the prognostic value of these anomalies for achieving a complete remission in AML and for transformation in MDS is intermediate, but if +8 or +11 is attendant with over representation or/and amplification of c-MYC and MLL genes, the prognosis assessment would be worse [4,10,15-16]. The final step in the malignant cell clone development that predicts resistance to therapy is karyotype complexity [15]. The 8q24 (c-MYC) and 11q23 (MLL) gains were observed in about 40% of the cases with AML and complex karyotype [17]. The objective of this study was to investigate the correlation between cytogenetically defined +8 or +11 in karyotypes at a different level of clonal cell development with molecular genetically proved amp c-MYC or amp MLL genes.

**PATIENTS AND METHODS**

**Patient Group.** A total of 26 patients aged 16 to 82 years (median about 62 years) were included in this study. The distribution at diagnosis was: 16 patients with overt AML, seven with secondary AML after MDS (sAML) and three with different types of MDS. Eighteen patients had +8; in half of them the tri- or tetrasomy 8 was a sole cytogenetic abnormality. There were additional karyotipical aberrations in the other nine cases. It was the only anomaly in three of the six cases with +11; the karyotypes in the other three cases were more complicated. Also included were two additional cases with complex karyotypes suspected for amp MLL. All patients with AML below or equal to 65 (≤65) years of age were treated with induction therapy consisting of antharacycline (Idarubicine, Farmorubicine or Mitoxantrone) and cytarabine according to the standard protocols. Patients above 65 (>65) years of age received chemotherapy with Cytosar only. Patients with MDS before transformation to AML received supportive therapy and after transformation were treated with standard chemotherapy. The study was approved by the local Ethics Committee of the National Hospital for Hematological Diseases. All participants had given written informed consent.

**Cytogenetic Analysis.** Routine cytogenetic analysis was performed on metaphase chromosomes from bone marrow samples using a direct method and after short-term 24- or 48 hour-culturing [18]. A minimum of 15 bone marrow metaphase cells were analyzed in each patient using GTG differentially-stained chromosomes at a discriminatory level of 300-400 bands per haploid count. Karyotypic findings were interpreted and described according to the International System for Human Cytogenetic Nomenclature (ISCN, 2009) [19].

**Fluorescent In Situ Hybridization (FISH).** Fluorescent in situ hybridization was performed according to the standard manufacturer’s protocol (Vysis®; Abbot Molecular Inc., Abbott Park, IL, USA) on interphase nuclei in suspension after a routine cytogenetic procedure and stored at –20°C. Locus-specific dual color MLL break apart rearrangement probe and c-MYC break apart rearrangement probe (Vysis®; Abbot Molecular Inc.) were used, and no less than 200 interphase nuclei per probe were analyzed. In these probes,
the 5’ portion of the MLL gene (or c-MYC) was labeled in green, and the 3’ portion in red. Thus, the presence of two normal gene signals in the cell was visualized as dual composite signals (red + green). The gene deletion was detected as a single composite signal, and +8 (or +11) as three composite signals. The presence of more than three composite signals was considered as a MLL (or c-MYC) gene amp. We recognized amplification level as a significant if amp were observed in more than 10% of interphase nuclei, under the 10%, as a low level amp.

RESULTS

Solely Tri- or Tetrasomy 8. In nine of 18 patients with an additional chromosome 8, this aberration was an isolated clonal anomaly in the karyotype: seven patients with +8 and two patients with tetrasomy 8. The FISH analysis does not show significant amp c-MYC in cases 1 through 7 (Table 1). In the karyotype of patients 1 to 4, the +8 aberration occurred in a minor cell clone (from 10 to 33% of the analyzed metaphases). Correlation between the number of c-MYC fluorescent signals in the interphase nuclei and the cytogenetically detected +8 metaphases in the first four patients showed absence or no significant proliferative advantage of the aberrant cell clone. In cases 5 to 7, the cell clone with the +8 anomaly had a proliferative advantage. Only two of our patients with solely +8 and without amp c-MYC have achieved a hematological remission. The other two patients from this group did not receive optimal dose chemotherapy due to complications during the neutropenic phase.

In patients 8 to 10, a karyotype progression from tri- to tetrasomy 8 or from partial clonality to total expansion of the aberrant cell clone was observed. Tetrasomy 8 in these cases was accompanied by amp c-MYC. In two patients with MDS and expansion of the cell clone harboring +8 and amp c-MYC, the disease evolved to AML.

Trisomy 8 in the Karyotype With Additional Aberrations. Seven of eight patients (11 through 17) with +8 and additional chromosome aberrations, had a different level of amp c-MYC: two with low (under 10%) and five with more than 10%. Coincidence of composite chromosome anomalies and amp c-MYC in most of the cases correlate with transformation of MDS to AML and short survival (about 3 months) without achieving a hematological remission. Only one of the patients (17) with MDS-RARS (refractory anemia with ring sideroblasts) and low level of amp c-MYC, had comparatively long (13 months) overall survival (OS) despite of his advanced age.

In conclusion, a different level of amp c-MYC was observed in 12 of 18 (66.7%) patients with +8. The karyotypes of patients with a significant level of amp c-MYC demonstrated progressive chromosome complications.

Trisomy 11 and Suspicion of Amp MLL Complex Karyotype. In two of the six cases with total or partial +11 expansion of the affected cell clone was observed. In four cases, a significant amp MLL was recorded. Two patients with +11 (5 and 6) did not have a significant amp MLL (Table 2). The median OS in the patient group with the low level of amp MLL was longer than that of the other patients with +11 (6 vs. 2 months, respectively).

In the two cases with suspected amp MLL and complex karyotype and rearrangements on chromosome 11, there were low, 6% and significant, 67%, levels of the amp MLL. Both had very short OS due to early death in induction. All patients with amp MLL and/or +11 did not achieve remission and had short survival times.

In conclusion, all our patients with +11 demonstrated a different level of amp MLL. The significant level of amp MLL in this group is correlated with a very short OS.

DISCUSSION

The biological mechanism of the oncoproliferative activity of the +8 cell clones is explained mostly with the gene dosage effect [20]. Some authors using microarray techniques observed overexpression of genes located on chromosome 8 in trisomic cells [20,21]. Further microarray analysis demonstrated that +8 MDS was notable for over expression of immune and inflammatory genes; some of these gene products also have roles in cellular proliferation and differentiation in an angiogenesis, whereas apoptotic inhibitors were down-regulated [22]. Another proposed explanation of the biological significance of the extra chromosome 8 was based on the observation of increased copies of the c-MYC gene that plays a central role as a downstream mediator of the myeloid leukemogenesis [23]. Furthermore, a comparative genomic hybridization ratio measurement revealed that a gain of 8q24 is
<table>
<thead>
<tr>
<th>#</th>
<th>Sex-Age</th>
<th>D( FAB)</th>
<th>Karyotype</th>
<th>FISH Results (c-MYC oncogene)</th>
<th>CRD (months)</th>
<th>OS (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F-62 AML-M4</td>
<td>47,XX,+8 <a href="10%25">2</a>/46,XX <a href="90%25">18</a></td>
<td>2Cs–86%; 3Cs–14%</td>
<td></td>
<td>no</td>
<td>1*</td>
</tr>
<tr>
<td>2</td>
<td>F-74 AML-M0</td>
<td>47,XX,+8 <a href="27%25">4</a>/46,XX <a href="73%25">11</a></td>
<td>2Cs–22%; 3Cs–78%</td>
<td></td>
<td>no</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>M-62 AML-M4</td>
<td>47,XY,+8 <a href="15%25">3</a>/46,XY <a href="85%25">17</a></td>
<td>2Cs–91%; 3Cs–9%</td>
<td>9</td>
<td>&gt;11</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>M-73 AML-M0</td>
<td>47,XY,+8 <a href="33%25">5</a>/46,XY <a href="67%25">10</a></td>
<td>2Cs–91%; 3Cs–9%</td>
<td>no</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>F-26 AML-M5a</td>
<td>47,XX,+8 <a href="60%25">12</a>/47,XX,add(4)(p16),+8 <a href="40%25">8</a></td>
<td>2Cs–8%; 3Cs–92%</td>
<td></td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>6</td>
<td>F-28 AML-M4</td>
<td>47,XX,+8 <a href="95%25">19</a>/46,XX <a href="5%25">1</a></td>
<td>2Cs–39%; 3Cs–55%; 4Cs–6%</td>
<td>no</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>M-85 AML-M4</td>
<td>47,XY,+8 <a href="80%25">12</a>/46,XY <a href="20%25">3</a></td>
<td>2Cs–15%; 3Cs–77%; 4Cs–8%</td>
<td>no</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>M-70 AML-M4</td>
<td>47,XY,+8 <a href="50%25">10</a>/48,XY,+8 <a href="30%25">6</a>/46,XY <a href="20%25">4</a></td>
<td>2Cs–18%; 3Cs–42%; 4Cs–32%; &gt;5Cs–8%</td>
<td>no</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>F-16 MDS-RAEB trans AML</td>
<td>ND</td>
<td>2Cs–30%; 3Cs–27%; 4Cs–42%; &gt;5Cs–1%</td>
<td>15+9</td>
<td>no</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>F-63 MDS-RAEB trans AML</td>
<td>47,XX,+8 <a href="53%25">8</a>/46,XX <a href="47%25">7</a></td>
<td>ND</td>
<td>no</td>
<td>10+3</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>M-61 AML-M0</td>
<td>47,XY,del(7)(q11q22),+8 <a href="100%25">17</a></td>
<td>2Cs–17%; 3Cs–72%; 4Cs–6%; &gt;5Cs–72%</td>
<td>no</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>M-82 AML-M5b</td>
<td>46,XY,+7,+8 <a href="28%25">5</a>/46,XY <a href="72%25">13</a></td>
<td>2Cs–32%; 3Cs–48%; 4Cs–13%; &gt;5Cs–7%</td>
<td>—3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>M-68 AML-M4</td>
<td>45-48,X,Y,-5,-7,+8s,2,+9,+15,-16,+mar*,+mar** <a href="100%25">15</a></td>
<td>2Cs–2%; 3Cs–10%; 3Cs–71%; &gt;5Cs–17%</td>
<td>no</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>M-62 MDS trans AML</td>
<td>47,XY,+8 <a href="87%25">13</a>/46,XY,+8,+19 <a href="13%25">2</a></td>
<td>2Cs–9%; 3Cs–80%; 4Cs–9%; &gt;5Cs–2%</td>
<td>no</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>M-61 MDS trans AML</td>
<td>56-59,XY,+1,+2,+4s,2,del(5)(q11q31),+6,-7,+8s,2,del(11)(p13),+15,-2,-19,+21,+21,+r(7),+mar [15] (100%)</td>
<td>2Cs–14%; 3Cs–54%; 4Cs–18%; &gt;5Cs–14%</td>
<td>no</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>M-78 MDS trans AML</td>
<td>46,XY,del(11)(q21q23),del(20)(q11-12)[2]/47,XY,8;8,t(2;4) (q32;q11),del(11)(q21q23),del(20)(q11-12)[2]/46,XY,t(9;22) (q34;q11)[1]/47,XY,8;8,t(9;22) (q34;q11)[1] (40%)</td>
<td>2Cs–17%; 3Cs–75%; 4Cs–5%; &gt;5Cs–3%</td>
<td>no</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>M-81 MDR-RARS</td>
<td>47,XY,+8 [18]/46,XY;del(7)(q11q31)[2]/46,XY,2[83%]</td>
<td>2Cs–17%; 3Cs–76%; 4Cs–5%; &gt;5Cs–2%</td>
<td>—3</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>F-66 MDS trans AML</td>
<td>45,XX,del(5)(q13),+8,-16,-18[6]/45,idem,del(12)(q22q24)[11]/44,XX,del(5)(q13),+8,der(11)(7;11)(q11;p15);16,-18 <a href="100%25">8</a></td>
<td>2Cs–88%; 3Cs–12%</td>
<td>no</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

D( FAB): Diagnosis (French, American and British classification of hematological diseases); FISH: fluorescent in situ hybridization; CRD: complete remission duration; OS: overall survival; AML: acute myeloid leukemia; Cs: composite signal (red+green) detected on the intact c-MYC gene; MDS: myelodysplastic syndromes; RAEB: refractory anemia with excess of blasts; trans: transformation; RARS: refractory anemia with ring sideroblasts.

* Death due to heart attack before the second induction course.

† Patient on supportive care only.
associated with mutation of the p53 tumor suppressor gene. The association between the gain at an 8q24 and the p53 mutation might be attributable to transactivation of the c-MYC gene by the p53 promoter [24].

Amplification mechanisms are not yet clearly understood [1-2]. Chromosomes have hot fragile sites that break under specific conditions and may be associated with chromosomal instability in cancer as breakpoint sites for translocation, deletion, and amplification [9].

Low-level amp c-MYC was reported in a number of patients with +8 AML, +8 MDS and chronic myeloid leukemia (CML) in blast phase [25-27]. Some authors suggest that c-MYC is not the true target of the amp but that abundant expression of another gene(s) included in an 8q24 amplicon is the pathogenetically important consequence [28].

In most of our overt AML and sAML +8 cases, the visible developmental effects such as aberrant cell clone expansion and the occurrence of additional chromosome deviations are connected with amp c-MYC that was observed in 12 of 18 (66.7%) patients. Absence of an amp c-MYC was found predominantly in the cases with minor +8 cell clones. We suggest that amp c-MYC is a logical result of the development in the proliferating +8 cell populations.

In most of our overt AML and sAML +8 cases, the visible developmental effects such as aberrant cell clone expansion and the occurrence of additional chromosome deviations are connected with amp c-MYC that was observed in 12 of 18 (66.7%) patients. Absence of an amp c-MYC was found predominantly in the cases with minor +8 cell clones. We suggest that amp c-MYC is a logical result of the development in the proliferating +8 cell populations.
The prognostic value of +8 and +11 is contradictory. A number of authors defined them as an intermediate, others as an adverse prognostic factor [11-13,15]. On the other hand, in most of the publications, the presence of amp c-MYC and amp MLL correlate with disease progression and poor risk for patients with myeloid malignancies [10,14,21].

We speculate that the conflicting results can be explained with the difference in the proportion of patients who had amp c-MYC or amp MLL in different series. The absence of the gene amp can be logically connected with the early evolutionary stage of the disease and with the cohort of early diagnosed patients. If during the investigation, the later diagnosed patients with amp c-MYC or amp MLL predominate, a worse prognostic effect may be expected.

All of our AML patients with +8 and amp c-MYC had a short OS (about 3.7 months) without hematological remission as well as the patients with +11 and amp MLL (about 2.4 months). Two of our MDS patients with expansion of the tri- and tetrasomy 8 cell clones had amp c-MYC. Both of them demonstrated a resistance to chemotherapy, disease progression and transformation to AML. In contrast, two of the five patients with +8 without amp c-MYC, achieved hematological remission and one on them is still alive. We suppose that appearance of +8 and +11 in karyotype provoke the further developmental events such as amp c-MYC or amp MLL that leads to therapy resistance. The earlier patients with +8 and/or +11 are diagnosed, the higher are their chances not to have amp c-MYC or amp MLL and not to be resistant to treatment.

According to the results in our comparatively small patient group, we can assume that amp c-MYC and amp MLL are natural developmental events, especially in cases with an aggressive expansion of the aberrant cell clone and appearance of additional chromosome anomalies.

REFERENCES

14. Wolman SR, Gundacker H, Appelbaum FR, Slovak ML. Impact of trisomy 8 (+8) on clinical presentation, treatment response, and survival in acute myeloid


