Brief report

DNA hypermethylation and epigenetic silencing of the tumor suppressor gene, SLC5A8, in acute myeloid leukemia with the MLL partial tandem duplication

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Introduction

The mixed lineage leukemia partial tandem duplication (MLL-PTD), present in 4% to 7% of adults with cytogenetically normal acute myeloid leukemia (CN-AML), is a cryptic gene rearrangement that most commonly duplicates introns 5 through 11 or introns 5 through 12 giving rise to an in-frame fusion transcript having exons 11 or 12 fused upstream of exon 5 within a full-length introns 5 through 12 giving rise to an in-frame fusion transcript having exons 11 or 12 fused upstream of exon 5 within a full-length transcript.1,2 Like MLL-WT, the MLL-PTD has the transcriptional role for the mutant rather than a loss of MLL WT function.5

Methods

Bone marrow (BM) and blood samples were Ficoll-enriched and cryopreserved with institutional review board approval from consenting adults, in accordance with the Declaration of Helsinki, who were treated on Cancer and Leukemia Group B (CALGB) 9621 or CALGB 19808. Pretreatment cytogenetics were centrally reviewed under CALGB 8461.21 NotI/EcoRV/HindIII restriction landmark genomic scanning (RLGS) and bisulfite-PCR-sequencing were described previously.15,22 The EOL-1 (ATCC, Manassas, VA) and MUTZ-11 (gift from Dr Drexler, DSMZ [German Collection of Microorganisms and Cell Culture], Braunschweig, Germany) cell lines have been described.23,24 MLL-PTD fusion transcripts were detected by nested reverse transcription–polymerase chain reaction (RT-PCR)/sequencing and real time RT-PCR.25,26 Cells were transfected with SLC5A8-expressing pcDNA3.1/V5-His-TOPO vector or empty vector (Amaza Biosystems, Gaithersburg, MD) and immunoblotting performed for SMCT1, the V5-epitope, or total acetylation of histones H3 and H4. Decitabine and VPA were purchased (Sigma-Aldrich, St Louis, MO). The difference in global DNA methylation between RLGS profiles from MLL-WT and
MLL-PTD AML groups, measured as the number of events of 321 evaluable, was assessed using the Wilcoxon rank sum test. The association between the methylation of each RLGS spot and MLL groups was assessed using Fisher exact test. Hierarchical cluster analysis of samples was carried out based on RLGS spots that were methylated in at least one patient (265 spots). Jaccard binary similarity metric was used. (C) The 18 RLGS spots with the strongest association, measured by Fisher exact test, between methylation and MLL AML groups are shown. Yellow squares represent a methylated locus; blue squares represent an unmethylated locus; gray squares indicate spot was not evaluable. (D) RLGS was carried out as described in "Methods." The area of the autoradiographs containing spot 3D41 (arrow) were scanned using a Storm 860 phosphorimager (Molecular Dynamics, Amersham Biosciences, Piscataway, NJ) and area with 3D41 enlarged (Photoshop v.8.0, Adobe Systems, San Jose, CA). Representative results are shown for the presence of 3D41 in a primary MLL-PTD AML patient sample. (E) Representative RLGS results showing nearly complete loss of 3D41 in a primary MLL-PTD AML patient sample. (F) SLC5A8 mRNA detection in primary AML patient samples that exhibited loss or presence of RLGS spot 3D41.

Results and discussion

Global methylation profiles in CN-AML patients with MLL-WT (n = 23) and patients with MLL-PTD (n = 9) were obtained by RLGS. A significant difference in global DNA methylation (ie, the number of methylation events of 321 evaluable events) between patients with MLL-PTD and MLL-WT AML was observed (P = .02; Figure 1A). Unsupervised hierarchical clustering resulted in 8 of 9 MLL-PTD cases clustering together (Figure 1B). The methylation status for individual patients of the top 18 differentially expressed RLGS spots between the 2 MLL groups is shown in Figure 1C.

We focused on RLGS spot “3D41” that corresponded to exon 1 of the TSG SLC5A8 and that was absent in 78% of MLL-PTD AMLs compared with only 17% of MLL-WT AMLs (P = .003; Figure 1C-E). Of the patient samples with material available for further analyses, 3 (AMLs 812, 9923 and 122) with complete absence (methylated) of the RLGS spot 3D41, had 24% to 78% CpG-methylation in the SLC5A8 CpG-island region tested by bisulfiti-PCR/sequencing and no detectable gene expression (Figure 1F). In contrast, 2 MLL-WT patients (AMLs 1 and 22) with presence of RLGS spot 3D41 and consistent bisulfiti-PCR/sequencing results (0%-12% CpG island methylation), expressed SLC5A8 (Figure 1F). SLC5A8 CpG island methylation was either an absent or rare event (0%-4%) in CD34+ cells from disease-free, normal donor BM samples (n = 5; not shown).

Similarly, the MLL-PTD+ MUTZ-11 and EOL-1 cell lines exhibited 92% (± 4%) and 91% (± 6%) CpG hypermethylation in the tested SLC5A8 promoter region, respectively, whereas the MLL-PTD- K562 and U937 cell lines exhibited only 43% (± 9%) and 28% (± 5%), respectively (not shown). Consistent with these results, SLC5A8 mRNA (not shown) and protein were detected only in the MLL-PTD+ cells (Figure 2A). Incubation with the hypomethylating agent decitabine and not with the histone deacetylase inhibitor VPA, used here as a control, reversed the silencing of the SLC5A8 gene in MLL-PTD+ MUTZ-11 and EOL-1 cells and not in the MLL-PTD K562 and U937 cells (Figure 2B).

To study the functional consequences of SLC5A8 reactivation, cell lines were transfected with empty vector or V5-tagged SLC5A8 expression vector and treated with VPA. As SMCT1 is a transporter of VPA into cells, we hypothesized that forced expression of SMCT1 would increase VPA pharmacologic activity. Consistent with the restored and/or enhanced function of the SMCT1, histones

![Image](https://example.com/image.png)
Figure 2. Epigenetic silencing of SLC5A8 and functional consequences of forced expression of SLC5A8 in MLL-PTD+ cell lines. (A) Whole cell lysates were prepared and immunoblotting performed as described in “Methods.” Anti-SLC5A8 antibody (A-15) was purchased from Santa Cruz Biotechnology (Santa Cruz, CA). Nucleofections with V5-empty and V5-SLC5A8 expression vectors and immunoblotting to detect the V5-epitope were performed as described in “Methods.” (B) The demethylating agent, decitabine, but not the histone deacetylase inhibitor, VPA activates SLC5A8 transcription in MLL-PTD+ AML cell lines. Cell lines were incubated in the absence or presence of the hypomethylating reagent decitabine (2.5 μM) or VPA (1 mM) for 48 or 24 hours, respectively. SLC5A8 mRNA levels were measured by real time RT-PCR using SYBR Green dye for detection (Prism 7700 SDS, Applied Biosystems, Foster City, CA). Primers were SLC5A8-for, 5’-TCGGAGGTCTACCGTTTTG-3’ and SLC5A8-rev, 5’-GGGCGGGACGATAAA-CAAACG-3’. The ΔΔCt method of relative quantification was carried out. SLC5A8 mRNA levels were normalized to 18S rRNA levels. Results are presented as relative SLC5A8 transcript levels (means ± SD). (C) Forced SMCT1 expression enhances VPA-induced acetylation of histone H3 and H4. Immunoblot analyses for total acetylated histones H3 and H4 were carried out on empty vector or V5-SLC5A8 vector transfected cells. Twenty-four hours after nucleofection, 1 mM VPA was added to the cultures for an additional 24 hours. Immunoblot detection of β-actin was used as a loading control. (D) Overexpression of SMCT1 sensitizes MLL-PTD+ cells to the growth inhibitory effects of VPA. Cell lines were incubated for an additional 24 hours with or without VPA (1 mM) beginning 24 hours posttransfection. The effect on viable cell numbers was measured using the trypan blue exclusion assay and is depicted as a fold-change in relation to the appropriate VPA-treated, empty-vector transfected cells. Error bars represent SD. (E) The sequential combination of decitabine followed by VPA results in enhanced apoptosis in the MLL-PTD+ cell lines. Cells were treated as described above, except with the inclusion of a sequential combination of decitabine (48 hours) followed by VPA (24 hours), and then harvested for staining with annexin V/propidium iodide and fluorescence-activated cell sorting analysis. The percentage of cells undergoing early apoptosis (lower right quadrant) is indicated.

H3 and H4 acetylation increased with SMCT1 forced expression in all cells, including MUTZ-11 and EOL-1 cells in which the endogenous gene was constitutively silenced (Figure 2C).

While VPA was cytotoxic to both MLL-WT cell lines, MUTZ-11 and EOL-1 cell viabilities were not significantly affected by VPA under similar treatment conditions (data not shown). However, MUTZ-11 and EOL-1 cells expressing SLC5A8/SMCT1 showed reduced cell viability with VPA in comparison to the VPA treated empty-vector transfected cells (Figure 2D). Cell viability remained unchanged in similarly treated and V5-SLC5A8-transfected K562 and U937 cell lines (Figure 2D). We speculate that the enhanced VPA-induced cytotoxicity in the MLL-PTD+ MUTZ-11 and EOL-1 may be due to reexpression of the MLL-WT allele that sensitizes MLL-PTD+ cells to HDAC inhibitors. Consistent with this, and our previous report, the fraction of MLL-PTD+ cells undergoing early apoptosis was higher after incubation with the combination of decitabine followed by VPA compared with either drug alone and untreated controls (Figure 2E).

We demonstrate that MLL-PTD presence is associated with global DNA hypermethylation relative to MLL-WT AML and provide evidence that the TSG, SLC5A8, is epigenetically silenced in this molecular subset of AML. DNA methylation-induced silencing of TSGs, such as SLC5A8, may represent a second “hit” in myeloid blasts harboring MLL-PTD that itself contributes to leukemogenesis via H3K4 methylation-induced transcriptional up-regulation of genes involved in self-renewal and proliferation of hematopoietic precursors. As in colon cancer, SLC5A8 silencing may contribute to an aggressive phenotype in subsets of CN-AML. Indeed, although a high proportion of MLL-PTD CN-AML patients treated on newer intensive regimens exhibited
long term disease-free survival, the majority of MLL-PTD patients still relapsed within 1.7 years after remission induction. The underlying reasons for this remain largely unknown but may also include other molecular and epigenetic defects present in these AMLs. Finally, a recent clinical strategy in AML is to overcome aberrant epigenetic events, that is, DNA methylation and histone deacetylation, both of which frequently cooperate to silence TSGs. Based on the data provided in this report, one could envision a sequential treatment for MLL-PTD AML consisting of the hypomethylator, decitabine, followed by the HDAC inhibitor VPA as a rational attempt to improve clinical outcome in this subset of patients.

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Authorship


Conflict-of-interest disclosure: The authors declare no competing financial interests.

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References

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