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REVIEW

The state of art of awake craniotomy in Latin American countries: a scoping review

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Abstract

Background and objective Awake craniotomy (AC) is a valuable technique for surgical interventions in eloquent areas, but its adoption in low- and middle-income countries faces challenges like limited infrastructure, trained personnel shortage, and inadequate funding. This scoping review explores AC techniques in Latin American countries, focusing on patient characteristics, tumor location, symptomatology, and outcomes.

Methods A scoping review followed PRISMA guidelines, searching five databases in English, Spanish, and Portuguese. We included 28 studies with 258 patients (mean age: 43, range: 11–92). Patterns in AC use in Latin America were analyzed.

Results Most studies were from Brazil and Mexico (53.6%) and public institutions (70%). Low-grade gliomas were the most common lesions (55%), most of them located in the left hemisphere (52.3%) and frontal lobe (52.3%). Gross-total resection was achieved in 34.3% of cases. 62.9% used an Asleep-Awake-Asleep protocol, and 14.8% used Awake-Awake-Awake. The main complication was seizures (14.6%). Mean post-surgery discharge time was 68 h. Challenges included limited training, infrastructure, and instrumentation availability. Strategies discussed involve training in specialized centers, seeking sponsorships, applying for awards, and multidisciplinary collaborations with neuropsychology.

Conclusion Improved accessibility to resources, infrastructure, and adequate instrumentation is crucial for wider AC availability in Latin America. Despite disparities, AC implementation with proper training and teamwork yields favorable outcomes in resource-limited centers. Efforts should focus on addressing challenges and promoting equitable access to this valuable surgical technique in the region.

Keywords Awake craniotomy · Global neurosurgery · Latino America · Low and middle-income countries

Abbreviations

AC	Awake craniotomy
AED	Antiepileptic drug
DES	Direct electrical stimulation
EEG	Electroencephalogram
GA	General anesthesia
LA	Local anesthesia
HGG	High-grade glioma
LGG	Low-grade glioma
LMIC	Low- and middle-income countries

Introduction

Awake craniotomy (AC), also known as awake brain surgery, is a robust and versatile procedure first described by Sir Victor Horsley in 1886 [1] AC has increasingly become a pivotal neurosurgical procedure used in challenging cases to perform a real-time mapping of eloquent areas first to achieve a maximal safe resection and second to minimize postoperative complications, decreasing ICU costs [2], and allowing a treatment alternative for otherwise inoperable tumors [3]. Duffau et al. highlighted mapping the functional connectome for each patient to perform resections in eloquent areas and optimize the once-functional balance, achieved mainly with AC [4].

Extended author information available on the last page of the article

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Intuitively, we can argue that the use of AC in low- and middle-income countries would result in more benefits, reducing costs in the postoperative period and helping the patients to reincorporate faster in their regular occupations, as was proved in high-income countries [5]; however, several factors have acted as barriers that make its use relatively uncommon in these countries [6]. In 2015, the Lancet Commission on Global Surgery summarized the surgical burden and limitations in providing safe and affordable surgical care worldwide, showing that at least 47 millions of Latin-American do not have access to surgical resources [7]. Little is known about the number of neurosurgical procedures and the current status in the region for AC.

In this scoping review, we explore AC's state of the art of AC in different Latin-American countries, the availability of information in different languages, the characteristics of the lesions, the extent of resection, complications, and the type of anesthesia used. Additionally, we aim to identify barriers to performing these procedures and explore potential strategies to overcome some of the challenges.

Materials and methods

Search strategy

This scoping review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis-Scoping Review (PRISMA-ScR). The relevant articles were searched via PubMed, Scopus, Google Scholar, and Web of Science, with the final date of retrievals on April 15th, 2023. The search was conducted in English, Portuguese, and Spanish. Additional details of the search terms for each database are available in Supplementary Table 1.

We did use Boolean terms for Latin America and Latin American countries individually. Additionally, we screened the affiliation of the listed authors for a more comprehensive search strategy. Articles selection was based on where the procedure was conducted and if at least one author affiliation was from a Latin American country. Full-text articles were evaluated to confirm the location and respective affiliations. This review protocol was submitted to Inplasy.

Inclusion and exclusion criteria

Articles were included if they met the following criteria: (1) original peer-reviewed articles with a digital objective identifier, (2) English, Spanish, or Portuguese as primary language, (3) AC used as a neurosurgical procedure in any Latino-American Country, (4) provided sufficient and high-quality data (5) articles involving human subjects only.

Exclusion criteria included (1) articles that aggregated AC data on Latino American and non-Latino American countries without differentiating the population and places, (2) studies that investigated neurosurgical interventions other than AC, (3) Articles with insufficient information or lack of quality in the provided analysis, (4) Letters to the editor due to the lack of validation by peer-reviewed or limited information.

Screening and data management

The initial search was performed by AS and UT, based on the following terms ("awake"[All Fields] OR "awakeness"[All Fields] OR "awakes"[All Fields] OR "awaking"[All Fields]) AND ("craniotomy"[MeSH Terms] OR "craniotomy"[All Fields] OR "craniotomies"[All Fields]) AND ("latin america"[MeSH Terms] OR ("Latin"[All Fields] AND "america"[All Fields])) ("awake"[All Fields] AND ("craniotomy"[MeSH Terms] OR "craniotomy"[All Fields] OR "craniotomia"[All Fields]) AND ("mexico"[MeSH Terms] OR "colombia"[All Fields] OR "brazil"[All Fields] OR "chile"[All Fields]).

LMH and LF performed the first abstract screening. JS, LF, and LM performed the following screening and full-text reading. The extracted data was added to a Google Drive document. DG, JAM, and EO performed confirmation of the data.

Data charting was performed in duplicate (UT, RM) and discussed data collection (AS, ES, LM, LF). The extracted information included demographics, type of health care of the center, place of training for awake craniotomy (first author or senior author), type of lesion, laterality, location, the extent of resection, type of anesthesia used, postoperative complications, and during, and experiences.

Statistical analysis

The data were compiled in a single spreadsheet and imported into Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA) for validation and coding. Fields allowing string values were examined for implausible values. The data were then exported into Graph Pad version 8.0 for Macintosh (GraphPad Software, San Diego, California USA, www.graphpad.com") for analyses and graph design. Descriptive statistics were calculated to summarize the data. Frequencies and percentages were utilized to describe nominal data.

Interview with specialists

We conducted a concise and voluntary interview consisting of three open-ended questions: "What is the primary challenge associated with Awake Craniotomy in your specific country and field?", "How does your team effectively address and manage these challenges?" and "What measures are essential for overcoming these challenges?" In cases

where interviews with specialists from certain countries were not feasible, we supplemented the information with relevant findings from the existing literature.

Results

Overview of literature search results

During the initial data search, 120 articles were identified from the mentioned databases. After the initial screening, 53 articles were selected for retrieval, of which 28 were excluded due to incomplete data or contradictory information. 3 additional reports were retrieved from the Peruvian Neurosurgical Association webpage. Ultimately, 27 articles were included in this review. All details are shown in Fig. 1. 12 articles were in English, 11 in Spanish, and 4 in Portuguese (Fig. 1).

Demographics

A total of 259 patients who underwent awake craniotomy for a specific pathology were identified from the 27 selected articles. These patients came from eight countries, of which 51.1% of the articles (n = 133) were from Brazil [6, 8–12]. The next two most represented countries were Mexico, with 19.3% of patients (n = 50), and Chile [11–14], with 15.5% (n = 40) (see Table 1). The retrieved patients had a mean age of 43.9 (SD = 18.14). Most hospitals were part of the public system (19/27–70%), while 8 corresponded to private institutions. Only 3 of the institutions linked to the articles did not have an academical link or were academical hospitals. All of them in the public service area. Most first authors trained in their country of origin, followed by the USA (Table 1). Gender was reported for 208 patients, of which 72% of patients (n = 149) were male, and 28.3% (n = 59) were female (Table 1).

CNS lesion characteristics and anatomical localization of awake craniotomy in adult and pediatric patients.

All the included studies reported the type of lesion. In total, 259 patients were included. Of these, 53.3% (n = 138) debuted with low-grade glioma. In comparison, 32% (n = 83) reported high-grade glioma, followed by other types of lesions such as cavernous malformations (n = 8), metastasis (n = 7), gliosis (n = 3), and a dermoid cyst (n = 1) (Table 2, 3, Fig. 2A). Left-sided lesions were more frequently reported (44%, n = 112) compared to right -sided lesion (18%, n = 46); three studies did not report the laterality (n = 99, 38%) (Table 2, 3, Fig. 2B). The lesions were more frequent

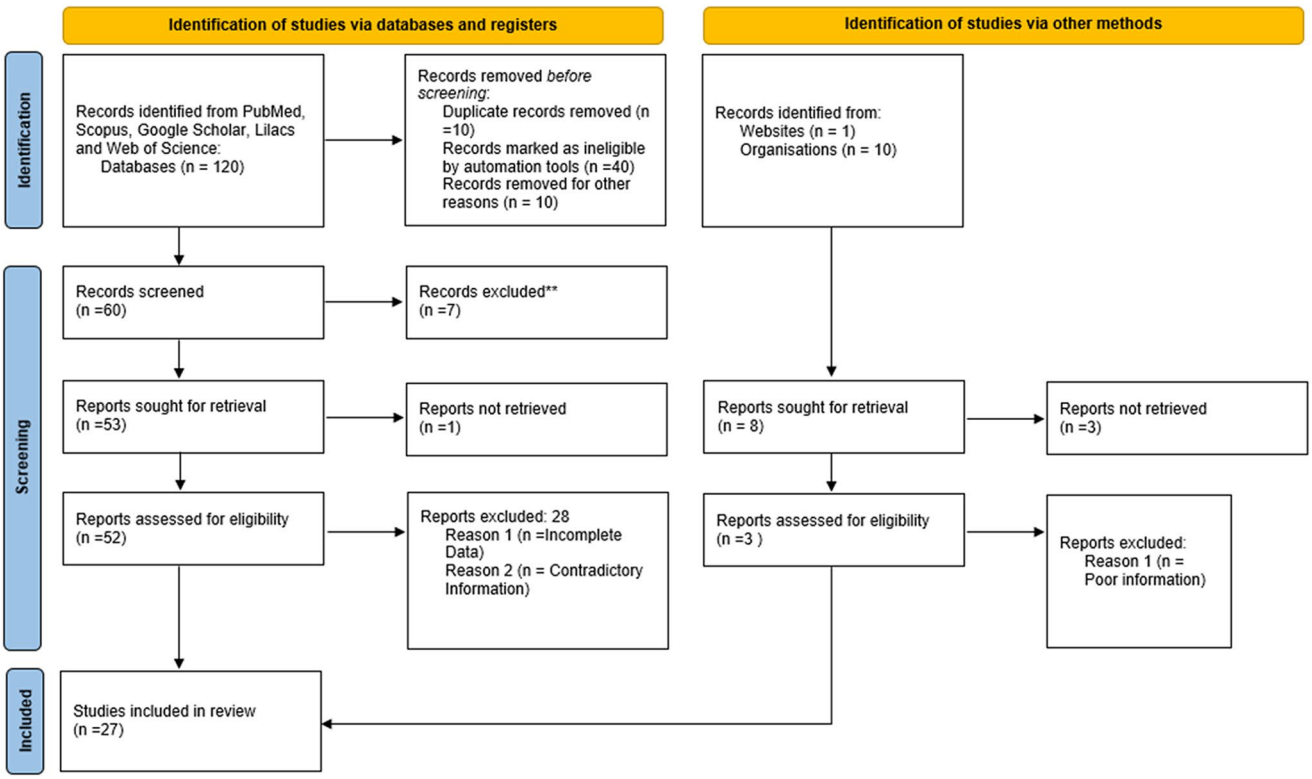


Fig. 1 Prisma guideline flowchart

Table 1 General distribution of articles by country, language, and description of the population

Study and year	Country	Language	Age (Mean)	N	Type of health care	Academical hospital or link with an academic institution? (Yes/No)	Place of training (fellowship)	Female (N)	Male (N)
Mamani et al. [24]	Mexico	English	44.5	45	Private	Yes	Mexico/Peru	12	33
Bennet et al. [25]	Chile	English	40.1	40	Public	No	France/Chile	*	*
Sandoval-Bonilla et al. [15]	Mexico	English	52	1	Public	Yes	Mexico	0	1
Vigo et al. [8]	Brazil	English	29	1	Public	Yes	USA	1	0
Albuquerque et al. [6]	Brazil	English	44	1	Public	Yes	France/Brazil	0	1
Barrenechea et al. [16]	Argentina	English	42	1	Private	Yes	USA	0	1
Krambek et al. [8]	Brazil	English	50	1	Private/Public	Yes	Brazil	1	0
Leal et al. [10]	Brazil	English	56	17	Public	Yes	Brazil	5	12
Leal et al. [20]	Brazil	English	57	19	Public	Yes	Brazil	7	12
Cole et al. [13]	Mexico	English	92	1	Private	Yes	USA	1	0
Amorim et al. [17]	Brazil	Portuguese	35.4	12	Public	Yes	Brazil	6	6
Pereira et al. [21]	Brazil	English	39.3	79	Public	Yes	Canada	20	59
Velazquez-Gonzalez et al. [36]	Cuba	Spanish	42	1	Public	Yes	Cuba	0	1
Gonzalez et al. [31]	Colombia	Spanish	67.8	10	Private	Yes	USA	3	6
Nuñez-Velasco et al. [14]	Mexico	Spanish	26.5	2	Public	Yes	USA/Mexico	0	2
Cruz et al. [18]	Cuba	Spanish	54	3	Public	Yes	Cuba	0	3
Martinez-Barreto et al. [37]	Mexico	Spanish	11	1	Private (part of a non-profit foundation)	Yes	Mexico	0	1
Bolzani et al. [11]	Brazil	Portuguese	36	1	Public	Yes	Brazil	0	1
Delgado-Maidana et al. [26]	Paraguay	Spanish	46	6	Public	Yes	Paraguay	2	4
Côrte et al. [19]	Brazil	Portuguese	27	1	Public	Yes	Brazil	0	1
Freitas et al. [12]	Brazil	Portuguese	30	1	Public	Yes	Brazil	0	1
Barbieri et al. [28]	Argentina	Spanish	71	1	Private	Yes	Argentina	0	1
Quiroz [29]	Perú	English	74	1	Public	No	Peru	0	1
Flores et al. [23]	Perú	Spanish	45	1	Public	No	Peru	0	1
Vasquez et al. [38]	Perú	Spanish	25	1	Private/Public	No	Mexico/Peru	0	1
Barreto-Acevedo et al. [22]	Perú	Spanish	16	1	Public	Yes	Spain	1	0
Longo et al. [27]	Argentina	Spanish	34	10	Private	Yes	Argentina	*	*

in the frontal lobe (51%), followed by the temporal (37%). Some lesions involved more than one region (2%) (Table 2, 3, Fig. 2C). None of the studies directly compared Awake Craniotomy with General Anesthesia Craniotomy. The extent of resection was reported in 18 studies, contributing to 143 patients. Gross-total resection was achieved in 49 patients (34.3%) [6, 8, 9, 13–19] and Subtotal Resection in 94 (65.7%) [10, 17, 20, 21]. One case required anterior left temporal lobectomy [22] (Table 2).

Although AC is an established technique, important differences exist between surgical approaches regarding the anesthesia protocol. 62.9% (17 articles) opted for an Asleep-Awake-Asleep protocol, [9, 12–18, 21–27] 14.8% Opted for an Awake-Awake-Awake [10, 20, 28, 29], and 22.2% of the studies did not report the type of anesthesia [6, 8, 22, 30, 31] (Table 2, 3, Fig. 2D).

With some specific variations, most centers used propofol, remifentanil, and dexmedetomidine. (Table 2).

Table 2 Characteristics of the lesions by N and percentage, the extent of resection, and type of anesthesia used

Authors	N	Lesion					Hemisphere		Location**						Surgery	Type of anesthesia		Pre-operative considerations	
		Meningioma (n)	HGG (n)	LGG (n)	Seizure control due to other pathology	Other	Left	Right	Frontal	Temporal	Parietal	Insular	Occipital	Other	Extent of resection	Type of anesthesia	Medication for sedation	Pre-operative Neuropsychological testing (Yes/No)	Intraoperative stimulation for cortical and subcortical areas. (Yes/No)
Mamani et al. [24]	45	0	24 (53.4%)	21 (46.6)	32*	-	NR	NR	24 (53.3%)	15 (33.3%)	5 (11.1%)	1(2.2%)	0	0	N/A	Asleep-awake-asleep	Propofol-dexmedetomidine	NR	Yes
Bennet et al. [25]	40	0	11 (27.5)	29 (72.5%)	NR	NR	NR	NR	19 (48%)	12 (30%)	6 (15%)	0	0	3 (7%) Multilobar	N/A	Asleep-awake-asleep	NR	No	No
Sandoval-Bonilla et al. [15]	1	N/A	N/A	N/A	1 (100%)	Cortical dysplasia	1(100%)	0	1 (100%)	0	0	0	0	0	Gross-total resection	Asleep-awake-asleep	NR	NR	Yes
Vigo et al. [8]	1	N/A	N/A	N/A	1 (100%)	Cavernous malformation	1(100%)	0	0	0	0	1 (100%)	0	0	Gross-total resection	NR	NR	NR	Yes
Albuquerque et al. [6]	1	N/A	N/A	N/A	1 (100%)	Cavernous malformation	1(100%)	0	1 (100%)	0	0	0	0	0	Gross-total resection	NR	NR	Yes	Yes
Barrenechea et al. [16]	1	N/A	N/A	N/A	N/A	Cavernous malformation	0	1(100%)	0	0	1(100%)	0	0	0	Gross-total resection	Asleep-awake-asleep	Dexmedetomedina-remifentanilo	No	Yes
Krambek et al. [8]	1	N/A	N/A	N/A	N/A	Cavernous malformation	0	1(100%)	1(100%)	0	0	0	0	0	Gross-total resection	Asleep-awake-asleep	Propofol-remifentanilo	Yes	Yes
Leal et al. [10]	17	0	7 (41%)	4 (23%)	N/A	Metastasis (n = 6 (35%))	11 (65%)	6 (35%)	12 (71%)	2 (12%)	2 (12%)	1 (6%)	0	0	Subtotal resection	Awake-awake-awake	Propofol-remifentanilo	Yes	Yes
Leal et al. [20]	19	N/A	8 (42%)	5 (26%)	N/A	Metastasis (n = 6 (31.5%)	11 (58%)	8 (42%)	13 (68%)	3 (16%)	2 (11%)	1 (5%)	0	0	Subtotal resection	Awake-awake-awake	Propofol-remifentanilo	Yes	Yes
Cole et al. [13]	1	0	1 (100%)	0	0	0	1 (100%)	0	1(100%)	0	0	0	0	0	Gross-total resection	Asleep-awake-asleep	NR	Yes	Yes
Amorim et al. [17]	12	0	0	6 (50%)	12 (100%)	3 (25%) Cavernous malformation, 1 (8.3%) Dermoid Cyst, 1(8.3%) Gliosis, 1(8.3%) Refractory Epilepsy	12 (100%)	0	8 (67%)	2 (16.5%)	2 (16.5%)	0	0	0	Gross total resection n = 8, sub-total resection n = 4	Asleep-awake-asleep	Dexmedetomedina-remifentanilo	Yes	Yes
Pereira et al. [21]	79	0	27 (34.2%)	52 (65.8%)	0	0	56 (71%)	23 (29%)	41 (52%)	0	10 (13%)	16 (20%)	12 (15%)	0	Gross total resection = 25, subtotal = 54	Asleep-awake-asleep	Propofol-remifentanilo	Yes	Yes

Table 2 (continued)

Authors	N	Lesion					Hemisphere		Location**						Surgery	Type of anesthesia		Pre-operative considerations	
		Meningioma (n)	HGG (n)	LGG (n)	Seizure control due to other pathology	Other	Left	Right	Frontal	Temporal	Parietal	Insular	Occipital	Other	Extent of resection	Type of anesthesia	Medication for sedation	Pre-operative Neuro-psycho-logical testing (Yes/No)	Intraoperative stimulation for cortical and subcortical areas. (Yes/No)
Velazquez-Gonzalez et al. [36]	1	N/A	0	1 (100%)	1 (100%)	0	0	1 (100%)	1(100%)	0	0	0	0	0	N/A	NR	NR	NR	Yes
Gonzalez et al. [31]	10	0	4 (40%)	6 (60%)	9 (90%)	0	6 (60%)	4 (40%)	4 (40%)	1 (10%)	2 (20%)	1 (10%)	0	2 (20%) Frontoparietal	N/A	NR	NR	Yes	Yes
Nuñez-Velasco et al. [14]	2	0	0	2 (100%)	2 (100%)	0	2 (100%)	0	0	0	2 (100%)	0	0	0	Gross total resection	Asleep-awake_asleep	NR	NR	Yes
Cruz et al. [18]	3	0	0	3 (100%)	3 (100%)	N/A	3 (100%)	0	2 (75%)	1 (25%)	0	0	0	0	Gross total resection	Asleep-awake-asleep	Propofol	Yes	NR
Martinez-Barreto et al. [37]	1	0	0	0	1 (100%)	Pediatric tumor (Unknown histology)	0	1(100%)	0	0	1 (100%)	0	0	0	N/A	Asleep-awake-asleep	Dexmedetomidina-propofol-remifentanilo	Yes	NR
Bolzani et al. [11]	1	0	0	0	1 (100%)	Cavernous malformation	1(100%)	0	0	0	1(100%)	0	0	0	N/A	Asleep-awake-asleep	Propofol-remifentanilo	Yes	Yes
Delgado-Maidana et al. [26]	6	0	0	6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	Asleep-awake-asleep	Remifentanilo-propofol	NR	NR
Côrte et al. [19]	1	0	0	1 (100%)	1(100%)	0	1(100%)	0	1(100%)	0	0	0	0	0	Gross-total resection	NR	NR	Yes	Yes
Freitas et al. [12]	1	0	0	1 (100%)	1 (100%	0	1(100%)	0	0	0	0	0	0	1 ((100%) Frontoparieto-temporal	N/A	Asleep-awake-asleep	Proppofol-remifentanile	Yes	Yes
Barbieri et al. [28]	1	N/A	N/A	N/A	N/A	Metastasis	1 (100%)	0	0	0	0	0	1 (100%)	0	Gross-total resection	Awake-awake-awake	Midazolam-droperidol-fentanilo por vía IV más sevofluorano	Yes	Yes
Quiroz [29]	1	0	1 (100%)	0	1 (100%)	0	1(100%)	0	1(100%)	0	0	0	0	0	Gross-total resection	Awake-awake-awake	Dexmedetomedina	No	Yes
Flores et al. [23]	1	0	0	1 (100%)	1 (100%)	0	0	1(100%)	1(100%)	0	0	0	0	0	Gross-total resection	Asleep-awake-asleep	Propofol—remifentanilo-dexmedetomidina	Yes	Yes
Vasquez et al. [38]	1	0	N/A	N/A	1 (100%)	0	1(100%)	0	1(100%)	0	0	0	0	0	Gross-total resection	Asleep-awake-asleep	Propofol—remifentanilo	Yes	Yes

Table 2 (continued)

Authors	N	Lesion					Hemisphere		Location**						Surgery	Type of anesthesia		Pre-operative considerations	
		Meningioma (n)	HGG (n)	LGG (n)	Seizure control due to other pathology	Other	Left	Right	Frontal	Temporal	Parietal	Insular	Occipital	Other	Extent of resection	Type of anesthesia	Medication for sedation	Pre-operative Neuro-psychological testing (Yes/No)	Intraoperative stimulation for cortical and subcortical areas. (Yes/No)
Barreto-Acevedo et al. [22]	1	0	0	0	0	Refractory Seizure	1(100%)	0	0	1(100%)	0	0	0	0	Left temporal anterior lobectomy without resection left frontal gliosis	NR	NR	Yes	Yes
Longo et al. [27]	10	0	"Predominant lesions were gliomas, no additional information" 1 patient had a diffuse astrocytoma 2 WHO CNS grade		4 (40%)	0	"Pre-dominant lesions"	NR	NR	"Pre-dominant lesions"	NR	NR	NR	NR	N/A	Asleep-awake-asleep	Propofol—remifentanilo	No	Yes

Table 3 Summary of characteristics and outcomes

	N	%
Total N	258	
Lesion		
Glioma		
High-grade glioma	83	32%
Low-grade glioma	138	53.00%
Meningioma	0	0
Others	27	10.00%
Hemisphere*		
Right	46	18%
Left	112	44%
Not reported	99	38%
Location**		
Frontal	132	51%
Temporal	37	14%
Parietal	34	13%
Insular	21	8%
Occipital	13	5%
Others	6	2%
Post-operative complications**		
Aphasia	6/167	3.6%
Hemiparesis	14/167	8.4%
Seizure	31/212	14.6%
Nausea	1/167	0.6%
Death	0	0
Did the patient recover from the complication?	23/23***	100%
Discharge Time (Hours) (mean/CI)	68 (24–168)	

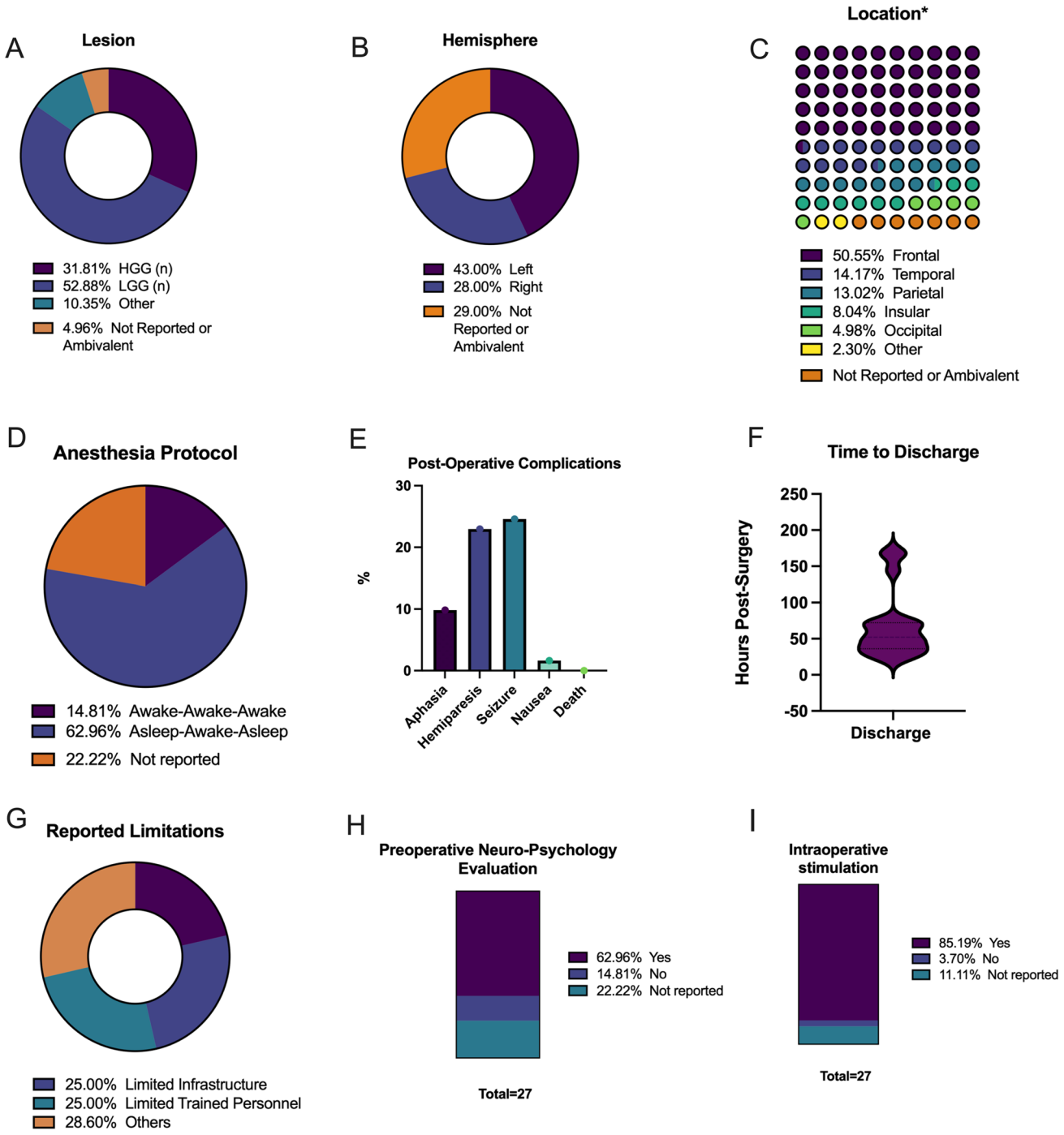
*Three studies did not report the laterality—The N for the sample excluding the individuals from these studies corresponded to 157 patients

**Two studies did not report the location—The N for the sample excluding the individuals from these studies corresponded to 241 patients

CI confidence interval

Postoperative complications in awake craniotomy patients

The most common complication was seizures, occurring in 14.5% (n = 31). Followed by hemiparesis in 8.4% (n = 14). Additional complications such as aphasia and nausea were reported but with lower percentages (3.6% and 0.6% of the patients, respectively) (Table 3 and Supplementary 1—Fig. 2E). On average, patients were hospitalized for approximately 68 h following the surgical procedure (Table 3 and Supplementary 1- Fig. 2F).



Constraints at AC in low-resource centers

Regarding the challenges, 25% of the studies mentioned having limitations in their infrastructures. 25% reported limitations in trained personnel, and 28% discussed challenges involving scarce economic resources, support for training, and instrumentation (Fig. 2G, Supplementary 1–2).

Discussion

Despite challenges, AC is a safe and valuable technique that has been progressively adopted in use in Latin American countries. The biggest advantages of AC vs. GA include shorter times in hospitalization, reduced postoperative complications, such as infection, and increased patient satisfaction, involving a faster time going back to work life [2]. The results suggest a need for greater accessibility to resources,

◂**Fig. 2** Characteristics of the lesions and used anesthesia. **A** Type of lesion, note that 53.3% (n = 138) had low-grade glioma. In comparison, 32% (n = 83) reported high-grade glioma, followed by other types of lesions such as cavernous malformations (n = 8), metastasis (n = 7), gliosis (n = 3), and a dermoid cyst (n = 1), **B** Laterality of the lesion:]44% of patients (n = 112) presented a left-sided lesion, while 18% of patients (n = 46) debuted with a right-sided lesion; three studies did not report the laterality (n = 99, 38%). **C** Location of the Lesions. The lesions were more frequent in the frontal lobe (51%), followed by the temporal (37%). Some lesions involved more than one region (2%). None of the studies directly compared Awake Craniotomy with General Anesthesia Craniotomy. **D** Type of Anesthesia Protocol: 62.9% (17 articles) opted for an Asleep-Awake-Asleep protocol [7, 10, 11, 13–19, 21, 24, 27–29]. 14.8% Opted for an Awake-Awake-Awake [8, 22, 23, 26], and 22.2% of the studies did not report the type of anesthesia [4, 6, 27, 30, 31]. *Other: Including Frontotemporal, Frontoparietal, and Frontoinsular, **E** post-operative complications: Seizure was the most common complication, occurring in 24.5% (n = 15). Followed by hemiparesis in 22.9% (n = 14). Additional complications such as aphasia and nausea were reported but with lower percentages (9.8% and 1.6% of the patients, respectively), **F** Discharge time: On average, patients were hospitalized for approximately 68 h following the surgical procedure. **G** Constraints at AC in Low-Resource Centers. Regarding the challenges, 25% of the studies mentioned having limitations in their infrastructures. 25% reported limitations in trained personnel, and 28% discussed challenges involving scarce economic resources, support for training, and instrumentation

particularly training and infrastructure, to ensure AC is available to patients in need at more neurosurgical centers throughout the region.

AC has increasingly become a pivotal neurosurgical procedure used in challenging cases to perform a real-time mapping of eloquent areas first to achieve a maximal safe resection and second to minimize postoperative complications, decreasing ICU costs [2] and allowing a treatment alternative for otherwise inoperable tumors [3].

A huge benefit of awake craniotomy over asleep technique is that can be performed safely with a limited number of technological (and expensive) tools, from the principle of knowing the anatomy, and anatomical guidance can be achieved directly with electrical stimulation. This point was also previously highlighted by Eseonu et al., Albuquerque et al., and Zhang et al. [5, 32, 33].

As mentioned by Albuquerque et al., one of the main challenges was limited access to technologies such as neuronavigation, diffusion tensor imaging MRI, functional MRI, and motor-evoked potentials, among others [34, 35]. An important conceptual challenge is mapping multiple cognitive functions, particularly in patients with lesions in the right hemisphere, where mere neurological exam and localization can be difficult—followed by the difficulty of achieving a highly trained and aligned multi-disciplinary team [34]. However, the challenges are managed in most centers with preoperative neuropsychological tests and intraoperative stimulation (Table 2, Fig. 2). Finally, late referrals and lacking reliable follow-up due to transportation limitations, suboptimal recovery, and in some cases, the low educational level of some of the patients interfere with the performance of the neurocognitive test, certainly a situation that mirrors the political influence in the region [32, 34–37]

The experts' opinions revealed a consensus regarding a multidisciplinary team capable of approaching the surgery from diverse perspectives, essential for ensuring success (Supplementary 2).

AC is a complex procedure requiring a series of elements, including brain mapping, specific anesthetics, and damage control elements, including cold IV infusions. As well as a highly trained team. This poses a challenge for Latin American countries, as socioeconomic barriers significantly influence the ability to meet these goals [26, 38]. Maldaun et al. demonstrated that AC could be safely performed with adequate training even though it was a learning curve regarding patient positioning and setup times [39]. Once again, this highlights the need for trained personnel capable of meeting the requirements of these complex procedures. However, in most centers in LMIC (low and middle-income countries), the educational challenges are difficult to access not only for neurosurgery residents but also anesthesiologists, electrophysiologists, neuropsychologists, and others, which are scarce in most health centers. The opinion of the experts highlights a straightforward yet complex solution: The Necessity for investments in health and education. Such investments can help bridge the gap and enhance healthcare quality in Latin American health institutions.

Our results suggest that besides some of these challenges, AC can be safely performed with complication rates below 30%, most of which are reversible. (Fig. 2E), even below the 34.5% reported in the literature based on a systematic review by Zhang et al. in 2020 [33]. Also, with a relatively short discharge time of fewer than three days (Table 3)**.** However, the extent of resection is still under the level projected by Zhang et al., where 74.7% [33] was achieved compared to 34.3% in our population (Table 2). This is a very low percentage compared to American reference centers, with > 83% [5]. In our cohort, only 18/27 reported the Extend of Resection, contributing to a possible bias. Another possible explanation could be a literature collection bias where some of the centers where awake craniotomy is performed on a bigger scale do not publish their cohorts, as suggested by Dr. Juan Mejia, M.D (Supplementary Data 2). Showing the importance of encouraging researchers in these areas to publish and contribute to the available literature. A similar situation can be addressed for the outcomes. Being seizures one of the most important compared to American cohorts like the one reported by Zanello et al., with only 3.5–7.9% [40] compared to 14.6% in our study.

In at least ¼ of the studies included the authors did not mention any complications or inform about the outcome, leaving the answer open to discussion if this was omission or effectively no complications occurred, a reason why we

only analyzed the studies that mentioned the variables, to avoid bias.

Gerritsen et al. presented a multicenter-international study that included 212 neurosurgeons from 42 countries. In this study, responses by the center (academic vs. nonacademic or private practice) Showed that academic neurosurgeons were more than five times as likely to perform awake craniotomies (OR = 5.15, P = 0.0007). In academic centers, it was more common to have a clinical neurophysiologist present with telemetric monitoring during asleep monitoring. In our cohort, most centers had an academic affiliation, and more than 85% of the hospitals performed intraoperative stimulation and pre-operative neuropsychological testing. The specific rates could be addressed deeply in future publications. Interestingly, this study also showed that European centers perform more intra-operatory neuropsychological tests than American centers, while Americans tend to include more motor skills [41]. Most of the first-author neurosurgeons in our cohort received international training in their countries, followed by the USA and Europe.

Postsurgical care at home and in the community requires appropriate infrastructure and an understanding of the pathology, which was also mentioned by Mofatteh et al. as an important challenge in the African community [1]. For example, it is known that limited infrastructure in rural areas delays medical interventions. Harrington et al. mentioned this issue in the American Heart Association Journal [42]. Therefore, we suggest that the living conditions and accessibility must be addressed when choosing a candidate for AC.

Best patient outcomes are achieved in centers with a multidisciplinary team [13, 21, 26, 32, 43]. Shows the necessity to increase human talent and support early training for residents, psychotherapists, and technicians, not only in the technique but in research and the importance of scientific divulgation, and to Adjust the parameters of neuropsychological batteries to the patient's necessities and understanding.

Finally, as mentioned by Mofatteh et al., *"Knowledge transfer can be used to initiate AC practice with minimum requirements. Enhancing global collaboration between centers with experience in performing AC in high-income countries is required to train competent staff and transfer knowledge for the sustainable establishment of AC centers"* [2]. Suggesting this is a first step to making AC more accessible in the Latin-American territory.

Limitations

The main limitation of this article consisted of the lack of reports. To mitigate the bias associated with limited information, we included our search articles in Spanish, English, and Portuguese search articles. However, this also added a new limitation, none of the articles directly evaluated the challenges or difficulties. This information was mentioned but not extended systematically, adding an interpretation bias. Furthermore, all the studies included corresponding only to 8 countries, limiting the scope of this work. In the future, a multicenter study that aims to investigate the challenges and ways to improve them is highly suggested, as well as cross-sectional and prospective cohorts from Latin-American countries. Despite all the limitations, this is the first study evaluating these topics in Latin America in a systematic critical review fashion.

Conclusion

Despite the challenges, AC is a safe and valuable technique that has increasingly become an essential neurosurgical procedure in anatomically challenging cases to perform a real-time mapping of eloquent areas. Considering that shorter hospitalization is achieved with AC, reduced postoperative complications are seen, and increased patient satisfaction is accomplished, its implementation and use in the context of low- and middle-income countries can lead to decreased financial burden and a more effective and targeted-oriented practice.

As was described, the main limitations faced in the Latin American context were infrastructure, human talent training, and economic resources. As mentioned, part of AC's success is relying on a multidisciplinary team capable of approaching the procedure and anticipating its potential complications, making this skill a fundamental part of neurosurgical training during residency, as well for technicians, neuropsychologists, and neuro anesthesiologists.

The results suggest a need for greater accessibility to resources (particularly early training at all levels), infrastructure, and adequate instrumentation to ensure that AC is available to patients in need at more neurosurgical centers throughout the region, as well an urge for the Latin-American centers of excellence to publish their experiences to increase the visibility of the region. Finally, this review shows the strong innovative capacity of Latin American medical professionals and demonstrates an excellent prospect for AC's feasibility and widespread application in Latin America.

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Author contributions LF, JS, AQH, and JPA developed the idea. RM, SF, and AS collected the data and contributed to Tables 1-3. LF, JS, and LM reviewed the papers included and corroborated the information. JAM, JFR, DG, FH, DG, CV, JN, MB, LA, and CN collected the information for the Supplementary Data and reviewed the draft and final manuscript. LF and JS wrote the draft and final manuscript. AS, UT, and RM contributed building figures 1-2. EO, AQH, RA, and JPA reviewed the final version.

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Declarations

Conflict of interest The authors declare no competing interests.

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