



# TET2 promoter methylation in low-grade diffuse gliomas lacking IDH1/2 mutations

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## ABSTRACT

**Background** Miscoding mutations of the *TET2* gene, which encodes the  $\alpha$ -ketoglutarate-dependent enzyme that catalyses the conversion of 5-methylcytosine to 5-hydroxymethylcytosine, thus producing DNA demethylation, have been detected in 10–25% of acute myeloid leukaemias lacking *IDH1/2* mutations. Most low-grade diffuse gliomas carry *IDH1/2* mutations (>85%), but molecular mechanisms of pathogenesis in those lacking *IDH1/2* mutations remain to be elucidated.

**Methods** Miscoding mutations and promoter methylation of the *TET2* gene were screened for in 29 low-grade diffuse gliomas lacking *IDH1/2* mutations.

**Results** Single-strand conformational polymorphism followed by direct sequencing showed the absence of miscoding mutations in *TET2*. Methylation-specific PCR revealed methylation of the *TET2* promoter in 5 of 35 cases (14%). In contrast, none of 38 low-grade diffuse gliomas with *IDH1/2* mutations had *TET2* promoter methylation ( $p=0.0216$ ).

**Conclusion** Results suggest that *TET2* promoter methylation, but not *TET2* mutation, may be an alternative mechanism of pathogenesis in a small fraction of low-grade diffuse gliomas lacking *IDH1/2* mutations.

## INTRODUCTION

*IDH1/2* mutations are very frequent (>85% of cases) in astrocytic and oligodendroglial diffuse gliomas (WHO grades II and III) as well as in secondary glioblastomas (WHO grade IV) that are derived from diffuse astrocytomas or anaplastic astrocytomas.<sup>1–2</sup> In contrast, *IDH1* mutations are very rare or absent in other neoplasms of the central nervous system or tumours of other organ sites, including cancers of the bladder, breast, stomach, colorectum, lung, ovary and prostate.<sup>3–5</sup> The only exceptions so far include acute myeloid leukaemia (AML; up to 20%),<sup>6–11</sup> melanomas (approximately 10%)<sup>12</sup> and anaplastic thyroid cancer (approximately 10%).<sup>13</sup> In contrast to diffuse gliomas in which *IDH1* mutations are significantly more frequent than *IDH2* mutations,<sup>14</sup> *IDH1* and *IDH2* mutations were detected at similar frequencies in AML.<sup>15–16</sup>

Recently, the *TET2* (ten-eleven-translocation 2) gene at chromosome 4q24 has been found to be mutated in 10–25% of cases of AML, myelodysplastic syndrome and myeloproliferative neoplasms.<sup>15–17</sup> Interestingly in AML, *IDH1/2* mutations and *TET2* mutations were mutually exclusive, and importantly, both *IDH1/2* and *TET2* mutations were associated with epigenetic defects

and a hypermethylation signature.<sup>15</sup> These observations suggest that *TET2* mutations represent an alternative molecular mechanism in the development of AML lacking *IDH1/2* mutations.

Epigenetic defects that resemble those seen in AML with either *IDH1/2* or *TET2* mutations have been recognised in gliomas carrying *IDH1/2* mutations. In a study by Noushmehr *et al*,<sup>18</sup> a distinct subset of glioblastomas showed concerted CpG island methylation at a large number of loci; these tumours typically carry *IDH1/2* mutations. In a study of 131 brain tumours, hypermethylation of CpG loci was strongly associated with *IDH1/2* mutations.<sup>19</sup>

These findings prompted us to screen for *TET2* mutations in low-grade diffuse gliomas lacking *IDH1/2* mutations. We also assessed *TET2* promoter methylation, since this has recently been reported in a small fraction (4.4%) of myeloproliferative neoplasms (essential thrombocythemia).<sup>20</sup>

## MATERIALS AND METHODS

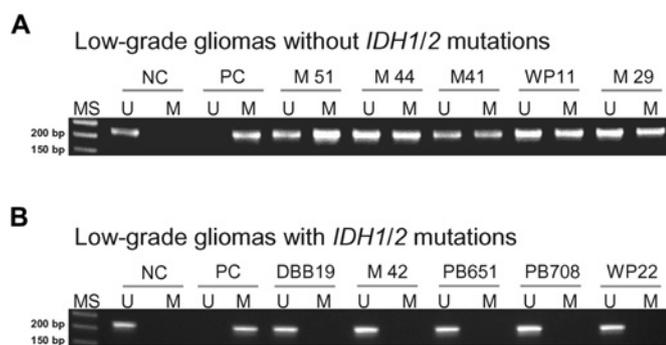
### Tumour samples

A total of 73 tumour samples of low-grade diffuse gliomas (WHO grade II) were obtained from the Department of Neuropathology, University Hospital Zürich, Switzerland, Department of Neuropathology, University Hospital Frankfurt, Germany, Institute of Neuropathology and Department of Neurosurgery, University Hospital Münster, Germany, Department of Neurosurgery, University Hospital Bern, Switzerland, and Institute of Neuroscience, Bordeaux, France.

Low-grade diffuse gliomas lacking *IDH1/2* mutations (total 35 cases) were diffuse astrocytoma (17 cases), oligoastrocytoma (6 cases) or oligodendroglioma (12 cases); those carrying *IDH1/2* mutations (total 38 cases) were diffuse astrocytoma (17 cases), oligoastrocytoma (9 cases) or oligodendroglioma (12 cases). The mean age of the patients was  $40.1 \pm 14.7$  years (range 5–82 years). Fifty-six patients were treated with surgery alone and 13 patients with surgery followed by radiotherapy. None of the patients were treated with chemotherapy. This study was approved by ethical committees in each collaborative centre as well as by the IARC ethical committee.

### TET2 mutations

We screened for mutations of the *TET2* gene at exons 3–11 containing the conserved domains 1 and 2, in which approximately 90% of all mutations have been detected in AML and myeloid disorders<sup>17–21–22</sup> in 29 low-grade diffuse gliomas lacking *IDH1/2* mutations. Single-strand



**Figure 1** Methylation-specific PCR analysis of the TET2 promoter region in low-grade diffuse gliomas. (A) Without *IDH1/2* mutations (14%); (B) with *IDH1/2* mutations (0%). MS, molecular size marker; U, PCR product amplified by unmethylated-specific primers; M, PCR product amplified by methylated-specific primers; NC, normal control; PC, positive control (universal methylated DNA).

conformational polymorphism (SSCP) analysis was carried out to pre-screen for mutations in exons 3–11 of the *TET2* gene, as described previously.<sup>23</sup> The primer sequences are available on request. DNA samples containing *IDH1* mutations and H<sub>2</sub>O served as positive and negative controls, respectively. Samples exhibiting mobility shifts in SSCP analyses were subsequently analysed by direct sequencing using an ABI 3100 PRISM DNA sequencer (Applied Biosystems, Foster City, California, USA) with the Big Dye Terminator cycle sequencing kit (ABI PRISM, Applied Biosystems).

### TET2 promoter methylation

Methylation-specific PCR was carried out in 35 low-grade diffuse gliomas without *IDH1/2* mutations and 38 low-grade diffuse gliomas with *IDH1/2* mutations, to assess *TET2* promoter methylation using primers reported by Chim *et al.*<sup>20</sup> For each methylation-specific PCR reaction, we included universal methylated DNA (Chemicon International, Temecula, California, USA) as positive control, and normal blood DNA as negative control.<sup>24</sup> Direct sequencing confirmed bisulfite-modified DNA in the positive control. Quality controls for bisulfite conversion were performed for each reaction, as previously described.<sup>25</sup>

### RESULTS

No miscoding mutations of *TET2* were detected in the 29 low-grade diffuse gliomas lacking *IDH1/2* mutations that we analysed.

Methylation-specific PCR showed *TET2* promoter methylation in 5 of 35 (14%) low-grade diffuse gliomas lacking *IDH1/2* mutations (three diffuse astrocytomas and two oligodendrogliomas; figure 1). None of 38 low-grade diffuse gliomas carrying *IDH1/2* mutations showed *TET2* promoter methylation. The difference in frequency of *TET2* promoter methylation in tumours with and without *TET2* promoter methylation was statistically significant ( $p=0.0216$ ). The median survival of patients was not significantly different between cases with or without *TET2* promoter methylation.

### DISCUSSION

Mammalian DNA contains two modified cytosine bases, 5-methylcytosine (5mC) and 5-hydroxymethylcytosine (5hmC).<sup>26</sup> Of these, 5mC is known to play a significant role in epigenetic modification involved in gene regulation, X-chromosome inactivation, genomic imprinting and cancer development.<sup>26</sup> In contrast, attention has only recently been drawn to 5hmC,

### Take-home messages

- ▶ In contrast to acute myeloid leukaemia, ten-eleven-translocation 2 (TET2) mutations are absent in low-grade diffuse gliomas lacking *IDH1/2* mutations.
- ▶ TET2 promoter methylation is present in a small fraction of low-grade diffuse gliomas lacking *IDH1/2* mutations.
- ▶ TET2 promoter methylation, but not TET2 mutation, may be an alternative mechanism of pathogenesis in a small fraction of low-grade diffuse gliomas lacking *IDH1/2* mutations

with the report that the TET family catalyses the conversion of 5mC to 5hmC,<sup>26 27</sup> and that one of the enzymes in this family, TET2, is frequently mutated in myeloid neoplasms.<sup>15 17</sup> The formation of 5hmC can lead to DNA demethylation, which may contribute to the dynamics of DNA methylation.<sup>26</sup> The conversion of 5mC to 5hmC by TET2 is  $\alpha$ -ketoglutarate ( $\alpha$ -KG)-dependent.<sup>27 28</sup>

IDH1 and IDH2 are enzymes that catalyse the interconversion of isocitrate and  $\alpha$ -KG.<sup>7 15 29 30</sup> *IDH1/2* mutations impair enzyme affinity and dominantly inhibit wild-type *IDH1/2* activity through the formation of catalytically inactive heterodimers,<sup>31</sup> which leads to down-regulation of  $\alpha$ -KG and up-regulation of 2-hydroxyglutarate.<sup>15 32</sup> Decrease in  $\alpha$ -KG expression results in up-regulation of HIF-1 $\alpha$  and its targets, such as GLUT1, VEGF and PGK1 in U87MG malignant glioma cells.<sup>31</sup> Thus, the functions of TET2 and *IDH1/2* may be linked via  $\alpha$ -KG.

The present study shows the absence of *TET2* mutations in low-grade diffuse gliomas lacking *IDH1/2* mutations. Thus, in contrast to AMLs, mutational inactivation of the *TET2* gene is not a mechanism of pathogenesis in low-grade diffuse gliomas.

Recent studies suggest that *TET2* is a tumour suppressor gene, since *TET2* mutations have been detected in 10–25% of AMLs, myelodysplastic syndrome and myeloproliferative neoplasms,<sup>15 17</sup> and *TET2* promoter methylation has been reported in a small fraction (4.4%) of myeloproliferative neoplasms.<sup>20</sup> Loss at the *TET2* locus (4q24) has been observed in a small fraction of glioblastomas (2%).<sup>33</sup> We postulated that *TET2* promoter methylation may occur in gliomas. Indeed, in the present study we show *TET2* promoter methylation in a fraction of low-grade diffuse gliomas lacking *IDH1/2* mutations (14%). In contrast, none of 38 low-grade diffuse gliomas carrying *IDH1/2* mutations had *TET2* promoter methylation ( $p=0.0216$ ). These results suggest that *TET2* promoter methylation, but not *TET2* mutation, may be an alternative mechanism of pathogenesis in a small fraction of low-grade diffuse gliomas lacking *IDH1/2* mutations. However, the low frequency of methylation of the *TET2* promoter in low-grade diffuse gliomas suggests that there may be other, as yet unknown, mechanisms of glioma development that do not involve the TET2 or *IDH1/2* pathways.

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### REFERENCES

1. Riemenschneider MJ, Jeuken JW, Wesseling P, *et al.* Molecular diagnostics of gliomas: state of the art. *Acta Neuropathol* 2010;**120**:567–84.
2. Balss J, Meyer J, Mueller W, *et al.* Analysis of the *IDH1* codon 132 mutation in brain tumors. *Acta Neuropathol* 2008;**116**:597–602.

3. **Yan H**, Parsons DW, Jin G, *et al*. IDH1 and IDH2 mutations in gliomas. *N Engl J Med* 2009;**360**:765–73.
4. **Bleeker FE**, Lamba S, Leenstra S, *et al*. IDH1 mutations at residue p.R132 (IDH1 (R132)) occur frequently in high-grade gliomas but not in other solid tumors. *Hum Mutat* 2009;**30**:7–11.
5. **Ohgaki H**, Kleihues P. Genetic alterations and signaling pathways in the evolution of gliomas. *Cancer Sci* 2009;**100**:2235–41.
6. **Mardis ER**, Ding L, Dooling DJ, *et al*. Recurring mutations found by sequencing an acute myeloid leukemia genome. *N Engl J Med* 2009;**361**:1058–66.
7. **Dang L**, Jin S, Su SM. IDH mutations in glioma and acute myeloid leukemia. *Trends Mol Med* 2010;**16**:387–97.
8. **Patel KP**, Ravandi F, Ma D, *et al*. Acute myeloid leukemia with IDH1 or IDH2 mutation: frequency and clinicopathologic features. *Am J Clin Pathol* 2011;**135**:35–45.
9. **Paschka P**, Schlenk RF, Gaidzik VI, *et al*. IDH1 and IDH2 mutations are frequent genetic alterations in acute myeloid leukemia and confer adverse prognosis in cytogenetically normal acute myeloid leukemia with NPM1 mutation without FLT3 internal tandem duplication. *J Clin Oncol* 2010;**28**:3636–43.
10. **Abbas S**, Lugthart S, Kavelaars FG, *et al*. Acquired mutations in the genes encoding IDH1 and IDH2 both are recurrent aberrations in acute myeloid leukemia: prevalence and prognostic value. *Blood* 2010;**116**:2122–6.
11. **Pardanani A**, Lasho TL, Finke CM, *et al*. IDH1 and IDH2 mutation analysis in chronic—and blast-phase myeloproliferative neoplasms. *Leukemia* 2010;**24**:1146–51.
12. **Shibata T**, Kokubu A, Miyamoto M, *et al*. Mutant IDH1 confers an in vivo growth in a melanoma cell line with BRAF mutation. *Am J Pathol* 2011;**178**:1395–402.
13. **Murugan AK**, Bojdani E, Xing M. Identification and functional characterization of isocitrate dehydrogenase 1 (IDH1) mutations in thyroid cancer. *Biochem Biophys Res Commun* 2010;**393**:555–9.
14. **Kim YH**, Nobusawa S, Mittelbronn M, *et al*. Molecular classification of low-grade diffuse gliomas. *Am J Pathol* 2010;**177**:2708–14.
15. **Figuera ME**, Abdel-Wahab O, Lu C, *et al*. Leukemic IDH1 and IDH2 mutations result in a hypermethylation phenotype, disrupt TET2 function, and impair hematopoietic differentiation. *Cancer Cell* 2010;**18**:553–67.
16. **Zou Y**, Zeng Y, Zhang DF, *et al*. IDH1 and IDH2 mutations are frequent in Chinese patients with acute myeloid leukemia but rare in other types of hematological disorders. *Biochem Biophys Res Commun* 2010;**402**:378–83.
17. **Bacher U**, Haferlach C, Schnittger S, *et al*. Mutations of the TET2 and CBL genes: novel molecular markers in myeloid malignancies. *Ann Hematol* 2010;**89**:643–52.
18. **Noushmehr H**, Weisenberger DJ, Diefes K, *et al*. Identification of a CpG island methylator phenotype that defines a distinct subgroup of glioma. *Cancer Cell* 2010;**17**:510–22.
19. **Christensen BC**, Smith AA, Zheng S, *et al*. DNA methylation, isocitrate dehydrogenase mutation, and survival in glioma. *J Natl Cancer Inst* 2011;**103**:143–53.
20. **Chim CS**, Wan TS, Fung TK, *et al*. Methylation of TET2, CBL and CEBPA in Ph-negative myeloproliferative neoplasms. *J Clin Pathol* 2010;**63**:942–6.
21. **Mohr F**, Döhner K, Buske C, *et al*. TET genes: new players in DNA demethylation and important determinants for stemness. *Exp Hematol* 2011;**39**:272–81.
22. **Smith AE**, Mohamedali AM, Kulasekararaj A, *et al*. Next-generation sequencing of the TET2 gene in 355 MDS and CMML patients reveals low-abundance mutant clones with early origins, but indicates no definite prognostic value. *Blood* 2010;**116**:3923–32.
23. **Watanabe T**, Nobusawa S, Kleihues P, *et al*. IDH1 mutations are early events in the development of astrocytomas and oligodendrogliomas. *Am J Pathol* 2009;**174**:1149–53.
24. **Zawlik I**, Vaccarella S, Kita D, *et al*. Promoter methylation and polymorphisms of the MGMT gene in glioblastomas: a population-based study. *Neuroepidemiology* 2009;**32**:21–9.
25. **Thirlwell C**, Eymard M, Feber A, *et al*. Genome-wide DNA methylation analysis of archival formalin-fixed paraffin-embedded tissue using the Illumina Infinium HumanMethylation27 BeadChip. *Methods* 2010;**52**:248–54.
26. **Dahl C**, Grønbaek K, Guldberg P. Advances in DNA methylation: 5-hydroxymethylcytosine revisited. *Clin Chim Acta* 2011;**412**:831–6.
27. **Ito S**, D'Alessio AC, Taranova OV, *et al*. Role of Tet proteins in 5mC to 5hmC conversion, ES-cell self-renewal and inner cell mass specification. *Nature* 2010;**466**:1129–33.
28. **Tahiliani M**, Koh KP, Shen Y, *et al*. Conversion of 5-methylcytosine to 5-hydroxymethylcytosine in mammalian DNA by MLL partner TET1. *Science* 2009;**324**:930–5.
29. **Kloosterhof NK**, Bralten LB, Dubbink HJ, *et al*. Isocitrate dehydrogenase-1 mutations: a fundamentally new understanding of diffuse glioma? *Lancet Oncol* 2011;**12**:83–91.
30. **Rocquain J**, Carbuccioni N, Trouplin V, *et al*. Combined mutations of ASXL1, CBL, FLT3, IDH1, IDH2, JAK2, KRAS, NPM1, NRAS, RUNX1, TET2 and WT1 genes in myelodysplastic syndromes and acute myeloid leukemias. *BMC Cancer* 2010;**10**:401.
31. **Zhao S**, Lin Y, Xu W, *et al*. Glioma-derived mutations in IDH1 dominantly inhibit IDH1 catalytic activity and induce HIF-1 $\alpha$ . *Science* 2009;**324**:261–5.
32. **Dang L**, White DW, Gross S, *et al*. Cancer-associated IDH1 mutations produce 2-hydroxyglutarate. *Nature* 2009;**462**:739–44.
33. **Cancer Genome Atlas Research Network**. Comprehensive genomic characterization defines human glioblastoma genes and core pathways. *Nature* 2008;**455**:1061–8.



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