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Anamnestic radiological metastases outcome surgical score (ARMO-S). A purpose of a predictive surgical scoring system for brain metastases

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ABSTRACT

Background: Several risk stratification scores have been suggested to aid prognostication and guide treatment strategies for brain metastases (BMs). However, the current scores do not focus on the specific neurosurgical population, therefore not predicting short-term mortality and postoperative performance status.
Methods: This retrospective observational study of 362 consecutive patients treated with surgery for BMs aims to identify the factors associated with post-surgical outcomes and propose a surgery-specific prognostic score for patients with BMs candidate for open surgery.
Results: Factors significantly associated with OS and performance status in multivariate analysis were age, KPS, surgical site, synchronous debut of BM, number, tumor volume, seizure, extra-cranial metastases, and deep-seated location. The variables were incorporated into the Anamnestic Radiological Metastases Outcome Surgical score (ARMO-S). The values range between 0 and 10. Patients were divided into two groups (low-risk and high-risk) based on each significant subgroup's median survival and performance status with an optimal cutoff value determined as 4. The two groups have significant differences in OS (9.6 versus 14 months, $p = 0.0048$) postoperative KPS (90 versus 70, $p = 0.012$) and KPS at last follow-up evaluation (75 versus 30, $p < 0.001$)
Conclusion: ARMO-S is a simple and comprehensive score for BM patients selected for neurosurgery, as it incorporates the main factors of the most important prognostic scores, implementing them with more surgery-specific predictive elements such as tumor location and volume, presence of seizures at onset, and involvement of eloquent brain areas.

1. Introduction

Brain metastases (BMs) represent the most prevalent malignant tumors within the central nervous system (CNS), exhibiting an incidence of 3–10 times greater than that of primitive brain tumors [1–3].

Overall survival (OS) varies widely and depends on the primary diagnosis, extracranial disease, tumor-specific biological factors, and the patient's age [4,5]. The treatment aims to relieve symptoms and maintain intracranial tumor control throughout the cancer disease [6].

Selecting the optimal treatment for individual patients poses a considerable challenge, given the diverse nature of diseases and the requirement for randomized controlled trials (RCT) to comprehensively compare various management options [7,8]. The diversity observed within this patient cohort highlights the complex characteristics of BMs [9], underscoring the importance of a nuanced assessment of prognosis and treatment planning.

Abbreviations: BMs, Brain metastases; OS, Overall survival; HRQoL, health-related quality of life; ROI, region of interest; KPS, karnofsky performance status; NSCLC, non-small cell lung cancer; MRI, magnetic resonance imaging; ECMs, extracranial metastases; SRS, stereotactic radiosurgery; WBRT, whole brain radiotherapy; RCT, randomized controlled trials.

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Surgery becomes necessary if there is histopathologic or molecular uncertainty about the brain tumor [10]. Moreover, radical resection of the tumor mass can provide rapid symptomatic relief and is usually preferred in BMs too large to undergo radiosurgery. [11]. Despite advancements in surgical techniques, the decision to pursue surgery is highly individualized, considering factors like the patient's overall health, the location and size of the metastases, and the presence of concurrent systemic disease.

The graded prognostic assessment (GPA) [6] and Recursive partitioning analysis (RPA)[12] have been developed to predict survival in cancer patients with BMs [13]. Their use has been supported and validated outside RCTs [13–17]. However, some useful evidence is known to select patients who are more likely to achieve a survival benefit from BM surgery. Some clinical, radiologic, and surgical features, which are currently not considered in most predictive scores, may make the outcome of surgery suboptimal for survival, performance status, and health-related quality of life (HRQoL) of the patient with BM. A specific surgical grading system could facilitate clinician decision-making by allowing them to make decisions based on evidence-based medicine rather than merely on their personal experiences [17]. This investigation aims to identify the factors associated with post-surgical outcomes, computing a simple surgery-specific prognostic score for patients with BMs irrespective of primary tumor location and candidate for open surgery.

2. Material and methods

2.1. Study population

Data from adult patients who underwent surgery for BMs in three different institutions between 2016 and 2021 were retrospectively analyzed. Consensus about diagnosis, treatment, and related information was obtained under written informed consent approved by our Institution's Principal Institutional Review Board. This study adheres to PROBE 2023 guidelines for reporting observational studies. All methods were performed following relevant guidelines and regulations. Patients were enrolled according to the following criteria:

- Adult patients (≥18 years) who are candidates for intracranial surgery with the aim of complete removal of the tumor and/or need for histologic diagnosis.
- Preoperative magnetic resonance imaging (MRI) suggestive for BMs without leptomenigeal involvement;
- No previous surgery;
- No previous radiotherapy;

The observational period of the cohort was planned at 18 months.

Table 1
Population study with anamnestic and clinical data.

Total patients: 362					%
Age	Mean	60.6			
Gender	Male	171			47.2
	Female	191			52.8
Follow-up	Mean	38			
	Min-Max	17–86			
	Female	191			
Primitive cancer	Lung	180	Stomach	2	
	Breast	80	Thyroid	6	
	Colon	31	Melanoma	14	
	Kidney	7	Prostate	3	
	Uterus	1	Unspecific	36	
	Ovarian	2			
KPS at diagnosis	Mean	85			
	90–100 154				42.5
	70–89 137				37.8
	50–69 58				16
	30–49 11				3
	<30 2				0.05
	≥70	212			58.6
	<70	150			41.4
Days hospitalized	Mean	12			
	Min-Max	7–69			
Clinical debut	Focal deficit	105			29
	Seizure	55			15.02
	Follow-up	192			35.6
	Incidental	10			2.08
Debut	Synchronous	129			35.6
	Metachronous	233			64.3
Extracranial metastases		112			30.9
Bone involvement		25			6.09

2.2. Clinical data

Clinical information was retrieved from medical records. We collected gender, age, symptoms, tumor lobe site, and side. Regarding onset symptoms, we considered seizures, focal sensory-motor neurological disorders, dizziness, altered mental status, memory loss, headache, and incidental or follow-up findings.

The surgical extent of resection (EOR) was considered gross total (GTR) when white matter appeared free of disease in any aspect of the surgical cavity. The surgical operator would interrupt the total excision when, despite a residual, intraoperative neuromonitoring or neuropsychological testing showed a risk of postoperative functional morbidity.

2.3. Images analysis

All enrolled patients underwent a pre-operative brain MRI scan (Achieva 3 Tesla). Pre- and postoperative T1-weighted MRI images with gadolinium contrast were used to determine the anatomical site and number of the BM and were confirmed by neuroradiological reports and an experienced consultant neurosurgeon. Tumor location was divided into infra- and supratentorial and further stratified into superficial and deep-seated. Deep-seated lesions were defined as tumor location in proximity with the cuneus, precuneus, corona radiata, basal ganglia, thalamus, cingulate gyrus, ventricles, operculum, medial and lateral occipitotemporal gyrus, orbital gyrus, insula, clivus, parahippocampal gyrus, corpus callosum, pineal region and gyrus rectus as reported in a specific previous work [2]. We further reported the presence of tumor located in a brain noted eloquent area. Eloquent areas were defined as areas of the brain with readily identifiable neurological function, in which injury results in a direct disability [16–19].

The tumor volumes were calculated by drawing a region of interest (ROI) in a volumetric enhancing post-contrast study weighted in T1 (a multi-voxel study), conforming to the margins of the contrast-enhancing lesion. The edema volume was measured by drawing an ROI in FLAIR-weighted research, from which the previously calculated lesion was subtracted. The study used the Horos Dicom Viewer (v 3.3.6, open-source software, Pixmeo SARL, Bernex, Switzerland; https://horosproject.org/) reported in a previous study [16].

2.4. Values and statistical analysis

The sample was analyzed with SPSS v21 (SPSS Inc., Released 2009, PASW Statistics for Windows, Version 21.0, Chicago, Illinois, USA). Comparisons between nominal variables was carried out using the Chi^2 test. Continuous variables correlations have been investigated with Pearson's Bivariate correlation. The OS was defined as the time between the radiological diagnosis and the last visit in our institutes or the patient's death. Survival times were analyzed depending on parameters with known or potential prognostic and predictive value

age, number and volume of BMs, control of primary disease, extracranial metastases (ECMs), location and pathology of the primary tumor, status of the systemic disease, time intervals between primary diagnosis and BMs diagnosis. A particular focus was centered on the performance status expressed as Karnofsky Performance scale (KPS) results. This

Table 2
Population study with radiological and surgical data.

No. 362			%
Location	Superficial/convexity	320	88.4
	Deep/periventricular	42	11.6
	Subtentorial	107	29.5
Eloquent area involvement		105	29
Multiple lesion		100	27.6
Major lobe involvement	Frontal	96	26.5
	Temporal	73	20.2
	Parietal	60	16.6
	Occipital	26	7.2
	Cerebellum	107	29.6
Side	Left	214	59.1
	Right	143	39.5
	Bilateral	5	1.4
Tumor volume	Mean	141	
	Min-Max	0.4–80	
	<10 cm3	229	63.3
	≥10 cm3	133	36.7

score was chosen since it is critical for a patient's survival when BM is present [18]. KPS was recorded before surgery at the time of diagnosis and was repeated 30 days after surgery (early post-operative evaluation and further recorded at the end of the adjuvant treatment, the last outpatient evaluation).

Kaplan–Meier estimator and log-rank test were used to analyze survival. Variables significantly associated with OS in univariate analysis were included in Cox multivariate analysis. The validity of the model was tested with the bootstrap method. Variables from the final model were used to construct a new prognostic index by assigning points according to the impact of a specific variable on OS. Characteristics that showed a significant association with survival, KPS ($p < 0.05$), or a trend ($p < 0.08$) were used to create the score. The threshold of statistical significance was considered $p < 0.05$. ROC curves were compared using DeLong's test.

3. Results

3.1. Study population and clinical data

The final cohort comprised 362 patients with a median follow-up of 38 months (range 17–86 months). The cohort comprised 171 (47.2 %) men and 191 (52.8 %) women. Mean age was 60.6 years (range 17–81 years). Data regarding histopathological diagnosis, clinical onset, and presence of seizures are summarized in Table 1. In 129 (35.6 %) of patients, cerebral dissemination was diagnosed before or together the primary tumor (synchronous debut), and the time from primary diagnosis to the first surgical treatment of BMs ranged from 0 to 4 months. In 60.4 % of patients, systemic therapy (chemo-, hormone- or immunotherapy) was additionally used.

Radiological features of BMs, including size, location, tumor volumes, major lobe involvement, the identification of multiple BMs, and the involvement of eloquent areas were detected and reported in Table 2.

3.2. Survival analysis and score

Median OS was 17 months (range 1–72 months). The 6-, 12- and 24-month OS rates were 64 %, 51.3 %, and 17.9 %, respectively.

Factors significantly associated with OS and/or performance status in multivariate analysis were as follows: age, pre-operative KPS, number of BMs (single vs. multiple), tumor volume, eloquent surgical site, supratentorial compartment involvement, deep-seated location, presence of seizure and control of the primary tumor (presence of ECMs and

Table 4
The ARMO score.

ARMO score				Points
1	**Anamnestic**	Age	<70	0
			≥70	1
2		Performance	KPS ≥ 70	0
			KPS < 70	1
3		Eloquency	No	0
			Yes	1
4		Debut	Metachronous	0
			Synchronous	1
5		Seizure	No	0
			Yes	1
6	**Radiological**	Numbers	1	0
			>1	1
7		Extracranial metastases	No	0
			Yes	1
8		Location	Superficial	0
			Deep	1
9		Subtentorial	No	0
			Yes	1
10		Volumes	<10 cm3	0
			>10 cm3	1

<5 points: low risk 5–10: high risk

Table 3
Table with multivariate analysis of the main scoring elements. We considered for scoring the values for variables with a substantial significant difference in OS or KPS value at the last clinical evaluation.

Multivariate analysis			Overall survival	P-value	Performance status (KPS)	P-value
1	Age	<70	14	**0.03**	70	**0.05**
		≥70	11		65	
2	Performance status on debut	KPS ≥ 70	17.3	**0.03**	75	**<0.001**
		KPS < 70	10.4		40	
3	Eloquency	No	15	**0.03**	75	**0.01**
		Yes	12		55	
4	Debut	Metachronous	14	**0.05**	75	**0.02**
		Synchronous	12		60	
5	Seizure	No	18	**0.044**	70	1
		Yes	13		70	
6	Numbers	1	14	**0.05**	65	1
		>1	12		65	
7	Extracranial metastases	No	13	1	70	**0.001**
		Yes	13		60	
8	Location	Superficial	17	**<0.001**	75	**0.05**
		Deep	7		55	
9	Subtentorial	No	13	1	70	**0.05**
		Yes	13		60	
10	Volumes	<10 cm3	10	0.1	50	**<0.001**
		≥10 cm3	15		35	

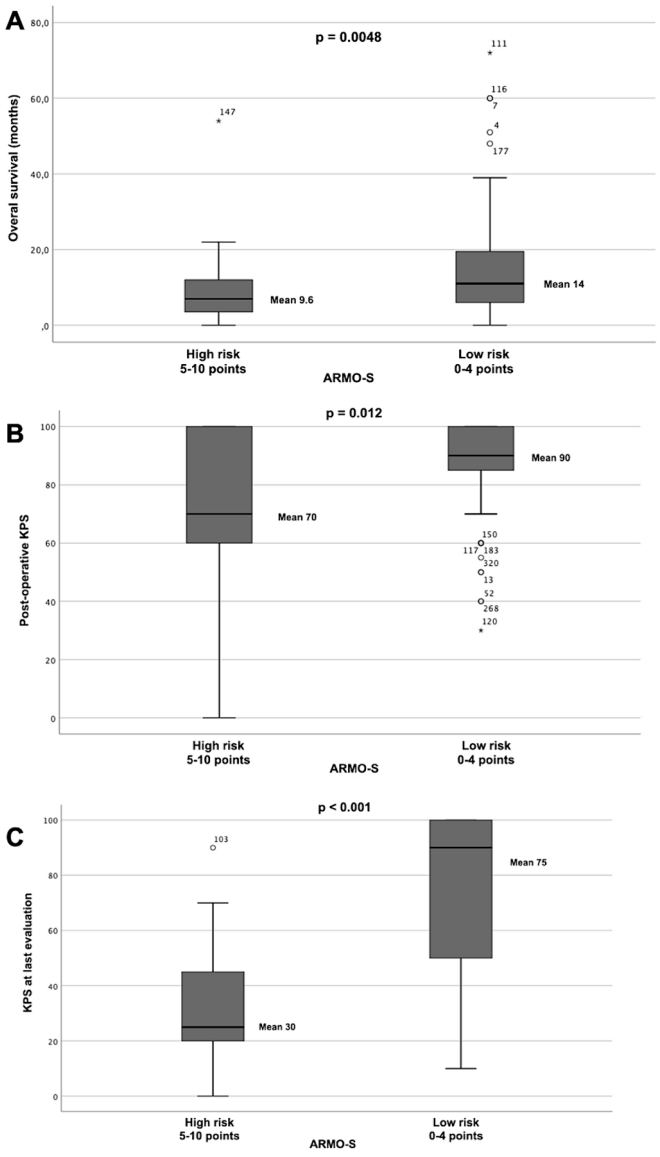

Fig. 1. The box-and-whiskers plots show the significant differences regarding the overall survival (OS, part A and the Karnofsky performance status, KPS, part B and C). OS is significantly higher in the low-risk group (mean value of 14) than the mean value in the high-risk-group (mean value of 9.6, p = 0.0048, part **A**); The KPS measured after surgical intervention is significantly higher in the low-risk group (mean value of 90) than the mean value in the high-risk-group (mean value of 70, p = 0.012, part **B**); The KPS measured at last clinical evaluation is significantly higher in the low-risk group (mean value of 75) than the mean value in the high-risk-group (mean value of 30, p < 0.0001, part **C**).

the metachronous debut of BM) (Table 3). There was no significant difference in OS or performance status between patients with two, three, or > three metastases (p = 0.26). Gender, systemic disease status, fractionation RT-scheme, and whole brain radiotherapy (WBRT) or systemic treatment application were not statistically significant predictors of survival in the whole cohort.

Statistically significant preoperative variables derived from the multivariable analysis were included in an additional binary logistic regression model. Odds ratios derived from this model were then used to assign weight to the variables included. Consequently, these variables were incorporated into the new prognostic score—Anamnestic Radiological Metastases Outcome Surgical score (ARMO-S). The corresponding scoring points of the variables are summarized in Table 4.

3.3. ARMO-Score validity

The scoring system was applied to the cumulative cohort, and resampling with the bootstrap method obtained similar estimations of the model parameters. The resulting score values range between 0 and 10. Patients were divided into two groups (low-risk and high-risk groups) based on each significant subgroup's median survival and performance status.

The optimal cutoff value was determined to be 5, suggesting a higher risk of reduced OS and KPS in patients with a score > 4. The median OS was 14 months for patients with 0–4 points (low risk group, SD = 9.24, Standard error mean = 2.35, 1 outlier) and 9.6 months for patients with ≥ 5 points (high risk group, *t*-test SD = 8.5, Standard error mean = 1.02, 6 outliers, p = 0.0048, Fig. 1**A**). The hazard ratio (HR) for reduced prognosis after resection in the "High risk group" was 1.10 (95 % CI, 1.08 –1.12; p = 0.001).

The two groups have significant differences in terms of postoperative KPS (Low-risk group

Mean = 90, SD = 15, Standard error mean = 1.5, versus 70 for High-risk group, SD = 25, Standard error mean = 5, 8 outliers p = 0.012, Fig. 1**B**) and KPS at last follow-up evaluation (Low-risk group: Mean = 75, SD = 30, Standard error mean = 2.5, High-risk group: Mean = 30, SD = 20, Standard error mean = 5, 1 outlier, p < 0.001, Fig. 1**C**). We identified a significant difference in the KPS status trend over time between the two groups, given the established correlation between the preoperative KPS value and the final performance at the end of follow-up. Specifically, we examined the trend of KPS recovery during the follow-up stages and found a significant distinction over time between the two groups (Repeated measures test, Sphericity assumed test: p < 0.001, Greenhouse-Geisser test: p < 0.001, Multivariate analysis within factors p < 0.001, Fig. 2).

The accuracy of the system in predicting surgical outcome was considered with the status of "good" based on the predictive ability criteria and after optimization with the Youden index.

Consequently in the model values we obtained a cross-validated area under curve (AUC) of 0.587 (p = 0.03, DeLong's test) and single-validation AUC for post-operative KPS (95 % CI, 0.43– 0.74), 0.583 (p = 0.03, DeLong's test) for KPS at the last evaluation (95 % CI, 0.42–0.74), 0.541 (p < 0.001, DeLong's test) and OS (95 % CI, 0.37– 0.709p < 0.001, Fig. 3).

The Kaplan-Meier curve shows the significant difference in survival between the two groups (Estimated OS in low-risk group 19.85 versus 10.7 in high-risk, 95 % CI = 30–45, SD = 4, p = 0.001 Fig. 4**A**). To further confirm the accuracy of the specific score for this surgical series, we compared the different classes of RPA with the actual OS and KPS, showing that for class I (t-student respectively p = 0.403, p = 0.06), class II (t-student respectively p = 0.77 and p = 0.514) and class III (p = 0.44 and p = 0.05) there is no significance for in the survival or performance predictive value (Fig. 4**B**). Finally, we compared the series with the GPA scoring system and showed low significance (*t*-test p = 0.77 and p = 0.51, respectively, for OS and KPS, Fig. 4**C**).

4. Discussion

Treatment options for patients with BMs range from open brain surgery, stereotactic radiosurgery (SRS), WBRT, or supportive care with corticosteroids or combinations [19]. Selection of the appropriate therapy for the right patient remains crucial [6,20]. Various scores have been proposed to suggest prognosis and guide treatment strategies [5,21]. However, attempts to identify short-term survival, such as after surgery, using the various indices alone or in combination, have been disappointing [22,23]. Although GPA and RPA scores have prognostic properties in a BM patient population [24–27], they do not take into account specific information necessary for the neurosurgeon to predict a radical surgical procedure that ensures good neurological function of the patient, such as the site of BMs, involvement of eloquent areas, presence

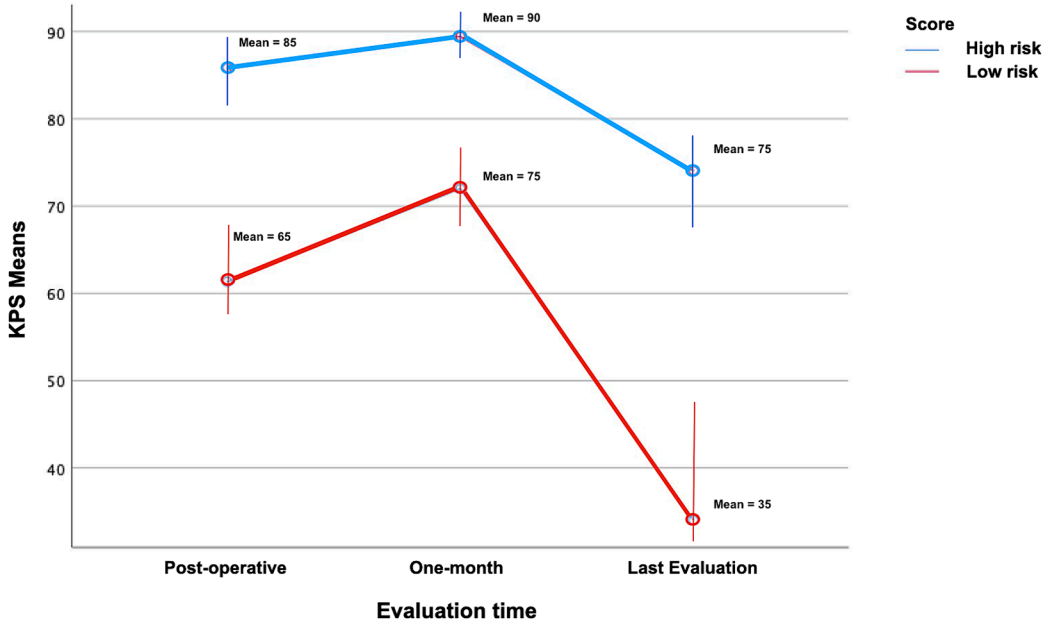

Fig. 2. The graph shows the change in patients' performance status measured as Karnofsky perfomance scale (KPS) during follow-up in cases of ARMO-S less than 5 points (low-risk group, red line) and high-risk group (blue-line).

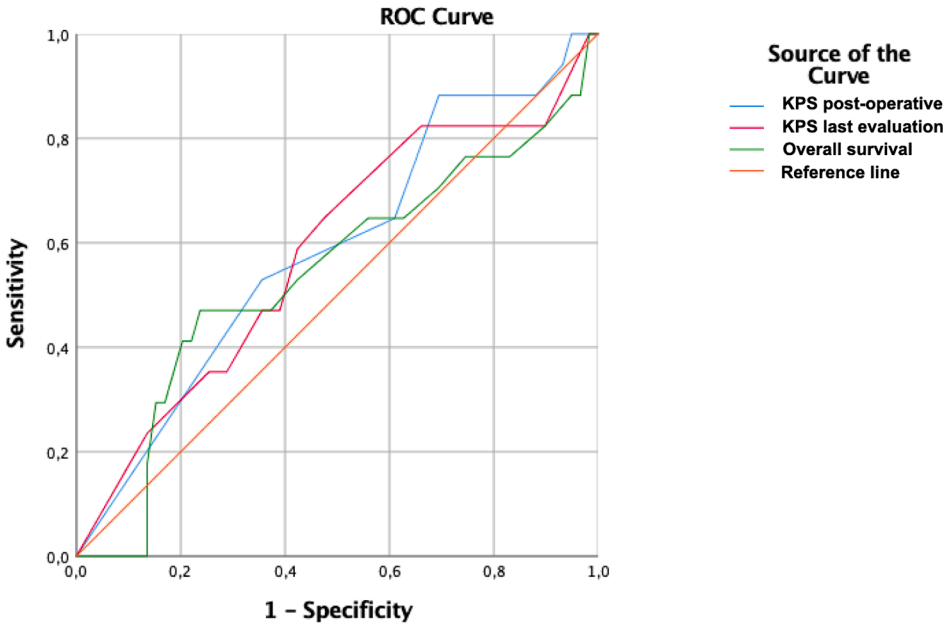

Fig. 3. ROC curve identifies a balance at the threshold < 5 points of sensitivity and specificity regarding differences between postoperative KPS (blue-line), KPS at last evaluation (red line), and survival (green line). As can be seen the cross-validated area under curve (AUC) turns out to be significant for all three endpoints.

of epileptogenic areas, or involvement of the subtentorial compartment.

Our study confirms that the critical prognostic elements remain those related to age, the number of metastases, the presence of known primary disease, the presence of ECMs, and the purposed score incorporates these factors. Class I evidence supports a level 1 recommendation for patients with single BM susceptible to surgical resection. In general, patients are considered eligible for treatment if they have a KPS of at least 70 [28]. At the same time, control of extracranial disease did not seem necessary since patients may benefit from aggressive forms of local adjuvant therapy [25]. Still, we thoroughly considered the possibility of managing a patient with a known presence of primary tumor with a metachronous debut [29] of BM and the presence of a primary debut of neurological symptoms in synchronous BM presentations as significant. Some studies suggested that total tumor volume may be correlated with patient outcome and should be added to the diagnosis-specific GPA index (DS-GPA). [30]. We confirm the correlation between tumor size and the risk of morbidity and mortality. By identifying a threshold of 10 cm^3, we documented how large lesions significantly impact performance status and postoperative recovery.

4.1. *Implemented surgical prognostic factors*

Patients with BM can debut with various symptoms such as focal neurologic deficits, headache, and nausea [31]. The impact of neurological deficits on a patient with neoplastic disease cannot be underestimated. Evidence shows that neurological deficits caused directly by

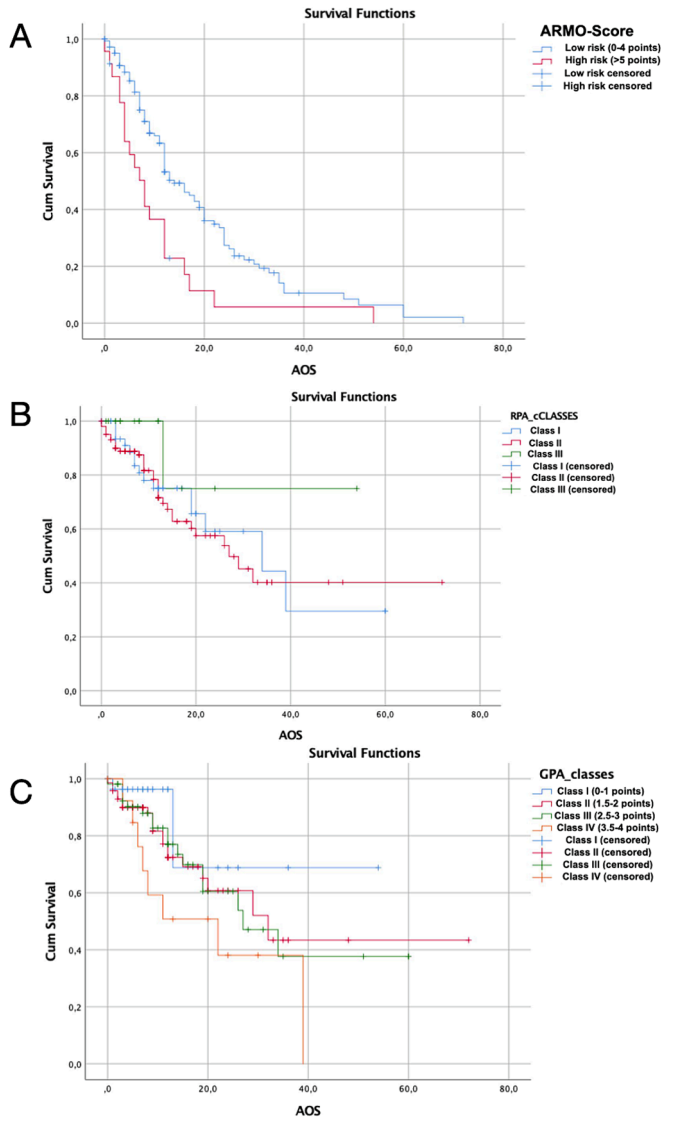

Fig. 4. The Kaplan-Meyer (K-M) curve shows the significant difference in survival between the two groups (Estimated OS in low-risk group 19.85, red curve versus 10.7 in high-risk, blue curve, p = 0.001 group) in ARMO-S (part **A**). The K-M curve in our surgical series does not significantly discriminate between RPA (part **B**) and GPA classes (part **C**).

BM are associated with reduced life expectancy and health-related quality of life (HRQoL) [31,32]. Preoperative seizures are common and occur in approximately 20–35 % of patients [32]. Seizures cause morbidity and mortality and are also a common complication after neurosurgery; nevertheless, patients with tumor-related epilepsy with unfavorable seizure outcomes embark on further adjuvant therapy, which may, itself, have an epileptogenic effect [33]. Recurrent seizures have a negative effect on the HRQoL, especially if they are not controlled postoperatively or with long-term medication only [34]. Further, they are also particularly concerning because antiepileptic drugs (AEDs) can impact quality of life and interfere with chemotherapeutic regimens [35]. We also confirm that the final impact on OS turns out to be significant.

Surgical management remains the central theme to prognosticate the outcome of our series. Patients with BMs experience a survival benefit with maximal EOR [36,37]. Furthermore, the location of the BM might significantly impact patient survival and, therefore, might be considered in clinical decision-making and patient counseling [38].

There are distinct brain regions in which brain tumors disrupt network dynamics or vegetative control areas with neurological consequences. In describing this process, the term “eloquent area” is used to define the brain areas with readily identifiable neurological function in which injury results in disability [39,40]. Tumor–associated neurological dysfunction occurs in the setting of the mass-effect into cortical and subcortical network structures, in lesions sustained following surgery, and through oncological therapeutic interventions such as brain irradiation and chemotherapy [39]. We demonstrated that BMs in the eloquent area significantly impact OS and performance status.

We confirmed that a deep tumor location is associated with a high rate of sub-total resection and poorer survival [41]. The EOR is often sacrificed [40] to prevent surgical complications [42]. In multivariate analysis, we demonstrated an impact of deep localization of BM on both OS and KPS.

At last, the posterior fossa is the site of many types of tumors, and BMs are the most common adult malignancies in this region. 20 % of BMs occur in the posterior fossa and are associated with significant morbidity [43]. Indeed, is demonstrated that although patients with supra- and infratentorial BMs experienced comparable post-operative survival, posterior fossa metastasis location was associated with a 2.5 times higher risk of neurological and/or non-neurological post-operative complications [44,45]. Our analysis confirmed that the difference in postoperative performance status with comparable OS appears significant in the subtentorial BMs group.

4.2. *Strengths of the score*

This is a reliable, practical, and manageable score for neurosurgeons and oncologists who are able to define patients who would benefit from surgery. This could help in many cases of unknown diagnosis when a prompt decision should be undertaken in emergent patients. In addition, the choice of factors influencing the score is based on survival and performance status at the end of surgical treatment, providing a more accurate prediction of the outcome. In daily clinical practice, cases are often reported of patients who, despite a favorable prognosis according to the most common classifications, have a significantly reduced outcome after surgery. Here we present a common scenario from our patient cohort in which two patients of the same age group with equal GPA and RPA score had a significantly different prognosis (Fig. 5). According to the ARMO-S, patient A, had a prognosis close to 11 months (precisely 13 months after brain surgery), while patient B (fell into the high risk group), resulting in a significantly reduced prognosis. After radical uncomplicated surgery, patient B, approximately after 4 days, experienced generalized seizures that required admission to the intensive care unit. On the sixth day, after seizure control was achieved, the patient discontinued sedation and returned to the neurosurgery unit with residual strenght deficit on the right arm. An early brain disease recurrence was reported at 30th day MRI, and the patient was hospitalized again for the onset of new generalized seizure. The patient deceased in the intensive care unit following the onset of infection during sedation at three months after surgery.

The use of evidence-based, well-known, and validated assessment methods like the GPA and RPA scores, developed in renowned and high-volume centers to guide the need for surgery, further strengthens the ARMO score.

5. Limitations of the score and study

One notable limitation is the retrospective nature of the study used to develop the clinical score. Retrospective analyses are inherently susceptible to biases, and while the score may demonstrate efficacy in our study cohort, prospective and external cohort validation is essential to establish its generalizability and reliability in real-time clinical scenarios. In addition, the patient population included in the study may be relatively homogenous, potentially limiting the generalizability of the clinical score to a broader and more diverse population of patients with

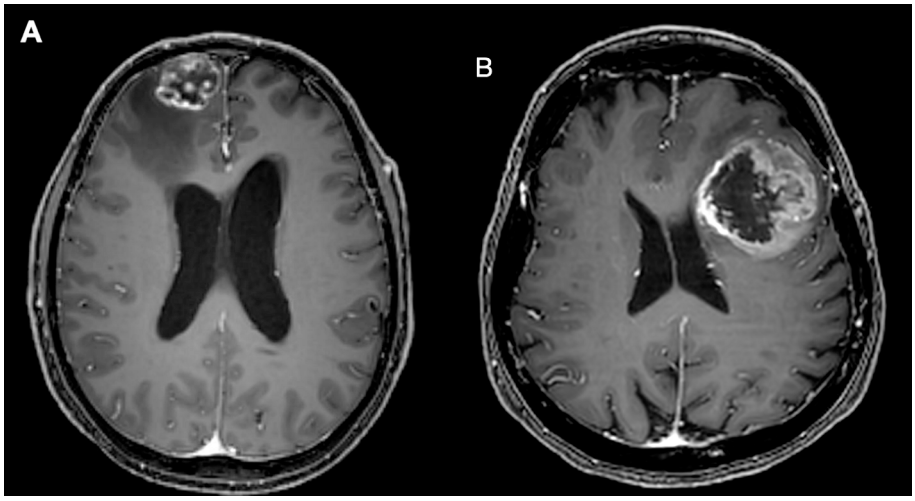

Fig. 5. Two male patients, both aged 70–75 years old, were diagnosed with primary non-small cell lung cancer (NSCLC). At their first follow-up, a brain neoformation was detected on total-body CT in the absence of other disease localizations. Subsequent brain MRI confirmed the heteroplasic nature of the two lesions. The GPA score and RPA score were identical, indicating a KPS > 70, primary disease control without ECMs, while also expressing a highly variable survival prognosis of 7–11 months. Patient B, however, experienced generalized seizures that were difficult to manage and required hospitalization, as well as a large lesion (>10 cm^3) involving deep areas and located near the primary motor area.

BMs. Variations in tumor types, locations, and patient characteristics might influence the score's performance in different clinical settings. The ARMO score may not fully reflect the impact of emerging therapeutic modalities or changes in standard treatment practices, and a useful external validation in independent patient cohorts is crucial.

6. Conclusion

ARMO-S is a ten-point simple and comprehensive score for BM patients selected for open surgery, as it incorporates the main factors of the most important prognostic scores such as GPA and RPA, implementing them with more surgery-specific predictive elements such as tumor location and volume, presence of seizures at onset, and involvement of eloquent brain areas. This investigation provides a novel, easy-to-use score that optimizes the delicate balance between the potential benefits of surgery and the associated risks.

Data availability

The dataset generated and analyzed during the current study is not publicly available or retrieved for National databases because it results from institutional internal research of all treated cases of gliomas in our Hospitals. The original dataset is available from the corresponding author upon reasonable request.

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This study was not funded by any association.

Ethics approval

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

Consensus about diagnosis, treatment, and related information was obtained under written informed consent approved by our Institution's Principal Institutional Review Board (IRB, 6961, prot. 0296/2023).

This article does not contain any studies with animals performed by any of the authors.

10. Consent to participate

Informed consent was obtained from all individual participants included in the study. The patient has consented to the submission of this review article to the journal. The participants and any identifiable individuals consented to publication of his/her image.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

CRediT authorship contribution statement

Daniele Armocida: Writing – original draft, Conceptualization. **Tamara Ius:** Methodology, Data curation. **Giuseppa Zancana:** Resources, Investigation. **Andrea Bianconi:** Methodology, Investigation, Data curation. **Fabio Cofano:** Visualization, Resources, Methodology, Investigation, Data curation. **Fulvio Tartara:** Visualization, Validation, Supervision. **Alessandro Frati:** Writing – review & editing, Supervision. **Diego Garbossa:** Validation, Data curation, Conceptualization. **Maurizio Salvati:** Validation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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