Original article

Ukrainian Neurosurgical Journal. 2025;31(4):61-67
doi: 10.25305/unj.333185

Status and prognostic impact of IDH1 in adult grade 4 diffuse gliomas

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Received: 20 June 2025
Accepted: 20 August 2025

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Background and objectives: The fifth edition of the WHO Classification of Tumors of the Central Nervous System divides grade 4 diffuse glioma based on *IDH1* mutation in grade 4 astrocytoma, IDH-mutant and glioblastoma, IDH-wild type tumors. This study aimed to evaluate the *IDH1* status in grade 4 diffuse glioma as well as its correlation with clinicopathological features and patient survival. To our knowledge, no Tunisian studies on the molecular profile of diffuse glioma have yet been published.

Methods: This is a retrospective study including all cases of adult, grade 4 diffuse glioma collected in the pathology department of Habib Bourguiba hospital.

Results: A total of 67 patients were included in the final analysis. The expression of *IDH1* was positive in 22 cases (32%). *IDH1*-positive tumors were classified as grade 4 astrocytoma, *IDH1*-mutant while, 45 *IDH1*-negative tumors were classified as glioblastoma, *IDH1*-wild type tumors (68%). *IDH1* expression was correlated with younger age (≤ 40 years old), frontal location, complete surgical resection and well-defined borders. *IDH1*-positive tumors were associated significantly with better prognosis. The 1-year overall survival (OS) for grade 4 astrocytoma, *IDH1*-mutant was 86% compared with 8% in glioblastoma, IDH1-wild type (p=0.008).

Conclusion: Our study investigated *IDH1* expression in grade 4 diffuse glioma and proved that grade 4 astrocytoma, IDH1 positive tumors displayed different characteristics with a more favorable outcome compared to glioblastoma, IDH1 negative. Thus, evaluation of *IDH1* mutation should be standardized routinely not only as diagnostic marker but also to refine the prognostic classification of these tumors.

Key words: *grade 4 diffuse glioma; IDH1; astrocytoma grade 4; glioblastoma; pathology; prognosis*

Introduction

Diffuse gliomas (DGs) are the most common primary tumors of the central nervous system (CNS) [1]. Traditionally, CNS tumor has been classified exclusively based on histological features. During recent years, large-scale researches have made rapid advances in understanding glioma genetics. The identification of genetic impairments involved in gliogenesis led to 2021 World Health Organization (WHO) classification based on an integrated histo-molecular diagnosis [2] including radiation, chemotherapy (temozolomide and PCV [procarbazine, lomustine, vincristine]. The isocitrate dehydrogenase 1 (IDH1) mutation and its prognostic impact remain the most studied. Despite their histological similarity, this classification divides the grade 4 DGs based on IDH1 mutation into two different prognostic entities: *grade 4 astrocytoma, IDH-mutant* and *glioblastoma, IDH-wild type* tumors. The most frequent IDH mutation is IDH1-R132H, which is detectable by immunohistochemistry using a specific antibody; other IDH mutations are rare (about 10%) and require DNA sequencing [3]. IDH 1 mutation is a landmark in the history of gliomas as a favorable prognostic biomarker, which is associated with a good clinical outcome [4]. In addition, several other genetic alterations have been identified in the pathogenesis of IDH-wild type glioblastoma such as *TERT* promoter mutation, *EGFR* amplification and +7/−10 copy number changes [5].

Therefore, the aim of our study was to evaluate the IDH1 status in grade 4 DGs and to assess its correlation with clinicopathological and survival features.

Methods

Study design and population

This is a retrospective study including all consecutive cases of grade 4 DG collected in the pathology and radiotherapy departments at the Habib Bourguiba University Hospital over a period of 9 years from 2016 through 2024.

Patients were enrolled in this study according to the following criteria: histological diagnosis of grade 4 DG (according to 2021 CNS WHO classification) [2], age over 18 years-old and available clinical and survival data. This report follows the Strengthening the Reporting

of Observational Studies in Epidemiology (STROBE) guidelines. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and the national research committee of Habib Bourguiba University Hospital and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Immunohistochemical study

Immunohistochemistry was performed on 5-µm –thick formalin fixed paraffin embedded tissues sections using antibodies against IDH1-R132H mutant protein (mouse monoclonal, clone IHC132-100, 1:400; Genome-Me). The expression of IDH1-R132H was determined by semi-quantitatively assessing the proportion of positively stained tumor cells. Cytoplasmic staining involving more than 10% of tumor cells was considered positive. Cases with less than 10% of tumor cells or staining of macrophages were considered as negative [6, 7].

Statistical analysis

Statistical analysis was performed using SPSS software version 22.0. Categorical variables were described as frequencies and percentages. For quantitative variables, means and standard deviations were used when their distributions were normal. Otherwise, medians and extreme values were reported. To examine the association of IDH1 expression with the different clinicopathological features the Pearson's chi-square test or Fisher's exact test was applied for categorical variables. Survival analysis was performed using the Kaplan-Meier estimator and log-rank test to assess the significant association of IDH1 expression with overall survival (OS) and progression free survival (PFS) times in diffuse gliomas patients. A $p \leq 0.05$ was considered statistically significant.

Results

Clinicopathological characteristics of study patients

The study population consisted of 67 patients representing 58.2 % of all DGs. The mean age at diagnosis was 56,7 years ± 12,9. The cohort included 36 males and 31 females (sex ratio: 1,16). The mean tumor size was 47.6 mm ± 14,8 mm. The tumors were localized at the cerebral hemispheres in 56 cases (83.5%) followed by diencephalon in 8 cases (12%) and ventricles in 2 cases (3%). Only one case was in the cerebellum. For hemispheres location, the frontal lobe was involved in 23 cases (34.3%) followed by the temporal lobe in 17 cases (25.4%) and the parietal lobe in 12 cases (17.9%) (***Table 1***).

Table1. Comparison of grade 4 diffuse glioma characteristics according to IDH1 expression

Variables			IDH1		p
			Negative (%)	Positive (%)	
Age (years)	≤ 40		5 (21.8)	18 (78.2)	< 0.001
	> 40		40 (90)	4 (10)	
sex	Male		26 (7.7)	10 (27.7)	0.14
	Female		19 (72.3)	12 (38.7)	
Location	hemispheres	Frontal	8 (34.8)	15 (65.2)	0.02
		Temporal	14(82.4)	3 (17.6)	
		Parietal	10 (83.3)	2 (16.7)	
		Occipital	4	0	
	Diencephalon		7	1	
	Ventricles		2	0	
	Cerebellum		0	1	
size (cm)	< 5		12 (63.2)	7 (36.8)	0.4
	≥ 5		19 (73)	7 (27)	
Surgical margins	Complete		8 (38.1)	13 (61.9)	0.006
	Partial		21 (77.8)	6 (22.2)	
	Biopsy		10 (83.3)	2 (16.7)	
Borders	Well-defined		2 (12.5)	14 (87.5)	<0.001
	Ill-defined		28 (90.3)	3 (9.7)	
p53	Negative		6 (57)	8 (43)	0.5
	Positive		16 (30,2)	37 (69,8)	

Notes. Data reported in bold refers to $p \leq 0.05$
Pearson's chi-square test was used to compare categorical variables
*Fisher test was used instead of chi-square test if one or more variables had an expected frequency of less than five.

Immunohistochemical analysis of IDH1

The expression of IDH1 was positive in 22 cases (32%). IDH1 positive tumors were classified as grade 4 astrocytoma, IDH1-mutant (***Fig. 1***) while IDH1 negative tumors were classified as glioblastoma, IDH1-wild type tumors (N= 45; 68%) (***Fig. 2***).

Comparison of tumor characteristics according to IDH1 expression

The clinical and pathological data of grade 4 astrocytoma, IDH1-mutant and glioblastoma, IDH1 wild type tumors are described and compared in (***Table 1)***. The two tumors displayed significant differences in various characteristics. Grade 4 astrocytoma, IDH1-mutant was associated with a younger patient age (<40 years) (p<0,001), a frontal location of the tumor (p=0,02), complete surgical resection (p=0.006) and well-defined borders (p<0.001). No correlation was observed with other the factors including sex, tumor size and p53 expression.

Survival analysis

IDH1 positive tumors were associated with a more favorable outcome. The OS of patients with grade 4 astrocytoma, IDH1 mutant were significantly longer than glioblastoma, IDH1 wild-type tumors (1- year OS: 82% versus 8%; p=0.008) (***Fig. 3***). In addition, grade 4 astrocytoma, IDH1 mutant showed a prolonged 1-year PFS compared to glioblastoma (48% versus 29%; p= 0.01) (***Fig. 4***).

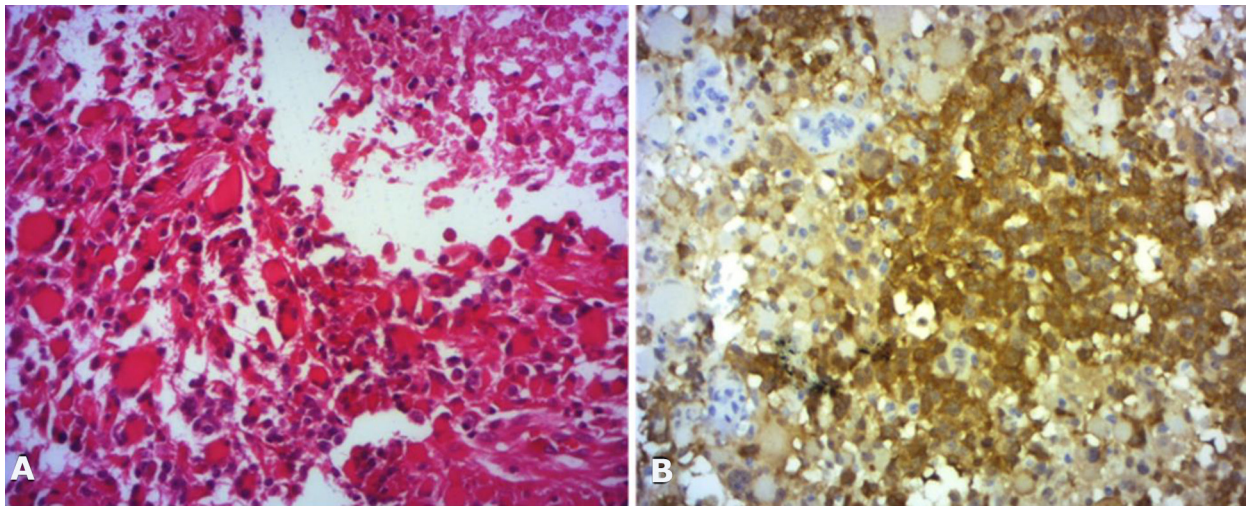

Fig. 1. Grade 4 astrocytoma, IDH1 positive (A) Gemistocytic astrocytoma grade 4 (H&E x 200) (B) Positive stain for IDH1 (X200)

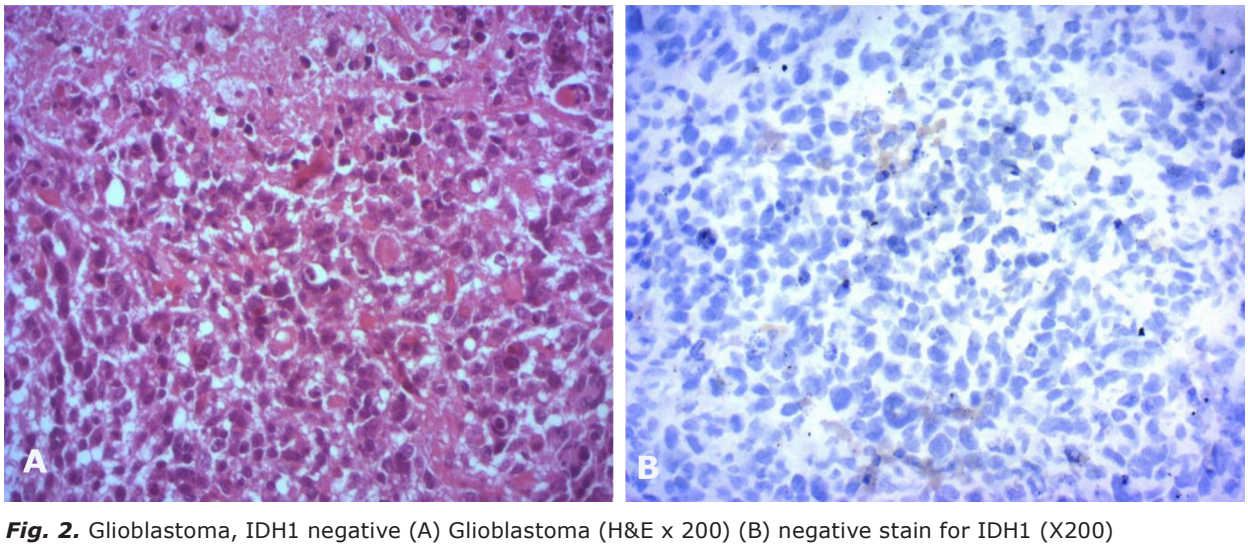

Fig. 2. Glioblastoma, IDH1 negative (A) Glioblastoma (H&E x 200) (B) negative stain for IDH1 (X200)

This article contains some figures that are displayed in color online but in black and white in the print edition.

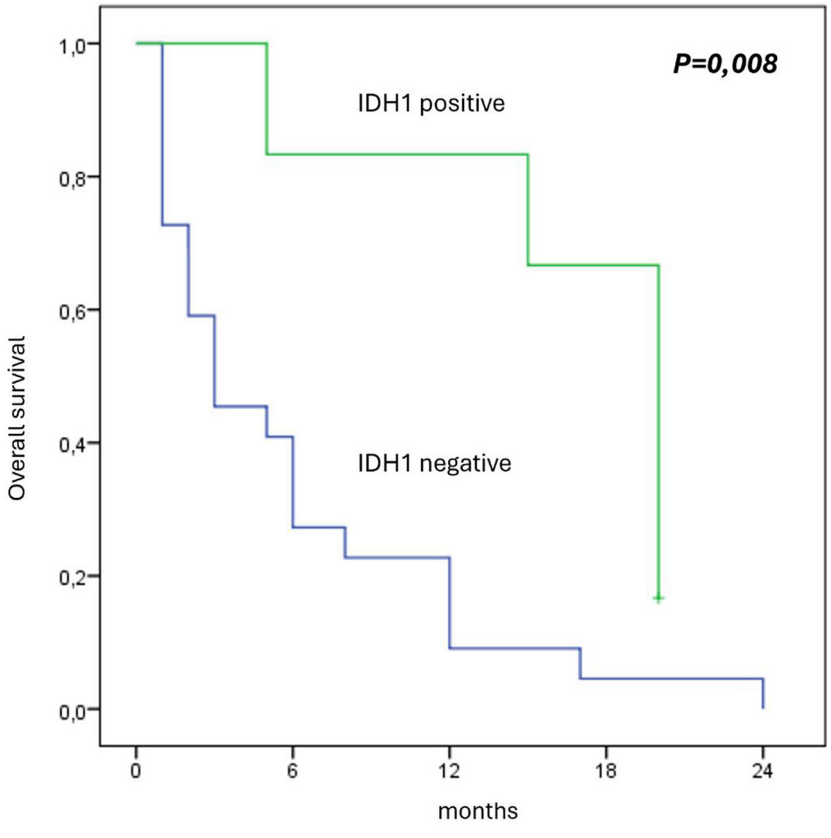

Fig. 3. Overall survival of grade 4 DG according to IDH1 expression

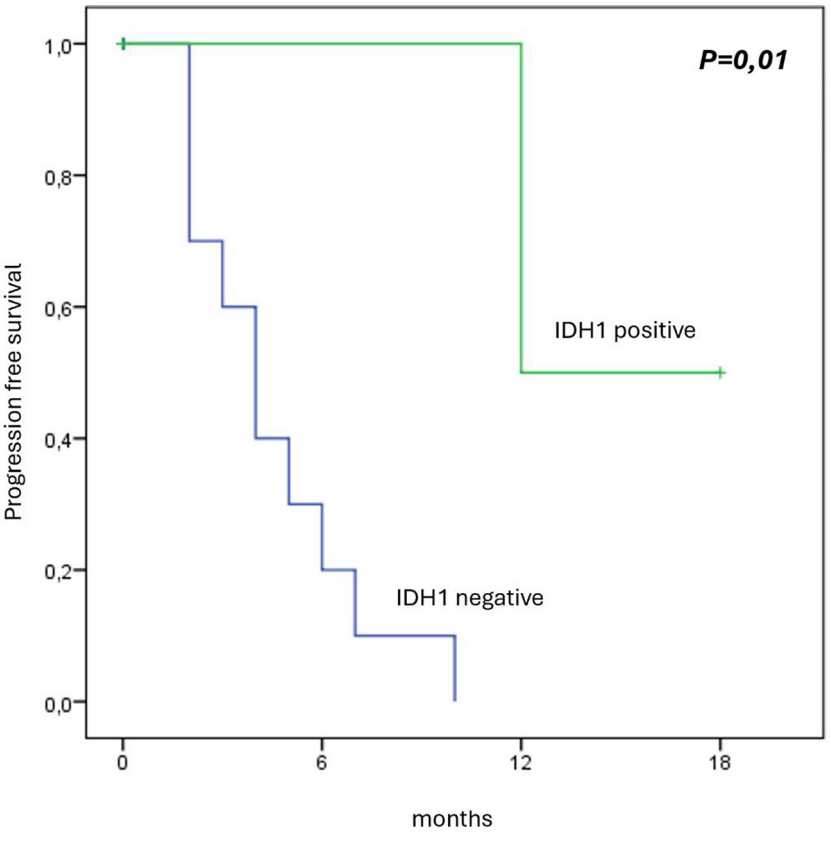

Fig. 4. Progression free survival of grade 4 DG according to IDH1 expression

Discussion

In the present study, we detected the IDH1-R132H expression using immunohistochemistry in grade 4 DG, and assessed its favorable prognostic impact among grade 4 astrocytoma compared with IDH1-negative glioblastoma. To our knowledge, this is the first study reporting the impact of IDH1 expression in grade 4 DG in Tunisia.

Nowadays, IDH1 mutation is commonly established as a hallmark molecular feature of diffuse gliomas [3]. IDH1–R132H is the most common mutation (90%), followed at a distance by IDH1- R132L, IDH1- R132S, IDH1- R132C and IDH1-R132G mutations [8]. Currently, immunohistochemistry is considered a reproducible and available method for assessing IDH1 mutation. IDH1-R132H antibody is highly specific for detecting the most common mutation in the gene and has a sensitivity of 94% because of the lack of detection of other types of IDH1 mutations [9, 10]. Immunohistochemical expression rates of IDH1 in grade 4 DG have varied across studies. A meta-analysis conducted by Chen et al. demonstrated a wide range in the reported frequency of IDH1 mutation with rates ranging from 18% to 81.8% [11].

The fifth edition of the WHO classification of tumors of the CNS incorporates numerous refinements and advances since the publication of the 2016 revised fourth edition. Notably, the nomenclature of diffuse gliomas has been significantly revised [2]. In the 2016 classification, IDH-mutant diffuse astrocytic tumors were divided into three distinct entities—diffuse astrocytoma, anaplastic astrocytoma, and glioblastoma based on histological criteria. In the updated classification, however, all IDH-mutant diffuse astrocytic tumors are grouped under a single category (IDH-mutant astrocytoma) and are assigned a CNS WHO grade of 2, 3, or 4. Furthermore, grading is no longer based solely on histology, as the presence of a homozygous deletion of *CDKN2A* and/or *CDKN2B* now qualifies the tumor for a WHO grade 4 designation, even in the absence of microvascular proliferation or necrosis [5]. Moreover, the 2021 fifth edition of WHO CNS classification emphasizes the role of molecular diagnosis building on the sixth update of the Consortium to Inform Molecular and Practical Approaches to CNS Tumor Taxonomy (cIMPACT- NOW) recommendations and 2016 WHO classification [12]. For IDH-wildtype diffuse astrocytic tumors, the presence of one or more of three genetic parameters: TERT promoter mutation, EGFR gene amplification, combined gain of chromosome 7 and loss of chromosome 10 are sufficient to assign the diagnosis of *glioblastoma, IDH-wild type* even in the absence of necrosis or microvascular proliferation [12, 13].

IDH1-mutant gliomas occur commonly in younger age compared to wild type tumors. According to a recent study, the median age at diagnosis of IDH1-mutant astrocytomas was 36 and versus 52 years in Glioblastoma, IDH1-negative [14]. Consistent with this, we found a positive association between IDH1 and age (< 40 years). In addition, tumor location also appears to correlate with IDH1 status. IDH1-wild type tumors are more deeply situated with more infiltrative pattern, although mutant gliomas are located frequently in the frontal lobe [16]. To date, correlation of IDH1 mutation with tumor size is unclear; some studies found that IDH1-wild type tumors are larger [17] while other authors didn't found such association [18] IDH status was determined on 114 and 27 patients, respectively. On univariable analysis, improved five-year survival was independently associated with concurrent TMZ (46.2 vs. 29.3 %, p = 0.02. Several studies have demonstrated an association between IDH1 status and the extent of tumor resection. Astrocytomas harboring IDH1 mutations are more likely to undergo complete tumor resection compared to IDH1-wildtype glioblastomas [19].

The association of IDH1 mutation with TP53 mutation has been widely studied in the literature and has led to contradictory results. IDH1 mutation was found associated with TP53 mutation in several studies [10, 21], whereas other authors did not found such an association, consistent to our results [22, 23]. Immunohistochemistry is a practicable surrogate for a molecular assay. Strong p53 staining of 10% of tumor cells is highly predictive of TP53 mutation with a sensitivity and specificity of 78.8% and 96.7% respectively [24]. TP53 mutation is common in grade 4 astrocytoma, IDH mutant, observed in about 70% of cases. However, this mutation is less common in glioblastoma, IDH-wild type (less than 30%) [25].

Based on previous research, IDH1 mutant gliomas present an improved outcome [20, 25–27]. The aim of our study was to establish a correlation between the survival outcome of grade4 DGs and IDH1 immunohistochemical expression.

Survival analysis based on IHC results showed a statistically significant better survival in both OS and PFS in IDH1 positive tumors than their counterparts. These results were consistent with several other reports. Sanson et al, have shown that the 5-year-OS of patients with grade 4 astrocytoma, IDH1-positive was 27.4 months versus 14 months in their counterparts [28]. Similarly in the study of Wang et al, glioblastoma presented a poor outcome with an OS of 14.2 months compared to grade 4 astrocytoma of which the OS was 26.6 months [20].

However, other authors haven't found such a correlation. Cai et al. reported that OS and PFS in IDH1-mutant grade 4 astrocytoma were not significantly better than those in glioblastoma [18]. These results were in line with those obtained by July et al; who concluded that IDH1 mutation was not a prognostic factor in grade 4 DGs [4].

Ultimately, our study provides a brand-new update of the value of IDH1 expression among grade 4 DGs; a subject not well elucidated in our population. Our study presented some limitations. The sample study may be limited; thus further larger investigations are recommended to better understand grade 4 diffuse gliomas. In addition, molecular profile supporting the diagnosis of glioblastoma IDH-wild type—such as TERT promoter mutation, EGFR amplification and +7/–10 copy number changes—were not available in our department.

Conclusion

The immunohistochemical profile of IDH1 is of significant importance for the diagnosis and prognosis in patients with grade 4 diffuse gliomas. In this study, we revealed that immunohistochemical staining of IDH1 in grade 4 astrocytoma was associated with distinct clinicopathological factors as well a good outcomes with

significant increased survival rates, compared to their counterparts of IDH1-negative glioblastomas. Thus, the evaluation of IDH1 mutation with other genomic markers, should be standardized and integrated into daily clinical practice — not only as diagnostic markers but also to refine the prognostic classification of these tumors.

Disclosure

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and the national research committee of Habib Bourguiba Hospital and the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

General informed consent was obtained from all individual participants included in the study, upon admission to the hospital.

Funding declaration

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors have no conflicts of interest to disclose.

References

1. Louis DN, Ohgaki H, Wiestler OD, Cavenee WK (Eds): WHO Classification of Tumors of the Central Nervous System (4th edition). IARC; Lyon. 2016.
2. Louis DN, Ohgaki H, Wiestler OD, Cavenee WK. (Eds): WHO Classification of Tumors of the central Nervous System (5th edition). IARC; Lyon. 2021.
3. Rousseau A. [Molecular diagnostics of diffuse gliomas]. Revue Francophone des Laboratoires. 2018;(506):61-7. French. doi: 10.1016/S1773-035X(18)30324-1
4. July J, Patricia D, Gunawan PY, Setiajaya H, Ginting TE, Putra TP, Wuisan Z, Budhiarko D, Masykura N, Prayogi G, Utomo AR, Tandean S, Loe ML. Clinicopathological associations and prognostic values of IDH1 gene mutation, MGMT gene promoter methylation, and PD-L1 expressions in high-grade glioma treated with standard treatment. Pan Afr Med J. 2020 Aug 20;36:309. doi: 10.11604/pamj.2020.36.309.24831
5. Thomas DL. 2021 updates to the World Health Organization classification of adult-type and pediatric-type diffuse gliomas: a clinical practice review. Chin Clin Oncol. 2023 Feb;12(1):7. doi: 10.21037/cco-22-120
6. Takano S, Kato Y, Yamamoto T, Kaneko MK, Ishikawa E, Tsujimoto Y, Matsuda M, Nakai K, Yanagiya R, Morita S, Tsuboi K, Matsumura A. Immunohistochemical detection of IDH1 mutation, p53, and internexin as prognostic factors of glial tumors. J Neurooncol. 2012 Jul;108(3):361-73. doi: 10.1007/s11060-012-0837-0
7. Lewandowska MA, Furtak J, Szylberg T, Roszkowski K, Windorbska W, Rytlewska J, Jóźwicki W. An analysis of the prognostic value of IDH1 (isocitrate dehydrogenase 1) mutation in Polish glioma patients. Mol Diagn Ther. 2014 Feb;18(1):45-53. doi: 10.1007/s40291-013-0050-7
8. Gondim DD, Gener MA, Curless KL, Cohen-Gadol AA, Hattab EM, Cheng L. Determining IDH-Mutational Status in Gliomas Using IDH1-R132H Antibody and Polymerase Chain Reaction. Appl Immunohistochem Mol Morphol. 2019 Nov/Dec;27(10):722-725. doi: 10.1097/PAI.0000000000000702
9. Gülten G, Yalçın N, Baltalarlı B, Doğu G, Acar F, Doğruel Y. The importance of IDH1, ATRX and WT-1 mutations in glioblastoma. Pol J Pathol. 2020;71(2):127-137. doi: 10.5114/pjp.2020.97020
10. Capper D, Weissert S, Balss J, Habel A, Meyer J, Jäger D, Ackermann U, Tessmer C, Korshunov A, Zentgraf H, Hartmann C, von Deimling A. Characterization of R132H mutation-specific IDH1 antibody binding in brain tumors. Brain Pathol. 2010 Jan;20(1):245-54. doi: 10.1111/j.1750-3639.2009.00352.x
11. Chen JR, Yao Y, Xu HZ, Qin ZY. Isocitrate Dehydrogenase (IDH)1/2 Mutations as Prognostic Markers in Patients With Glioblastomas. Medicine (Baltimore). 2016 Mar;95(9):e2583. doi: 10.1097/MD.0000000000002583
12. Miller JJ, Shih HA, Andronesi OC, Cahill DP. Isocitrate dehydrogenase-mutant glioma: Evolving clinical and therapeutic implications. Cancer. 2017 Dec 1;123(23):4535-4546. doi: 10.1002/cncr.31039
13. Larsen C. Anomalies génétiques et moléculaires des glioblastomes (GBM) [Genetic and molecular abnormalities of glioblastomas (GBM)]. Bull Cancer. 2010 Nov;97(11):1389-407. French. doi: 10.1684/bdc.2010.1215
14. Molinaro AM, Taylor JW, Wiencke JK, Wrensch MR. Genetic and molecular epidemiology of adult diffuse glioma. Nat Rev Neurol. 2019 Jul;15(7):405-417. doi: 10.1038/s41582-019-0220-2
15. Suh CH, Kim HS, Jung SC, Choi CG, Kim SJ. Imaging prediction of isocitrate dehydrogenase (IDH) mutation in patients with glioma: a systemic review and meta-analysis. Eur Radiol. 2019 Feb;29(2):745-758. doi: 10.1007/s00330-018-5608-7
16. Olar A, Raghunathan A, Albarracin CT, Aldape KD, Cahill DP 3rd, Powell SZ, Goodman JC, Fuller GN. Absence of IDH1-R132H mutation predicts rapid progression of nonenhancing diffuse glioma in older adults. Ann Diagn Pathol. 2012 Jun;16(3):161-70. doi: 10.1016/j.anndiagpath.2011.08.010
17. Kizilbash SH, Giannini C, Voss JS, Decker PA, Jenkins RB, Hardie J, Laack NN, Parney IF, Uhm JH, Buckner JC. The impact of concurrent temozolomide with adjuvant radiation and IDH mutation status among patients with anaplastic astrocytoma. J Neurooncol. 2014 Oct;120(1):85-93. doi: 10.1007/s11060-014-1520-4
18. Cai J, Zhu P, Zhang C, Li Q, Wang Z, Li G, Wang G, Yang P, Li J, Han B, Jiang C, Sun Y, Jiang T. Detection of ATRX and IDH1-R132H immunohistochemistry in the progression of 211 paired gliomas. Oncotarget. 2016 Mar 29;7(13):16384-95. doi: 10.18632/oncotarget.7650
19. De Leeuw BI, Van Baarsen KM, Snijders TJ, Robe PAJT. Interrelationships between molecular subtype, anatomical location, and extent of resection in diffuse glioma: a systematic review and meta-analysis. Neurooncol Adv. 2019 Oct 1;1(1):vdz032. doi: 10.1093/noajnl/vdz032
20. Wang XW, Ciccarino P, Rossetto M, Boisselier B, Marie Y, Desestret V, Gleize V, Mokhtari K, Sanson M, Labussière M. IDH mutations: genotype-phenotype correlation and prognostic impact. Biomed Res Int. 2014;2014:540236. doi: 10.1155/2014/540236
21. Jakovlevs A, Vanags A, Gardovskis J, Strumfa I. Molecular classification of diffuse gliomas. Pol J Pathol. 2019;70(4):246-258. doi: 10.5114/pjp.2019.93126
22. Stancheva G, Goranova T, Laleva M, Kamenova M, Mitkova A, Velinov N, Poptodorov G, Mitev V, Kaneva R, Gabrovsky N. IDH1/IDH2 but not TP53 mutations predict prognosis in Bulgarian glioblastoma patients. Biomed Res Int. 2014;2014:654727. doi: 10.1155/2014/654727
23. Balss J, Meyer J, Mueller W, Korshunov A, Hartmann C, von Deimling A. Analysis of the IDH1 codon 132 mutation in brain tumors. Acta Neuropathol. 2008 Dec;116(6):597-602. doi: 10.1007/s00401-008-0455-2
24. Takami H, Yoshida A, Fukushima S, Arita H, Matsushita Y, Nakamura T, Ohno M, Miyakita Y, Shibui S, Narita Y, Ichimura K. Revisiting TP53 Mutations and Immunohistochemistry--A Comparative Study in 157 Diffuse Gliomas. Brain Pathol. 2015 May;25(3):256-65. doi: 10.1111/bpa.12173
25. Chaurasia A, Park SH, Seo JW, Park CK. Immunohistochemical Analysis of ATRX, IDH1 and p53 in Glioblastoma and Their Correlations with Patient Survival. J Korean Med Sci. 2016 Aug;31(8):1208-14. doi: 10.3346/jkms.2016.31.8.1208
26. Barresi V, Eccher A, Simbolo M, Cappellini R, Ricciardi GK, Calabria F, Cancedda M, Mazzarotto R, Bonetti B, Pinna G, Sala F, Ghimenton C, Scarpa A. Diffuse gliomas

in patients aged 55 years or over: A suggestion for IDH mutation testing. Neuropathology. 2020 Feb;40(1):68-74. doi: 10.1111/neup.12608
27. Rajmohan KS, Sugur HS, Shwetha SD, Ramesh A, Thennarasu K, Pandey P, Arivazhagan A, Santosh V. Prognostic significance of histomolecular subgroups of adult anaplastic (WHO Grade III) gliomas: applying the 'integrated' diagnosis approach. J Clin Pathol. 2016 Aug;69(8):686-94. doi: 10.1136/jclinpath-2015-203456
28. Sanson M, Marie Y, Paris S, Idbaih A, Laffaire J, Ducray F, El Hallani S, Boisselier B, Mokhtari K, Hoang-Xuan K, Delattre JY. Isocitrate dehydrogenase 1 codon 132 mutation is an important prognostic biomarker in gliomas. J Clin Oncol. 2009 Sep 1;27(25):4150-4. doi: 10.1200/JCO.2009.21.9832