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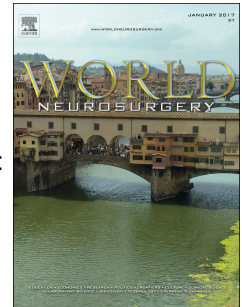
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The prognostic role of gender and MGMT methylation status in glioblastoma patients: the female power.

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Abstract

Background: Clinical and molecular factors are essential to define prognosis in glioblastoma (GBM) patients. MGMT methylation status, age, Karnofsky performance status (KPS) and extent of surgical resection are the most relevant prognostic factors. The role of gender in predicting patients prognosis has been investigated showing a slight survival advantage for female patients. **Methods:** We performed a prospective evaluation from a registry called the Project of Emilia Romagna on Neuro-Oncology (PERNO) about prognostic factors in GBM patients who received standard treatment. **Results:** One hundred sixty-nine patients were prospectively evaluated. Among male patients 36 were MGMT methylated (25.7%) and 47 were unmethylated (33.6%); among female patients 32 were methylated (22.9%) and 25 were unmethylated (17.9%). Survival was longer in methylated females than methylated males ($p=0.028$) but not significantly different between unmethylated female and male patients ($P=0.395$). In multivariate analysis, gender and MGMT methylation status considered together (methylated female vs methylated male HR=0.459; 95% CI 0.242 – 0.827; $P=0.017$), age (HR 1.025; 95% CI 1.002 – 1.049; $P=0.032$) and KPS (HR 0.965; 95% CI 0.948 – 0.982; $P<0.001$) were significantly correlated with survival. **Conclusion:** Survival was consistently longer among MGMT methylated females than males. Gender could be regarded as a further prognostic factor.

Keywords: glioblastoma, gender, MGMT, methylation, PERNO

Introduction

Primary GBMs occur more frequently in male patients with a mean age of diagnosis of 62 years; secondary GBMs have a predilection for female patients with a mean age of 45 years. Glioblastoma prognosis is poor with a median survival of 12-18 months and less than 10% of patients are alive 5 years after diagnosis. Patients surviving over 2 years after diagnosis have a higher survival probability compared to newly diagnosed patients [1, 2].

Extent of surgical resection, performance status and age (> 50 years) are the most important and widely accepted clinical prognostic factors [3-6]. Other factors could impact on prognosis: site of tumors [1]; body surface area (BSA) that is the only factor influencing temozolomide clearance and pharmacokinetics [7]; marital status [8] and care center expertise. About this last topic, in the prospective study of the Project of Emilia-Romagna on Neuro-Oncology (PERNO), overall survival was related to treatment received in a high versus low-volume center [9].

Various prognostic molecular markers have been identified in GBM, including methylation status of the O6-methylguanine-DNA methyltransferase (MGMT) gene promoter, isocitrate dehydrogenase enzyme 1/2 (IDH1/2) mutation, epidermal growth factor receptor (EGFR) overexpression and amplification, glioma-CpG island methylator phenotype (G-CIMP), tumor protein (TP53) mutation and genetic losses of chromosomes [1].

The role of gender has been investigated as potential prognostic factor.

Male patients have a significant survival advantage than female in the first year after the diagnosis, thereafter the difference is not significant [10]. The

results of survival analysis of GBM patients included in the PERNO registry suggest a survival advantage for MGMT methylated females.

Methods

The Project of Emilia-Romagna Region on Neuro-Oncology (PERNO) was created in Italy, in the Emilia-Romagna region in 2008, funded by the Italian Ministry of Health. A prospective study from PERNO registry database about clinical and prognostic features and outcomes of patients with GBM was conducted from January 2009 to December 2010. The main inclusion criteria were: 1) histologically proven GBM according to the WHO classification; 2) age ≥ 18 years; 3) KPS 30-100%, 4) no prior surgery for brain tumor; 5) residence within the Emilia-Romagna region [9,11].

Approval for the project was obtained from the Ethical Committee of each participating center and, before registration, informed written consent of the patient was obtained according to ICH/GCP and national recommendations.

MGMT methylation status was assessed through methylation-specific polymerase chain reaction (MSP).

Treatment

GBM patients younger than 70 years received the standard postsurgical treatment [12]. For patients older than 70 years the decision about schedule and time of radiotherapy and the choice to administer chemotherapy were

taken by oncologists and radiotherapists, based on patient's performance status, clinical conditions and comorbidities.

Temozolomide (TMZ) concomitant with radiotherapy was administered at the dose of 75 mg/m^2 for 7 days per week until the end of radiotherapy.

Adjuvant TMZ was administered at the dose of $150\text{-}200 \text{ mg/m}^2$ on days 1-5 every 28 days for up to 12 cycles or until radiological and/or clinical progression or unacceptable toxicities [9,11].

Statistical analysis

Data are reported as median, range and frequency. Survival data (median survival times with 95% confidence interval) were calculated by Kaplan-Meier procedure and were analyzed by log-rank test. Multivariate analysis was done through Backward Stepwise Cox proportional hazard model. The hazard ratios (HRs) were computed with 95% confidence intervals (95% CI). Two-tailed P values less than 0.05 were considered significant. The SPSS (Version 13.0 for Windows; SPSS Inc., Chicago, IL, USA) was used as statistical software.

Results

One hundred sixty-nine GBM patients were treated with TMZ concomitant with and adjuvant to radiotherapy. Median age was 60 years (range 29 – 82 years). Ninety-nine patients were male (58.6%) and 70 were female (41.4%). According to MGMT methylation status assessment, 68 patients were MGMT

methyated (48.6%), 72 were unmethyated (51.4%). Only four patients received hypofractionated treatment: one was methyated female, one was unmethyated female, one was methyated male and one was with unknown methylation status female. Patients' characteristics are described in **Table 1**.

Survival

Survival was similar between male patients (15.6 months 95% CI 12.9 – 18.4) and female patients (16.7 months 95% CI 13.5 – 19.9) ($P= 0.519$).

Overall survival (OS) in MGMT methyated patients was 20.0 months (95% CI 14.2 – 25.9) versus 14.1 months (95% CI 11.0 – 17.2) in unmethyated patients ($P= 0.001$).

Combining gender and methylation status, at univariate analysis, we observed a significant survival improvement for methyated females compared to methyated males: the female methyated group did not reach the median survival, however overall survival at 12 months (OS12) was significantly higher with respect to male methyated group (78.1% vs 66.7% $P= 0.028$). No significant difference was found between unmethyated females and unmethyated males ($P=0.158$) [**Figure 1**].

Multivariate analysis [**Table 2**] showed that gender and MGMT methylation status simultaneously considered ($P< 0.000$), age ($P= 0.032$) and performance status ($P= 0.000$) were the most important prognostic factors. Radical resection rate was not significantly different between female methyated group and other groups (62.5% vs 51.4%, $P= 0.574$).

Discussion

Age, performance status and extent of surgical resection are well known prognostic factors for GBM.

In a randomized EORTC-NCIC phase III trial [13] in newly diagnosed GBM, survival was not significantly different between female and male patients who received radiotherapy alone (survival difference 1,4 months) or standard treatment (survival difference 2,2 months). Based on these results, EORTC nomogram [14] included MGMT promoter methylation status, age at diagnosis, KPS, extent of surgery and mini-mental state evaluation (MMSE) as important prognostic factors but it did not include gender. More recently, a combined analysis of data from two independent clinical trials (NRG Oncology/Radiation Therapy Oncology Group 0525 and 0825) was used to develop a validated nomogram for estimation of survival in 1354 newly diagnosed GBM patients. It showed that gender was independently associated with survival, being male gender associated with shorter survival [14]. Particularly, a slight survival benefit for female versus male patients was confirmed also in the group of MGMT methylated patients, giving more convincing evidence of this association.

In a retrospective study of 105 newly diagnosed GBM patients we also evaluated the interaction between gender and GBM molecular features [15]. We found that female patients with MGMT methylation presented an improved survival compared to other groups (median OS 28.6 months, $P=0.008$).

It was hypothesized that pharmacodynamic, pharmacokinetic and molecular factors can create some differences among male and female patients, but a clear explanation of this is still unknown.

Females have a different body fat distribution, which may influence the absorption of the drug and a lower glomerular filtration rate with a consequent decreased elimination.

Some evidences [16,17] showed that sexual dimorphism might modulate the biology of GBM. In mice models, male exhibited higher proliferation and enhanced tumorigenesis compared to female counterparts [16]. Further, the tumors showed a more extensive necrosis in male patients than in female, due to the association of tumor cell death with MYC increased activity in female and with TP53 activity in male patients [17].

In 2016, a report by Schiffgens et al. analyzed sex-specific differences in relation to survival in GBM patients through the evaluation of a novel biomarker that promotes tumor progression: the Wnt receptor Frizzled-7 (FZD7). In this study, methylated MGMT promoter was found to be significantly associated with longer survival in female patients. Interestingly, combining FZD7 and MGMT methylation, sex-specific differences were deleted [18]. In addition, the role of gender has to be reminded when considering toxicity. The incidence of grade 3-4 hematological toxicity in GBM patients treated with temozolomide is in the range of 7% [12].

In a trial of 445 patients treated with TMZ, a higher incidence (11%) of significant myelotoxicity was reported in female patients. Older female

patients who received higher doses had a major chance to develop both neutropenia and thrombocytopenia [7].

To demonstrate the modulation of gender on the risk of severe myelotoxicity, Armstrong et al. conducted a retrospective review of all GBM patients treated with temozolomide from 1997 to 2004 at M.D. Anderson Cancer Center. They found that grade 3-4 myelotoxicity was significantly different according to the gender, being 16% in female and 7% in male patients, respectively ($P=0.015$). Patients carrying the G allele of MGMT (rs2308327) presented a 240% increase in risk of myelotoxicity (95% CI, 0.99 – 5.84) [19].

Other myelotoxic effects of TMZ are represented by aplastic anemia and myelodysplastic syndromes (MDS) and gender might have a role in predicting these conditions too. Villano et al. [20] reported all TMZ associated hematologic events reported in the FDA Med-Watch database between 1997 and 2008 and showed that aplastic anemia was observed in 39 out of 112 cases. Of these 39 patients, 11 died above all for infection. Moreover, these severe and often fatal hematologic toxicities seemed to occur two or three times more frequently in female than in male patients [21].

According to EORTC-NCIC phase III trial and NRG Oncology/Radiation Therapy Oncology Group 0525 and 0825 independent trials, our results from the prospective PERNO registry suggest that females have a survival advantage, though the difference is not significant (16.7 vs 15.6 months, $P=0.519$).

MGMT methylation status confirms its role of important prognostic factor (median survival 20.0 months for methylated group vs 14.1 months for unmethylated group, $P=0.001$).

When considering MGMT methylation status with gender, we observed a survival benefit in methylated female patients (met vs unmet $p<0.001$) but, interestingly, not in male patients (met vs unmet $P=0.395$).

At multivariate analysis, simultaneous evaluation of patients' gender and MGMT methylation status has a significant prognostic role: MGMT methylation is associated with longer survival in female patients when compared to unmethylated females (HR 4.108, 95% CI 2.105 – 8.016, $P=0.000$), to methylated males (HR 0.459, 95% CI 0.242 – 0.827, $P=0.017$), to unmethylated males (HR 0.327 95% CI 0.176 – 0.607 $P=0.000$).

Conclusion

The results of this PERNO registry analysis is of particular interest to drive oncologists in their clinical choices to select GBM patients to treat with standard treatment. MGMT methylated promoter has already been shown to be associated with a better prognosis but also gender should be considered as a potential prognostic factor and a predictive factor for myelotoxicity.

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Disclosure

The authors have declared no conflicts of interest. All authors have read and approved the manuscript and have participated to a sufficient extent to be named as authors.

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M.R., Urbini B., Zini G. (Ferrara); Giorgi C., Montanari E. (Fidenza, PR); Cerasti D., Crafa P., Dascola I., Florindo I., Giombelli E., Mazza S., Ramponi V., Servadei F., Silini EM., Torelli P. (Parma); Immovilli P., Morelli N., Vanzo C. (Piacenza); Nobile C. (Padova).

References

- 1) Thakkar JP, Dolecek TA, Horbinski C, Ostrom QT, Lightner DD, Barnholtz-Sloan JS, Villano JL. *Epidemiologic and molecular prognostic review of glioblastoma*. Cancer Epidemiol Biomarkers Prev; **23(10)**:1985-1996.
- 2) Johnson DR, Ma DJ, Buckner JC, Hammack JE. *Conditional probability of long-term survival in glioblastoma: a population-based analysis*. Cancer; **118(22)**:5608-5613.
- 3) Hegi ME, Diserens AC, Gorlia T, Hamou MF, de Tribolet N, Weller M, Kros JM, Hainfellner JA, Mason W, Mariani L, Bromberg JE, Hau P, Mirimanoff RO, Cairncross JG, Janzer RC, Stupp R. *MGMT gene silencing and benefit from temozolomide in glioblastoma*. N Engl J Med 2005; **352(10)**:997-1003.
- 4) Stummer W, Reulen HJ, Meinel T, Pichlmeier U, Schumacher W, Tonn JC, Rohde V, Oppel F, Turowski B, Woiciechowsky C, Franz K, Pietsch T. *Extent of resection and survival in glioblastoma multiforme: identification of and adjustment for bias*. Neurosurgery 2008; **62(3)**:564-576; discussion 564-576.
- 5) Lacroix M, Abi-Said D, Fourney DR, Gokaslan ZL, Shi W, DeMonte F, Lang FF, McCutcheon IE, Hassenbusch SJ, Holland E, Hess K, Michael C, Miller D, Sawaya R. *A multivariate analysis of 416 patients with*

glioblastoma multiforme: prognosis, extent of resection, and survival. J Neurosurg 2001;**95**(2):190-198.

6) Lamborn KR, Chang SM, Prados MD. *Prognostic factors for survival of patients with glioblastoma: recursive partitioning analysis.* Neuro Oncol 2004;**6**(3):227-235.

7) Jen JF, Cutler DL, Pai SM, Batra VK, Affrime MB, Zambas DN, Heft S, Hajian G. *Population pharmacokinetics of temozolomide in cancer patients.* Pharm Res 2000;**17**(10):1284-1289.

8) Putz F, Putz T, Goerig N, Knippen S, Gryc T, Eyupoglu I, Rossler K, Semrau S, Lettmaier S, Fietkau R. *Improved survival for elderly married glioblastoma patients: Better treatment delivery, less toxicity, and fewer disease complications.* Strahlenther Onkol;**192**(11):797-805.

9) Brandes AA, Franceschi E, Ermani M, Tosoni A, Albani F, Depenni R, Faedi M, Pisanello A, Crisi G, Urbini B, Dazzi C, Cavanna L, Mucciarini C, Pasini G, Bartolini S, Marucci G, Morandi L, Zunarelli E, Cerasoli S, Gardini G, Lanza G, Silini EM, Cavuto S, Baruzzi A, Baruzzi A, Albani F, Calbucci F, D'Alessandro R, Michelucci R, Brandes A, Eusebi V, Ceruti S, Fainardi E, Tamarozzi R, Emiliani E, Cavallo M, Franceschi E, Tosoni A, Cavallo M, Fiorica F, Valentini A, Depenni R, Mucciarini C, Crisi G, Sasso E, Biasini C, Cavanna L, Guidetti D, Marcello N, Pisanello A, Cremonini AM, Guiducci G, de Pasqua S, Testoni S, Agati R, Ambrosetto G, Bacci A, Baldin E, Baldrati A, Barbieri E, Bartolini S, Bellavista E, Bisulli F, Bonora E, Bunkheila F, Carelli V, Crisci M, Dall'Occa P, de Biase D, Ferro S, Franceschi C, Frezza G, Grasso V, Leonardi M, Marucci G, Mazzocchi V, Morandi L, Mostacci B, Palandri G, Pasini E, PastoreTrossello M, Pession A, Ragazzi M,

Riguzzi P, Rinaldi R, Rizzi S, Romeo G, Spagnolli F, Tinuper P, Trocino C, Cerasoli S, Dall'Agata M, Faedi M, Frattarelli M, Gentili G, Giovannini A, Iorio P, Pasquini U, Galletti G, Guidi C, Neri W, Patuelli A, Strumia S, Casmiro M, Gamboni A, Rasi F, Cruciani G, Cenni P, Dazzi C, Guidi A, Zumaglini F, Amadori A, Pasini G, Pasquinelli M, Pasquini E, Polselli A, Ravasio A, Viti B, Sintini M, Ariatti A, Bertolini F, Bigliardi G, Carpeggiani P, Cavalleri F, Meletti S, Nichelli P, Pettorelli E, Pinna G, Zunarelli E, Artioli F, Bernardini I, Costa M, Greco G, Guerzoni R, Stucchi C, Iaccarino C, Rizzi R, Zuccoli G, Api P, Cartei F, Fallica E, Granieri E, Latini F, Lelli G, Monetti C, Ramponi V, Saletti A, Schivalocchi R, Seraceni S, Tola MR, Urbini B, Giorgi C, Montanari E, Cerasti D, Crafa P, Dascola I, Florindo I, Mazza S, Servadei F, Silini E, Torelli P, Immovilli P, Morelli N, Vanzo C. *Pattern of care and effectiveness of treatment for glioblastoma patients in the real world: results from a prospective population-based registry. Could survival differ in a high-volume center?* Neurooncol Pract; **1**(4):166-171.

10) Ostrom QT, Gittleman H, Farah P, Ondracek A, Chen Y, Wolinsky Y, Stroup NE, Kruchko C, Barnholtz-Sloan JS. CBTRUS statistical report: *Primary brain and central nervous system tumors diagnosed in the United States in 2006-2010*. Neuro Oncol; **15**Suppl2:ii1-56.

11) Franceschi E, Depenni R, Paccapelo A, Ermani M, Faedi M, Sturiale C, Michiara M, Servadei F, Pavesi G, Urbini B, Pisanello A, Crisi G, Cavallo MA, Dazzi C, Biasini C, Bertolini F, Mucciarini C, Pasini G, Baruzzi A, Brandes AA. *Which elderly newly diagnosed glioblastoma patients can benefit from radiotherapy and temozolomide? A PERNO prospective study*. J Neurooncol; **128**(1):157-162.

- 12) Stupp R, Mason WP, van den Bent MJ, Weller M, Fisher B, Taphoorn MJ, Belanger K, Brandes AA, Marosi C, Bogdahn U, Curschmann J, Janzer RC, Ludwin SK, Gorlia T, Allgeier A, Lacombe D, Cairncross JG, Eisenhauer E, Mirimanoff RO. *Radiotherapy plus concomitant and adjuvant temozolomide for glioblastoma*. N Engl J Med 2005;**352**(10):987-996.
- 13) Gorlia T, van den Bent MJ, Hegi ME, Mirimanoff RO, Weller M, Cairncross JG, Eisenhauer E, Belanger K, Brandes AA, Allgeier A, Lacombe D, Stupp R. *Nomograms for predicting survival of patients with newly diagnosed glioblastoma: prognostic factor analysis of EORTC and NCIC trial 26981-22981/CE.3*. Lancet Oncol 2008;**9**(1):29-38.
- 14) Gittleman H, Lim D, Kattan MW, Chakravarti A, Gilbert MR, Lassman AB, Lo SS, Machtay M, Sloan AE, Sulman EP, Tian D, Vogelbaum MA, Wang TJC, Penas-Prado M, Youssef E, Blumenthal DT, Zhang P, Mehta MP, Barnholtz-Sloan JS. *An independently validated nomogram for individualized estimation of survival among patients with newly diagnosed glioblastoma: NRG Oncology RTOG 0525 and 0825*. Neuro Oncol;**19**(5):669-677.
- 15) Franceschi E, Tosoni A, Bartolini S, Scopece L, Lombardo L, Poggi R, Mazzocchi V, La Torre L, Ermani M, Brandes AA. *Prognostic factors in newly diagnosed glioblastoma: Have we missed gender?* 10.1200/jco.2011.29.15_suppl.2058.
- 16) Sun T, Warrington NM, Luo J, Brooks MD, Dahiya S, Snyder SC, Sengupta R, Rubin JB. *Sexually dimorphic RB inactivation underlies mesenchymal glioblastoma prevalence in males*. J Clin Invest;**124**(9):4123-4133.

- 17) Colen RR, Wang J, Singh SK, Gutman DA, Zinn PO. *Glioblastoma: imaging genomic mapping reveals sex-specific oncogenic associations of cell death*. Radiology; **275**(1):215-227.
- 18) Schiffgens S, Wilkens L, Brandes AA, Meier T, Franceschi E, Ermani M, Hartmann C, Sandalcioglu IE, Dumitru CA. *Sex-specific clinicopathological significance of novel (Frizzled-7) and established (MGMT, IDH1) biomarkers in glioblastoma*. Oncotarget; **7**(34):55169-55180.
- 19) Armstrong TS, Cao Y, Scheurer ME, Vera-Bolanos E, Manning R, Okcu MF, Bondy M, Zhou R, Gilbert MR. *Risk analysis of severe myelotoxicity with temozolomide: the effects of clinical and genetic factors*. Neuro Oncol 2009; **11**(6):825-832.
- 20) Villano JL, Letarte N, Yu JM, Abdur S, Bressler LR. *Hematologic adverse events associated with temozolomide*. Cancer Chemother Pharmacol; **69**(1):107-113.
- 21) Dixit S, Hingorani M, Allgar V. *An analysis of temozolomide-related adverse drug reactions reported to the medicines and healthcare products regulatory agency through the yellow card scheme aiming to characterise idiosyncratic profound bone marrow suppression tantamount to aplastic anaemia*. ClinOncol (R Coll Radiol); **26**(2):120-121.

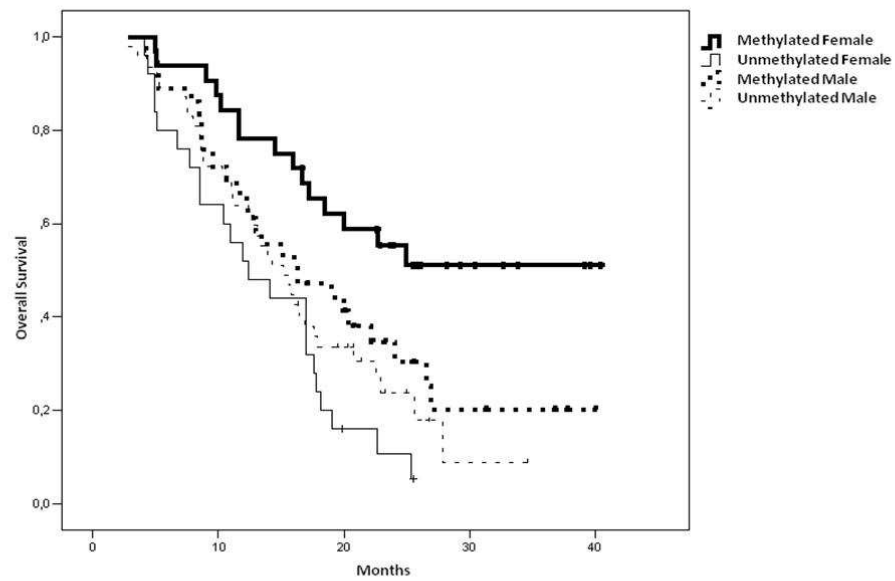
Table 1**Table 1: Patients' characteristics**

Patients' characteristics	N (tot. 169) and %
Age	
< 70 years	141(83%)
≥ 70 years	28 (17%)
Gender	
Male	99 (58.6%)
Female	70 (41.4%)
KPS (Karnofsky performance status)	
< 70%	10 (5.9%)
≥70%	159 (94.1%)
MGMT methylation status	
Methylated	68 (40.3%)
Unmethylated	62 (36.7%)
Age and MGMT methylation status	
Methylated males	36 (25.7%) median age 60 years
Unmethylated males	47 (33.6%) median age 60 years
Methylated females	32 (22.9%) median age 58 years
Unmethylated females	25 (17.9%) median age 63 years
Surgery	
Biopsy	23 (13.6%)
Partial resection	65 (38.5%)
Complete resection	81 (47.9%)

Table 2**Table2: Results from multivariate analysis**

	MULTIVARIATE ANALYSIS		
	HR	95%CI	P
Group			<0.001
- methylated female vs methylated male	0.459	0.242 - 0.827	0.017
- methylated male vs unmethylated female	0.530	0.301 - 0.934	0.028
- methylated female vs unmethylated male	0.327	0.176 - 0.607	<0.001
- methylated female vs unmethylated female	0.243	0.125 - 0.475	<0.001
Age	1.025	1.002 - 1.049	0.032
KPS	0.965	0.948 - 0.982	<0.001
MGMT methylation			1
Gender			1
			1

¹ Not included in the forward stepwise selection model

Figures**Figure 1****Fig. 1: Survival status when considering gender and MGMT methylation status**

Highlights

- MGMT methylation is a relevant prognostic factor for glioblastoma patients.
- From literature a prognostic advantage for female patients has been reported.
- In this analysis we report a survival benefit for methylated female GBM patients.

Abbreviations

BSA: body surface area

EGFR: epidermal growth factor receptor

FZD7: Wnt receptor Frizzled-7

GBM: glioblastoma

G-CIMP: glioma-CpG island methylator phenotype

HR: Hazard ratio

ICH/GCP: International Conference of Harmonisation/Good Clinical Practice

IDH: isocitrate dehydrogenase enzyme

KPS: Karnofsky performance status

MDS: Myelodysplastic syndromes

MGMT: O6-methylguanine-DNA methyltransferase

MMSE: mini-mental state evaluation

MSP: methylation-specific polymerase chain reaction

OS: overall survival

PERNO: Project of Emilia-Romagna on Neuro-Oncology

TMZ: Temozolomide

TP53: tumor protein 53

WHO: World Health Organization

Disclosure form

All named authors have read the manuscript and have agreed to submit the paper in its present form.

The manuscript has not been and will not be submitted simultaneously to another journal, in whole or in part.

The paper reports previously unpublished work.

All those named as authors have made a sufficient contribution to the work.

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The authors declare they have observed appropriate ethical guidelines and legislation in conducting the study described in the paper.