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Decompressive Craniectomy in Extensive Ischemic Stroke. An Experience in a Single Institution

Craniectomia descompressiva no acidente vascular cerebral isquêmico extenso. Uma experiência em uma única instituição

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Abstract

Introduction Decompressive craniectomy (DC) is a valuable treatment for reducing early lethality in malignant intracranial hypertension (IH); however, it has been shown that the decision to implement DC in patients with extensive ischemic stroke should not be based solely on the detection of IH with the use of intracranial pressure (ICP) devices.

Objective To establish the usefulness of DC in patients with extensive ischemic stroke who came to the emergency room during the period between May 2018 and March 2019.

Methods This was an analytical, prospective, and longitudinal study whose population corresponded to all patients with a diagnosis of extensive ischemic stroke.

Results The sample consisted of 5 patients, of which 3 were female and 2 males, the average age was 62.2 years old (minimum 49 years old, maximum 77 years old). Of all the patients who underwent DC, it was found that 80% of the patients did not present an increase in intracranial pressure. Decompressive craniectomy was not performed in a case that responded adequately to medical treatment. The mean values of ICP were 25 mmHg with a minimum value of 20 mmHg and a maximum value of 25 mmHg; in patients with a moderate value, the ICP averages were < 20 mmHg. The mortality was of 40% (RANKIN of 6 points).

Conclusions Decompressive craniectomy is useful in extensive ischemic stroke. The decision to implement DC in patients with extensive stroke rests on clinicoradiological parameters. The monitoring of the IPC was not particularly useful in the early detection of the neurological deterioration of the patients studied.

Keywords
- ► decompressive craniectomy
- ► intracranial hypertension
- ► intracranial pressure
- ► ischemic stroke

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Resumo

Fundamento A craniectomia descompressiva (CD) é um tratamento valioso para reduzir a letalidade precoce na hipertensão intracraniana (HI) maligna; no entanto, foi demonstrado que a decisão de implementar a CD em pacientes com acidente vascular cerebral (AVC) isquêmico extenso não deve ser baseada apenas na detecção de HI com o uso de dispositivos de pressão intracraniana (PIC).

Objetivo Estabelecer a utilidade da CD em pacientes com AVC isquêmico extenso que chegaram ao pronto-socorro no período entre maio de 2018 e março de 2019.

Métodos Foi realizado um estudo analítico, prospectivo e longitudinal cuja população correspondeu a todos os pacientes com diagnóstico de AVC isquêmico extenso.

Resultados A amostra foi composta por 5 pacientes, sendo 3 do sexo feminino e 2 do sexo masculino, com média de idade de 62,2 anos (mínimo 49 anos, máximo 77 anos). De todos os pacientes que realizaram CD, verificou-se que 80% dos pacientes não apresentaram aumento da pressão intracraniana. Não foi realizada uma CD que tenha respondido adequadamente ao tratamento médico. Os valores médios de pressão intracraniana foram de 25 mmHg, com o valor mínimo de 20 mmHg e o valor máximo de 25 mmHg; em pacientes com escala moderada, as médias de PIC foram < 20 mm Hg. A mortalidade foi de 40% (RANKIN de 6 pontos).

Conclusões A DC é útil no AVC isquêmico extenso. A decisão de implementar uma CD em pacientes com AVC extenso depende de parâmetros clínico-radiológicos. O monitoramento do PCI não foi muito útil na detecção precoce da deterioração neurológica dos pacientes estudados.

Palavras-chave
- craniectomia descompressiva
- hipertensão intracraniana
- pressão intracraniana
- acidente vascular cerebral isquêmico

Introduction

Ischemic stroke constitutes the second cause of death worldwide, with 15.2 million deaths in 2016; it is the most expensive pathology that exists, consuming 2 to 4% of health resources worldwide, being the leading cause of disability in the world, with an estimated incidence of 345 cases per 100,000 inhabitants per year.[1,2,3] In Venezuela, it constitutes the fourth cause of death.[2] The number of strokes is expected to increase in the future (from 16 to 23 million cases from 2005 to 2030, with a mortality that will rise from 5.7 to 7.8 million annually).[3]

The presence of a large hemispheric ischemic stroke associated with intracranial hypertension (IH) can be defined as a malignant cerebral infarction due to rapid neurological deterioration and high associated mortality (close to 80%), despite the use of adequate diagnostic and therapeutic methods.[4] Numerous studies have consistently revealed that higher intracranial pressure (ICP) (to levels ~ 20 to 25 mmHg) is independently associated with a high risk of mortality. The mortality rate has also been shown to be further increased in patients with prolonged refractory elevated ICP.[4,5,6]

Extensive experimental and clinical data indicate that DC is a valuable treatment for reducing early lethality in malignant IH. This type of surgery has been performed in patients with extensive ischemic stroke, in whom, due to the development of cerebral edema, increased ICP, and consequent cerebral herniation, there is a high mortality rate. Considering that nonsurgical treatment to reduce ICP has been shown to be mostly ineffective, the release of the cranial vault and of the dura mater allows the edematous brain tissue to expand outwards, thus offering a clear survival advantage, decreasing the mortality rate from 80% to ~ 20%, which appears to be related to changes in the pressure gradients that develop within the skull, provided by surgical decompression.[7,8,9,10]

There are currently no well-defined levels for the treatment of elevated ICP caused by clinical conditions other than traumatic brain injury. However, in different medical centers, therapy is started when ICP is > 20 to 25 mmHg. The key to surgical treatment of ischemic stroke lies in the early detection of patients who will progress to extensive ischemia. Candidate selection is based primarily on clinical and neuroradiological data.[8,11,12,13,14,15,16,17,18,19,20,21]

The purpose of the present study was to establish the usefulness of DC in patients with extensive ischemic stroke.

Methods

An analytical, prospective, and longitudinal study was performed. The population corresponded to all patients with a diagnosis of extensive ischemic stroke who entered the emergency room during the period between May 2018 and March 2019. The sampling technique was of an intentional nonprobabilistic type and it was made up of those patients who met the inclusion criteria, which were: Patients with a diagnosis of extensive ischemic stroke, presence of malignant cerebral edema, deterioration of the neurological state according to the National Institute of Health Stroke Scale (NIHSS)[22,23] and to the Glasgow scale,[24] patients > 18 years old, and patients or family members who have signed the informed consent. Patients with thrombocytopenia and/or altered clotting times and Glasgow scale <4 points were excluded. The present case series has been reported in line with the Preferred Reporting of Case Series in Surgery (PROCESS) guideline.

Procedures

Patients with ischemic stroke were received and were indicated, based on the clinical examination (taking into account the NIHSS scale, the Glasgow scale, and pupillary diameter) to undergo an imaging study (computed tomography [CT] or magnetic resonance imaging [MRI]), which confirmed the diagnosis of ischemic stroke. The device (Codman microsensor Metal Bolt kit manufactured in Raynham MA USA) used to measure ICP was placed at the Kocher point. After the device with continuous ICP measurement was placed, clinical follow-up was performed to define the surgical time; the definition of the surgical time was determined by the deterioration of the clinical state of the patient, with an NIHSS >25 points, Glasgow <8 points, pupillary anisocoric and an ICP $\geq$ 20 mmHg refractory to antiedema medical treatment. Once the surgical time was defined, it was decided to perform a DC (see surgical technique), with the two-month postoperative follow-up of the patients being performed using the modified RANKIN scale.[25]

Placement of the intracranial pressure-measuring catheter[26]

The patient was positioned in dorsal decubitus; after asepsis and antisepsis, sterile bonnets were placed, a 2-cm long linear incision was made on the affected cerebral hemisphere at the Kocher point, and an automatic separator was used to separate the edges of the skin. The 2.7 mm drill bit was placed into the hand drill bit holder and a hole was made through the bone. The cranial screw was placed and manually screwed in by turning it clockwise until it was properly seated. The dura mater obturator/perforator was used to open the passage through the screw and the durotomy was performed. The canal was irrigated with sterile saline. The fiber was connected to the monitor and calibrated to 0. The CODMAN device fiber was then guided through the 15 to 20 mm screw into the white matter.[27] The compression cap was rotated firmly clockwise to fix the transducer. The skin incision was closed in a single plane, with separate stitches.

Surgical technique to perform decompressive craniectomy[16,28]

The patient was positioned in dorsal decubitus; after asepsis and antisepsis, sterile bonnets were placed, and a Rasmussen incision was made. The incision should be extended through the subcutaneous tissue, including the temporalis muscle, down to the cranium. The resulting myocutaneous flap was challenged anteriorly and secured with scalp hooks. A trepan hole was made just above the posterior root of the zygomatic arch and another one behind the frontal insertion of the lower zygomatic arch to the superior temporal line, a frontal-temporo-parieto-occipital craniectomy of 12 cm by 16 cm was performed. Hemostasis was performed with bone wax and Dural suspension stitches, respectively. Durotomy was performed leaving 1 centimeter from the edge of the craniectomy. Duroplasty with autologous graft was performed. In a second surgical period, the bone flap was placed subdermally in the abdominal wall.

Statistical Analysis

A database was made IBM SPSS Statistics for Windows, Version 19 (IBM Corp., Armonk, NY, USA). The data were analyzed using descriptive statistics such as median, mean, absolute (n) and relative frequencies (%). The Fisher test, the chi-squared test, and the Kendall Taub C test were performed. A p-value <0.05 was considered statistically significant.

Results

The sample consisted of 5 patients who met the selection criteria, of which 3 were female and 2 males, the average age was 62.2 years old (minimum 49 years old, maximum 77 years old). ►**Table 1** shows the clinical characteristics of the patients and ►**Table 2** shows the surgical characteristics. It was found that the time between the onset of symptoms and surgery was 48 hours in 2 cases, 72 hours in 1 case and >72 hours in 1 case, additionally it was observed that one of the cases did not need surgery due to responding to medical treatment.

At admission, 60.0% ($n=3$) of the patients had a mild score in the NIHSS scale, whereas at the time of surgery all patients had severe NIHSS ($p=0.05$). Regarding the Glasgow scale, there was a statistically significant difference between admission (moderate Glasgow [80%]) and at the time of surgery (severe Glasgow [100%]) ($p=0.02$). Regarding the pupillary diameter, a significant difference was found ($p=0.003$); on admission, all patients had isochoric pupils and, at the time of surgery, they were anisocoric. More than 70% of the cases had an ICP $\leq$ 20 mmHg both at admission and at the time of surgery. ►**Table 3**.

Regarding the frequency of the decompressive craniectomies performed, it was found that 80% of the patients did not present an increase in ICP; the incidence of ICP frequency >20 mmHg with DC was of 20% ($n=1$), observing that 60% of the patients presented an ICP <20 mmHg. In one case, no DC was performed due to a clinical response to medical treatment.

Of the 5 patients evaluated, 1 had a severe score in the NIHSS scale, with an average intracranial pressure of 25 mmHg with a minimum value of 20 mmHg and a maximum value of 25 mmHg. In patients with a moderate score in the NIHSS scale, the mean ICP was <20 mm Hg. ►**Table 4**.

Three patients were found to have an ICP $\leq$ 20 mm Hg and a moderate score in the NIHSS scale (►**Fig. 1**). The association between the modified RANKIN scale at admission and at 2 months is shown in ►**Fig. 2**.

A total of 40% of the patients with a moderate score in the NIHSS scale were associated with 40% of the patients with a moderate Glasgow scale; 20% of the patients with a moderate score in the NIHSS scale were associated with 20% of the patients with a moderate score in the Glasgow; and 20% of

Table 1 Clinical status at admission of patients with ischemic stroke with intracranial pressure monitoring

Patient	Clinical picture upon admission	Clinical picture at the time of surgery	Finding on brain CT
1	NIHSS scale 23 pts	NIHSS scale 26 pts	Hypodensity in the right frontotemporoparietal area with displacement of the midline of 2 cm
	Glasgow scale 8 pts	Glasgow scale 6 pts	
	Isochoric pupils	Anisocoric pupils	
	Left hemiplegia	Left hemiplegia	
2	NIHSS scale 28 pts	NIHSS scale 31 pts	Hypodensity in the right frontotemporoparietal area with displacement of the midline of 2 cm
	Glasgow scale 9 pts	Glasgow scale 5 pts	
	Isochoric pupils	Anisocoric pupils	
	Left hemiplegia	Left hemiplegia	
3	NIHSS scale 14 pts	NIHSS scale 23 pts	Hypodensity in the left frontotemporoparietal area with displacement of the midline of 2 cm
	Glasgow scale 1 pt	Glasgow scale 7 pts	
	Isochoric pupils	Anisocoric pupils	
	Right hemiplegia	Right hemiplegia	
4	NIHSS scale 8 pts	No surgery was performed	Hypodensity in the right frontotemporal area with 1 cm displacement of the midline
	Glasgow scale 13 pts		
	Isochoric pupils		
	Left hemiplegia		
5	NIHSS scale 13 pts	NIHSS 28 pts	Hypodensity in the right frontotemporoparietal area with 2 cm displacement of the midline
	Glasgow scale 10 pts	Glasgow 5 pts	
	Isochoric pupils	Anisocoric pupils	
	Left hemiplegia	Left hemiplegia	

Abbreviations: CT, computed tomography; NIHSS, National institute of Health Stroke Scale; pt, point.

Table 2 Surgical characteristics of patients with ischemic stroke with intracranial pressure monitoring

Patient	Age (years old)	Gender	Time between onset of symptoms and surgery	ICP (mmHg)	Craniectomy location
1	71	M	48 hours	12	Right
2	49	F	72 hours	25	Right
3	77	F	4 days	8	Left
4	74	M	———	10	——
5	40	F	48 hours	15	Right

Abbreviation: ICP, intracranial pressure.

the patients with a severe score in the NIHSS scale were associated with 20% of the patients who presented a severe Glasgow scale, with a statistically significant linear association ($p = 0.025$). ►**Table 5**.

It was observed that, on average, the ICP at admission was 14 ± 6.7 mmHg; in the postoperative period, the ICP was 11.6 ± 5.9 mmHg, with a mean difference of 2.4 mmHg (95% confidence interval [CI]: 0.5–4.3 mmHg), which was statistically significant ($p = 0.02$). ►**Table 6**.

In this series of patients, it was observed that females with an injury to the left hemisphere presented a 3-fold greater risk than the rest of the patients (95%CI: 0.61 -14.86). The risk of NIHSS > 60 years was 2 (95% CI, 0.75 -5.33) the risk was two times higher in the left hemisphere than in the right. The same was observed in the deviation from the midline of 20mm over 10mm which was 2 (95% CI 0.05 -78.25) and mortalitywas higher in patients older than 60 years (relative risk [RR] 1.33; 95% CI 0.27 -6.61) ►**Table 7**.

The probability of survival of the patients who were monitored for ICP lowered as the hours of evolution passed. ►**Fig. 3**.

Discussion

The sample of patients who met the inclusion criteria in the present study has similarities with those of other studies conducted in the same period.[3,8] It is important to note that extensive ischemic stroke represents ~ 10 to 15% of all

Table 3 Clinical characteristics at admission and at the time of surgery of patients with ischemic stroke with intracranial pressure monitoring

NIHSS scale	Admission ($n = 5$)		At the time of surgery ($n = 4$)		*p-value**
	n	%	*n*	%	
Mild	3	60.0	0	0.0	0.05
Moderate	0	0.0	0	0.0	
Serious	2	40.0	4	100.0	
Glasgow scale					0.02
Mild	0	0.0	0	0.0	
Moderate	4	80.0	0	0.0	
Severe	1	20.0	4	100.0	
Pupillary diameter					0.003
Anisocoric	0	0.0	4	100.0	
Isochoric	5	100.0	0	0.0	
Intracranial Pressure		0.0			0.85
$\leq$ 20 mmHg	4	80.0	3	75.0	
$>$ 20 mmHg	1	20.0	1	25.0	

Abbreviation: NIHSS, National institute of Health Stroke Scale.
*Chi-squared test

Table 4 Frequency of the functional disability severity scale according to the averages of intracranial pressure in patients with ischemic stroke

Patient	NIHSS scale	Intracranial pressure		
		Mean	Maximum	Mininum
1	Moderate	12	12	9
2	Serious	25	25	20
3	Moderate	8	8	6
4	Mild	10	10	8
5	Moderate	15	15	13

Abbreviation: NIHSS, National institute of Health Stroke Scale.

supratentorial infarcts. Mortality rates of up to 80% have been reported and can leave people surviving with severe disabilities. On the other hand, even with the technological advances in medicine, the treatment of malignant cerebral edema is difficult. Nonetheless, the role of DC in such infarcts has been reported to be lifesaving and to even help improving functional outcomes.[20,29]

In addition, investigations have been performed to evaluate the specific prognostic factors that lead to the favorable course of DC in extensive ischemic stroke. In these studies, it can be seen that younger patients (< 60 years old) with a higher score on the Glasgow scale who are operated on in the first 24 hours after the ischemic stroke, before presenting neurological deterioration, show a more favorable result.[7,29]

However, considering that patients with extensive ischemic stroke have a poor prognosis, the use of ICP monitoring has been more useful in different units that opt for more aggressive therapies, such as DC; despite this, we can find in other studies that these new therapeutic measures are beneficial only when applied early.[19,30]

That being said, ICP monitoring in patients with extensive ischemic stroke would aim to guide therapeutic decision-making, to assess the efficacy of applied therapeutic maneuvers, and to detect unexpected complications, such as hemorrhagic transformation of ischemic stroke.[30] However, in our study, we found that a considerable percentage of patients (80%) had normal ICP values despite the marked displacement of the midline. In addition, 3 patients presented anisocoric while their ICP was below the accepted threshold of 20 mm Hg.

It has been found that, in patients with extensive ischemic stroke who present neurological impairment, the ischemic stroke is not accompanied by significant increases in ICP.[26,30] Our findings suggest that despite normal ICP values, severe brain herniation with brainstem compression can be found.

These findings do not imply that ICP monitoring is of no value in these patients because hemorrhagic transformation, a sudden increase in midline displacement, or new lesions, can be detected based on an increase in ICP values.[30]

Additional monitoring methods are necessary despite patients presenting with normal ICP values in order to avoid sudden neurological deterioration. Sequential CT and, above all, strict monitoring of their clinical evolution are the most useful elements in evaluating the evolution of these patients.

Various elements could justify the presence of normal ICP in patients with extensive ischemic stroke with cerebral herniation. Probably, one of these elements is the sudden reduction in cerebral blood flow and, therefore, in cerebral blood volume in the ischemic hemisphere at the beginning of the event and later in the nonrecovered brain. However, in

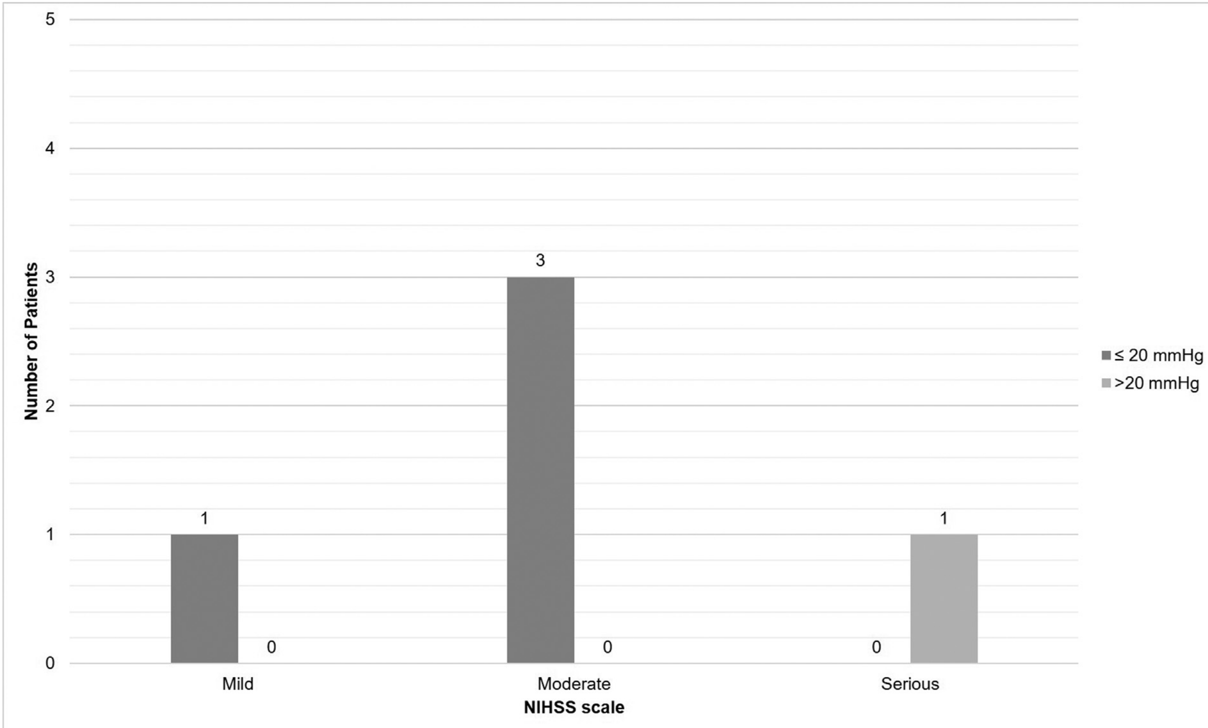

Fig. 1 Relationship between ICP and the NIHSS scale in patients with ischemic stroke.

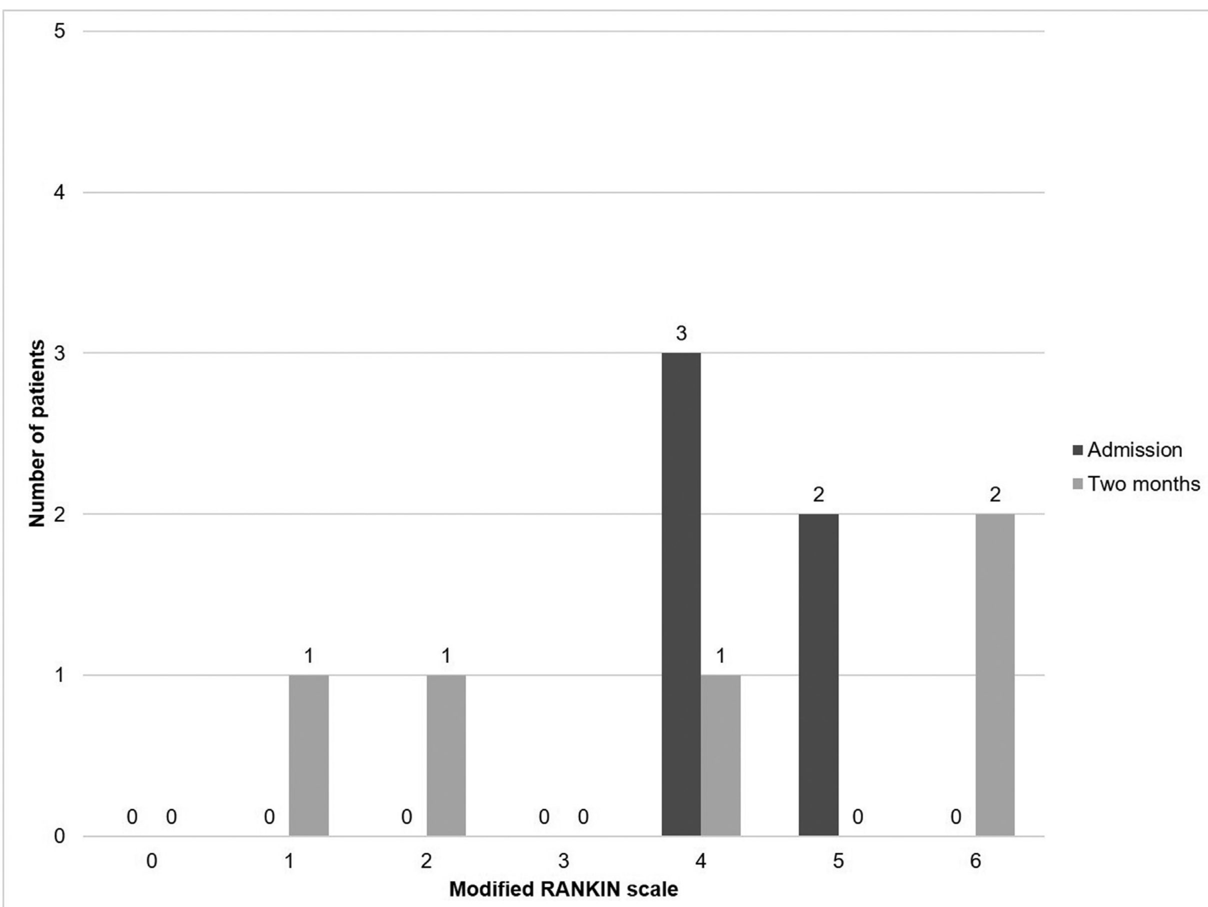

Fig. 2 Comparison of the frequency of the modified RANKIN scale at admission and at 2 months in patients with ischemic stroke.

Table 5 Association between NIHSS severity and the Glasgow scale in patients with ischemic stroke

NIHSS Scale	Glasgow scale						Total	
	Mild		Moderate		Severe			
	n	%	*n*	%	*n*	%	*n*	%
Mild	0	0.0	0	0.0	0	0.0	0	0.0
Moderate	1	20.0	2	40.0	1	20.0	4	80.0
Severe	0	0.0	0	0.0	1	20.0	1	20.0
Total	**1**	**20.0**	**2**	**40.0**	**2**	**40.0**	**5**	**100.0**

Abbreviation: NIHSS, National institute of Health Stroke Scale.
Tau c Kendall = 0.64; $p = 0.025$ (significant)

Table 6 Variation of intracranial pressure at admission and postoperatively in patients with ischemic stroke

Intracranial pressure (mmHg)	Mean	Standard deviation	Mean difference	Standard deviation	95%CI for the difference		*p-value**
					Inferior	Superior	
Admission	14.0	6.7	2.4	1.5	0.5	4.3	**0.02**
Postsurgery	11.6	5.9					

Abbreviation: CI, confidence interval.
*t student

Table 7 Relative risk in patients with ischemic stroke with intracranial pressure monitoring

Association	Relative risk	95%CI	
		Inferior	Superior
Female / left hemisphere	3.00	0.61	14.86
NIHSS severe / age > 60 years old	2.00	0.75	5.33
Hemisphere (left / right)	2.00	0.05	78.25
Midline deviation 20mm / 10mm	2.00	0.05	78.25
Mortality /> 60 years old	1.33	0.27	6.61

Abbreviation: CI, confidence interval.

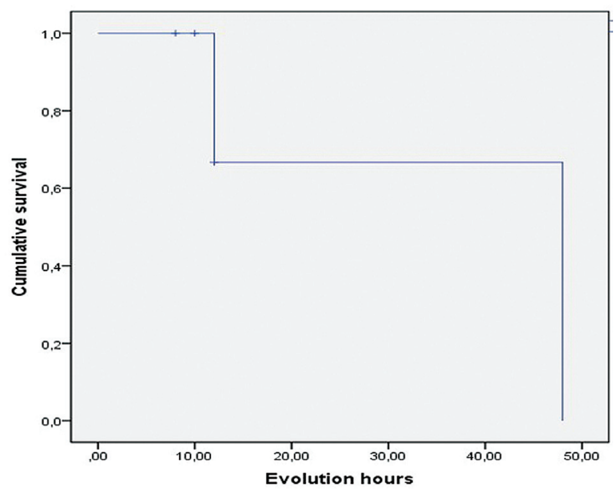

Fig. 3 Kaplan-Meier survival curve according to hours of evolution in patients with ischemic stroke.

a second stage, this reduction in blood volume in the affected hemisphere is compensated by the formation of edema (cytotoxic and vasogenic).[30]

Another factor that could have caused the maintenance of normal ICP in these patients is that the brain volume remains partially compensated at the time the patient begins the course of the disease; therefore, the patient is still in the initial period of the pressure-volume curve, when changes in brain volume are easily compensated for.[26,30]

Pupillary changes before ICP rises may occur from compression of the third nerve and the brainstem due to primary temporal lobe injury.[30]

Another explanation for this phenomenon is that the appearance of a hernia requires a pressure delta between 2 compartments and not an absolute value; thus, a pressure of 12 mmHg in 1 hemisphere can cause uncus herniation if the contralateral hemisphere presents a pressure of 3 mmHg.[31]

On the other hand, it must be taken into account that DC reduces the mortality rate, but increases morbidity, mainly in patients >60 years of age, with a longer survival, but adjusted for quality of life. Therefore, the decision to perform DC must be individualized.[32] Knowing this, we purpose a therapeutic algorithm for the management of the extensive ischemic stroke. (►**Fig. 4**)

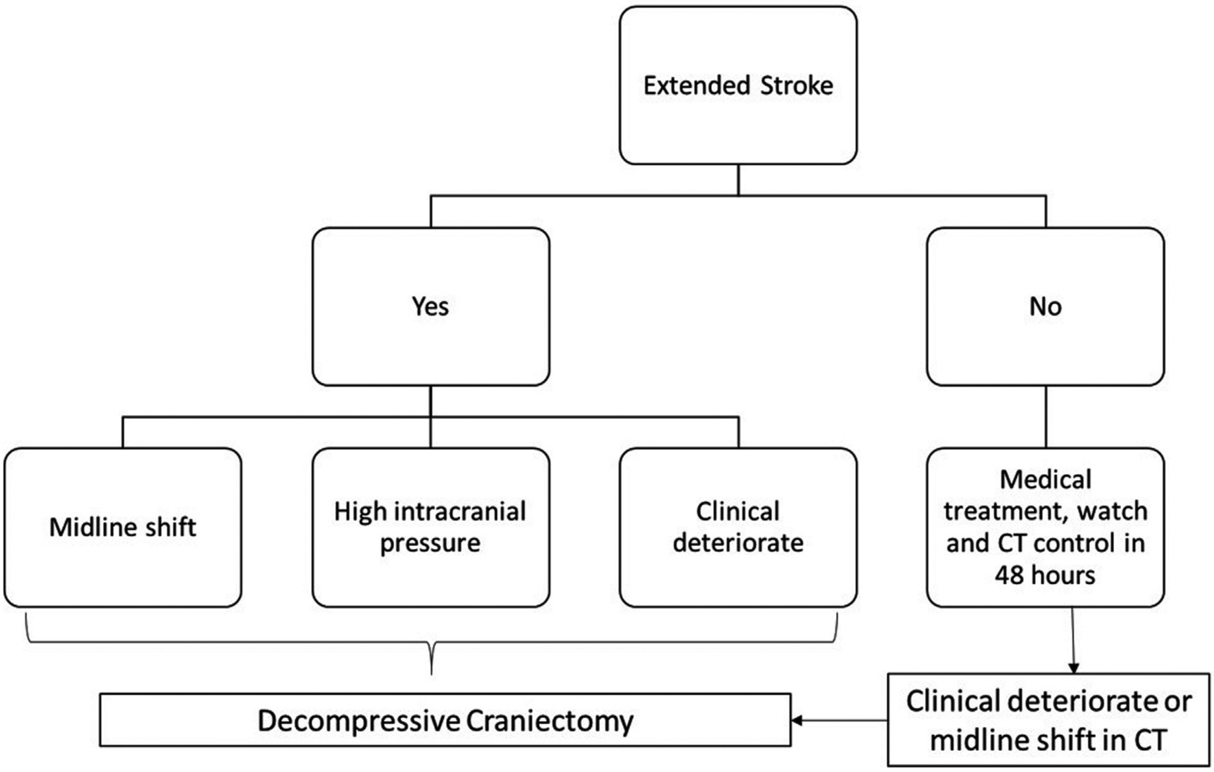

Fig. 4 Proposed algorithm for the management of extensive ischemic stroke.

Conclusion

The female gender was the most affected. The average age was 62.2 years old. In patients <60 years old with extensive stroke with 48-hour deterioration despite medical therapy, DC reduced mortality by $\sim 50\%$, and 100% of the survivors of the surgery achieved moderate disability or 2-month modified RANKIN score of 2 points. In those >60 years old, a DC can be considered since it reduced mortality by $\sim 30\%$, and 30% of the surgical survivors have a moderate disability. A total of 80% of the patients presented with neurological deterioration without elevation of ICP. The probability of survival of the patients lowered as the hours of evolution passed. In the present series, the mortality was of 40%.

The decision to implement DC in patients with extensive ischemic stroke should not be based solely on the detection of IH with the use of ICP devices. Currently, the decision to perform DC in patients with extensive stroke rests on clinicoradiological parameters.

Conflict of Interests
The authors have no conflict of interests to declare.

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