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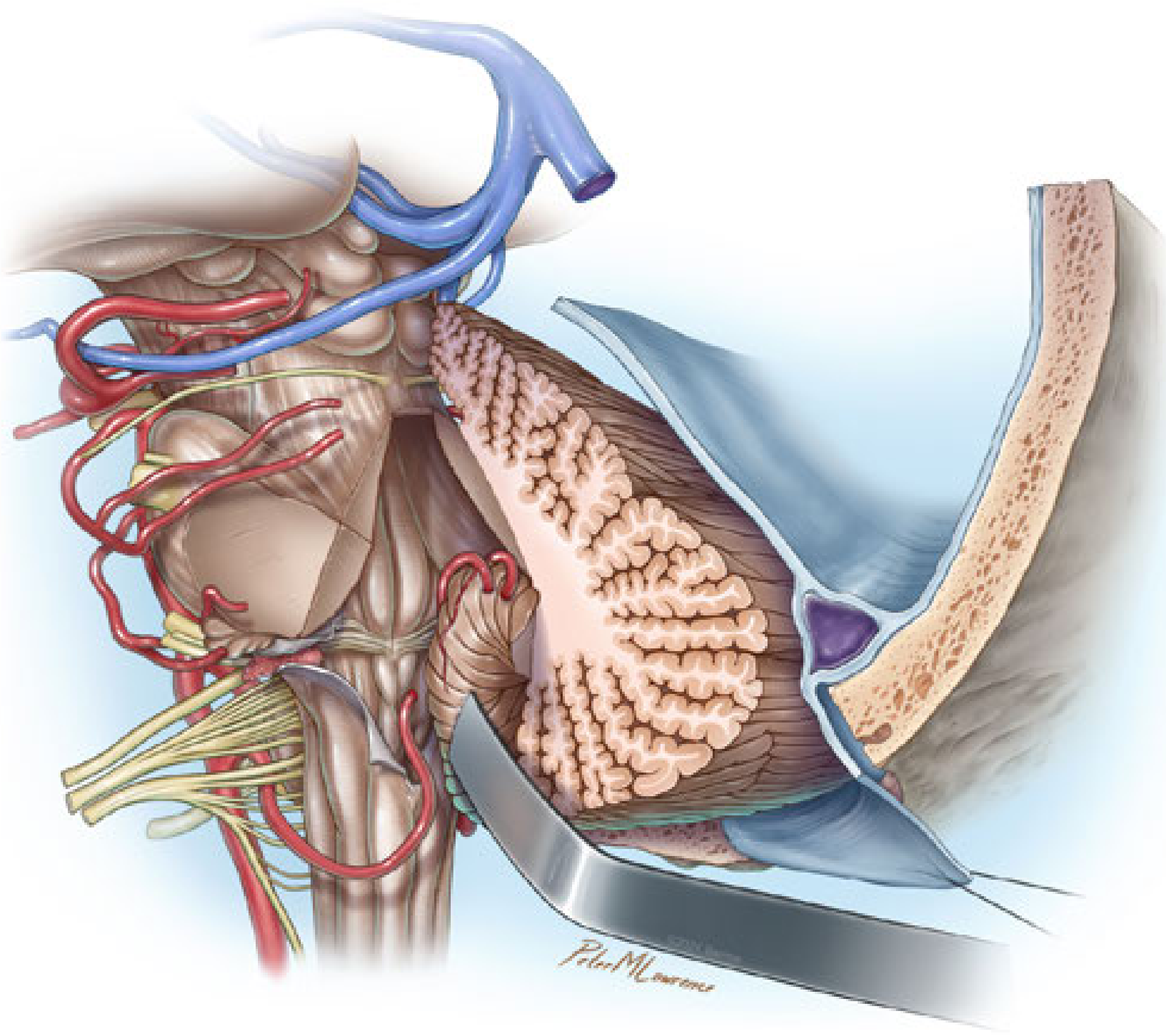

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Submissions must follow the limits and specific requirements outlined on the table below, according to their section.

Section	Abstract	Text sections	Text length	Tables & Figures	References (max)
Original article	structured not exceeding 200 word	introduction, methods, results, discussion, conclusion and references	4000 words	10	75
Review (preferably systematic review)	non-structured not exceeding 200 words	introduction, method, results, discussion, conclusion and references	4000 words	10	75
Case Report (preferably with systematic rev <<	non-structured not exceeding 200 words	introduction (with brief literature review), clinical case presentation, discussion, final comments and references	3500 words	8	45
Brief Note	non-structured not exceeding 200 words	no requirement	1500 words	3	30
Clinical Images	non-structured not exceeding 200 words	no requirement	1500 words	5	30

INTRODUCTION

In the Introduction section we state the motivation for the work presented in the manuscript. Its contents could be: 1) context (to orient readers who are less familiar with the topic and to establish the importance of the manuscript), 2) need (to state the need for the work, as an opposition between what the scientific community currently has and what it wants), 3) task (to indicate what was done in the effort to address the need), and 4) object of the document (to prepare the readers for its structure).

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In Materials and Methods section, the technical specifications and quantities and source or method of preparation are described. Attention to the use only scientific names of drugs; inclusion of the manufacturer in brackets when describing equipment. Discuss statistical methods if needed.

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In Results section, the results of the paper are presented in logical order, using tables and graphs as necessary. Remember that results must be presented and then explained. The results are explained showing how they help to answer the research questions (already cited in the Introduction section).

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In Discussion section, the principles, relationships and generalizations shown by the results are presented. Also, exceptions or lack of correlations are pointed out. The authors show how their results agree or disagree with previously published papers, and discuss the theoretical implications as well as practical applications of the paper, and the significance of their results.

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- Wong, B. Points of view: Color blindness. Nat Methods 8, 441 (2011). https://doi.org/10.1038/nmeth.1618

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- "What's in a picture? The temptation of image manipulation" (Mike Rossner, Kenneth M. Yamada. J Cell Biol 5 July 2004; 166 (1): 11–15. doi: https://doi.org/10.1083/jcb.200406019).
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- **References and Citations:** Ensure that all sources referenced in their work are cited accurately and formatted correctly.
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Investigation	Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection
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Brief Note


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Original

Comparative Analysis between Different Methods for Estimating Volumes of Non-traumatic Intracranial Intraparenchymal Hematomas

Análise Comparativa entre Diferentes Métodos para Estimativa de Volumes de Hematomas Intraparenquimatosos Intracranianos Não Traumáticos

Luiz Fernando Cannoni[1]
Henrique Zuleta de Barros Couto[2]
Euro de Barros Couto Junior[3]
José Carlos Esteves Veiga[4]

ABSTRACT

Introduction: *Volumetric evaluation of intraparenchymal hematomas is essential for diagnosis, treatment planning, and outcome prediction. While the ABC/2 formula is widely used, its accuracy may be limited, especially in irregularly shaped lesions.* **Objective:** *To propose and validate three novel CT-based methods for estimating hematoma volume, comparing them to the traditional ABC/2 (LIT) formula, and explore their broader applicability.* **Methods:** *This retrospective study included CT data from 16 patients with non-traumatic intraparenchymal hematomas (Feb 19–Mar 16, 2025). Images were acquired using Siemens® SOMATOM go.All scanners. Three new methods—MED (simple mean), POND (weighted mean), and SCA (mean slice area-based)—were compared with the LIT formula (a·b·c/2).* **Results:** *The proposed methods produced values similar to LIT (MED: p = 0.326; POND: p = 0.379; SCA: p = 0.225). SCA showed significantly lower volumes than MED (p = 0.026) and a trend toward lower values compared to POND (p = 0.063).* **Conclusion:** *Despite greater computational demand, SCA may offer improved accuracy through integral-based modeling, particularly for irregular geometries. The LIT formula remains a practical tool, but the proposed methods—especially SCA—present promising alternatives for precise volumetric analysis in medical and broader contexts.*

Keywords: *Atraumatic; Hematoma; Intraparenchymal; Radiology; Tomography*

RESUMO

Introdução: *A avaliação volumétrica de hematomas intraparenquimatosos é essencial para o manejo clínico. A fórmula ABC/2 é amplamente utilizada, mas pode apresentar limitações em lesões com morfologia irregular.* **Objetivo:** *Propor e validar três novos métodos de estimativa volumétrica baseados em tomografia computadorizada (TC), comparando-os à fórmula tradicional ABC/2 (LIT), e avaliar sua aplicabilidade em outras áreas.* **Métodos:** *Estudo retrospectivo com dados de TC de 16 pacientes com hematomas intraparenquimatosos não traumáticos (19/02 a 16/03/2025), obtidos com tomógrafos Siemens® SOMATOM go.All. Foram comparadas três fórmulas: MED (média simples), POND (média ponderada) e SCA (média das áreas dos cortes), em relação à fórmula LIT (a·b·c/2).* **Resultados:** *Os três métodos apresentaram resultados semelhantes à LIT (MED: p = 0,326; POND: p = 0,379; SCA: p = 0,225). O método SCA gerou volumes significativamente menores que o MED (p = 0,026) e tendencialmente menores que o POND (p = 0,063).* **Conclusão:** *O SCA, embora mais complexo, pode oferecer maior precisão ao considerar áreas seccionais por meio de cálculo integral. A fórmula LIT permanece útil, mas os métodos propostos — especialmente o SCA — são alternativas promissoras para estimativas volumétricas mais precisas.*

Palavras-Chave: *Não-traumático; Hematoma; Intraparenquimatoso; Radiologia; Tomografia*

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INTRODUCTION

Interest in the medical field

The volume of a lesion can help the healthcare professional to plan a surgical procedure, or even predict a prognosis for a certain case. Therefore, knowing the value of the volume of a given lesion as accurately as possible is necessary. Several models have already been proposed to obtain the desired value. The following method would be one of the most accepted in the medical literature: I) to assume that the intracranial lesion has an ellipsoid shape; II) to analyze the tomographic sections of the three axes [axial, sagittal and coronal] and to obtain the following measurements [using the Ruler tool from Xero Viewer® or similar] for other operating systems), such as, a = the biggest antero-posterior diameter of the lesion, b = the biggest lateral-lateral diameter of the lesion, and c = the biggest cranial-caudal diameter of the lesion; and III) to use one of the following formulas::

$$V_A = \frac{a.b.c}{2} \quad (1)$$

$$V_B = \frac{2}{3}.a.b.c. \quad (2)$$

Initial observations on the VA and VB models

Regardless of the formula used, it is possible to notice that there are several inconsistencies: 1) an intracranial hematoma-type lesion (whether intraparenchymal, subdural, epidural or subarachnoid) does not necessarily have an ellipsoid shape; a three-dimensional reconstruction of this blood accumulation (by computer tomography angiography (CTA) or magnetic resonance imaging (MRI)) makes this quite evident, despite the extremely high costs of doing so; 2) as already systematically reviewed by Zhao et al.[1], the volume value obtained by the a.b.c/2 method (LIT) overestimates the real value between 8.53% and 29.3%; 3) any of the "simple formulas" ignore defects and amorphous sectors of the lesion.

As previously mentioned, the work [1] compared different methods for calculating the volume of a type of hematoma; while some methods underestimated the values, others overestimated them. The "gold standard" of the team [1] was the volume estimated by the 3D Slicer software, and the formulas that the researchers used fit the same inconsistencies mentioned previously. It seemed necessary to accept the challenge of proposing a new method for calculating volume, in such a way that it comes as close as possible to the real value and that takes into account the imperfections present in the lesion of interest.

The team of Ishisaka et al.[2] researched the validity of the a.b.c/2 method (called "XYZ/2") for chronic subdural hematomas, using computerized analysis as the "gold standard" (somewhat similar to our proposed method). Our analysis, on the other hand, assumes that two methods (a.b.c/2 and 2/3 x a.b.c) are the "gold standards" and we compare the values obtained by the computerized analysis method, reformulated in such a way as to try to overcome some inconsistencies from the work 2. An inconsistency detected was that only one of the three available axes was used to carry out the volumetric analysis, instead of using the three available axes (as we implemented). A second inconsistency was assuming that the distance between two consecutive slices of a CT was equal to 5 millimeters, a value that we did not find in our analysis; it is interesting to note that the software Hospital da Santa Casa uses assumed values that differed from 5 millimeters between consecutive slices for each axis (it is therefore inconsistent to assume that the distance between two consecutive images 'h' was the same for the three axes). Our method tried to overcome this inconsistency and proposed an alternative for this.

The prospect of a new proposal

This paper proposes a method for estimating the volume of intraparenchymal hematomas, or even of any given object of interest, knowing only the parallel and equidistant slices of such, with its orthogonal axes, the surface area of each slice, the distance between each slice or the diameters of each slice.

Mathematical deductions

Obtaining the volume of regular solid objects such as cubes and prisms is obtained by applying formulas that involve the three spatial dimensions (length, width and height).

The volume of a simple cube is easily obtained when the measurement of one of the sides is entered. As it is a regular solid figure, that is, the length, width and height measurements have the same dimensions, simply raise the side measurement to the cubic power ($V_{cube} = side_3$), obtaining the result in cubic units.

A prism is a solid that has all congruent plane sections in the shape of a polygon. Therefore, it does not matter where the section is made parallel to the base, as the section always has the same area. To calculate its volume, simply multiply the area of its base by the height of the solid ($V_{prism} = area_{base}.h$), in cubic units.

Intraparenchymal hematomas, on the other hand, generally have very irregular cross-sectional surfaces; logically, the greater the number of slices and the smaller their thicknesses, consequentially the greater precision in calculating the volume of any object will be. This is because if the number of slices tends to infinity, it means that the thickness of each slice tends to zero. This also applies to regular figures.

In mathematical terms, the representation of the area calculation through a defined integral of the function f(x) is shown, where 'S' corresponds to the surface area, '0' and 'b' correspond to the starting and ending point of the measurement of the area (also known as its extension) and 'f(x)dx' represents the function that describes the area to be calculated (Formula 3):

$$S = \int_0^b f(x)\,dx \qquad (3)$$

In this paper, we measured volumes of non-traumatic intracranial hematomas, using the principle of dividing the solid figure (hematoma) into the largest possible number of cross-sections (created by CT scans) in order to obtain the best approximation for calculating the volume of the lesion, which was done by our Hospital's CT.

We compared with formulas offered in the literature for calculating the volume of epidural hematomas, with a certain extension to subdural hematomas.

These hematomas tend to have a more regular geometry when compared to intraparenchymal hematomas, making it easier to use these formulas to calculate the volume of those lesions.

Inclusion and exclusion criteria

Inclusion: non-traumatic, lobar intraparenchymal hematomas without contact with the bony surface were included, due to the possibility of overestimating the slice area of surface.

Exclusion: epidural and subdural hematomas were excluded, as the calculation could include bone surface or partial effect of bone structures which, as highlighted above, would overestimate its values.

METHOD

Images from CT scans of 16 patients who were admitted and treated at the Hospital da Santa Casa de Misericórdia de São Paulo were used. Data collection was carried out between February 19, 2025 and March 16, 2025.

The software used to observe tomographic images is XERO Viewer® version 8.1.2, together with its "Ruler" and "Polygon" tools, which provides linear and superficial measurements. The hardware used is: two Siemens® tomographs model SOMATOM go.All with 32 channels, volumetric and with no definition of slice thickness, providing sections of the lesion, in three orthogonal axes (axial, sagittal and coronal); a Windows 10 desktop computer from Microsoft Corporation. CT scanners were configured equally.

The method for obtaining the defined measurements was established prior to the start of data collection. The steps used in our work are described as following:

1. With the CT exam available, we opened the file in the XERO Viewer® software.

2. The hyper-attenuating region was identified, characterizing the presence of the lesion.

3. The contours of the lesion were manually drawn, with the help of the 'Polygon' tool of the software. The precision of fitting each point to the margins of the hyper-attenuating image and the distance between them was up to each examiner.

4. With the contour drawn and the area of surface calculated by the software, we used the "Ruler" function of XERO Viewer® program to obtain the values of the largest observable dimensions of that section, as long as this measurement is parallel to one of the axes studied.

5. Therefore, let us call this measurement the diameter of a slice, for a given axis. For each slice, then, there will be 2 diameter values that will be obtained, and they are as follows:

    a. For an axial slice, both antero-posterior and lateral-lateral diameters are obtained;

    b. For a coronal slice, both lateral-lateral and cranial-caudal diameters are obtained;

    c. For a sagittal slice, both antero-posterior and cranial-caudal diameters are obtained.

6. Once the values of all areas and diameters are obtained, we carry out the following operations:

7. The values of the areas of all cuts for a given axis are added:

   a. For the axial axis, let us call the value of the sum of the areas S_{axial} ;

   b. For the coronal axis, let us call the value of the sum of the areas $S_{coronal}$;

   c. For the sagittal axis, let us call the value of the sum of the areas $S_{sagittal}$.

8. For each axis chosen for the study, the largest value of the diameter corresponding to it should be chosen in such way that this diameter is perpendicular to the studied axis and parallel to one of the axes of interest, with the relationships being as following:

   a. For the axial axis, one should choose the biggest value of cranial-caudal diameters (let us call this value $D_{cranial-caudal}$).

   b. For the coronal axis, one should choose the biggest value of antero-posterior diameters (let us call this value $D_{antero-posterior}$).

   c. For the sagittal axis, one should choose the biggest value of lateral-lateral diameters is chosen (let us call this value $D_{lateral-lateral}$).

9. We then perform the following generic operation:

$$\boxed{V_{axis} = D_{perpendicular} * \frac{S_{axis}}{n_{axis}}}$$

   a. For the sagittal axis, we have:

$$V_{sagittal} = D_{lateral-lateral} * \frac{S_{sagittal}}{n_{sagittal}}$$

   b. For the coronal axis, we have:

$$V_{coronal} = D_{antero-posterior} * \frac{S_{coronal}}{n_{coronal}}$$

   c. For the axial axis, we have: $V_{axial} = D_{cranial-caudal} * \frac{S_{axial}}{n_{axial}}$

With three volume values obtained, three methods were developed to work with them:

I. Calculate the arithmetic mean between the values (MED):

$$V_{final} = \frac{V_{sagittal} + V_{coronal} + V_{axial}}{3};$$

II. Make the weighted average between the values, given that the weights of each axis are equivalent to the number of slices obtained for such axis (POND):

$$V_{final} = \frac{V_{sagittal} * n_{sagittal} + V_{coronal} * n_{coronal} + V_{axial} * n_{axial}}{n_{sagittal} + n_{coronal} + n_{axial}};$$

III. Perform the following operation (SCA):

$$V_{final} = \frac{b * S_{sagittal} + c * S_{sagittal} + a * S_{coronal} + c * S_{coronal} + a * S_{axial} + b * S_{axial}}{2 * n_{sagittal} + 2 * n_{coronal} + 2 * n_{axial}}$$

10. We compared the values obtained in each of the proposals with the values that models accepted in the literature would obtain.

Method for obtaining the diameter for a given axis

The measurement of the diameter of an axis ($D_{cranial-caudal}$, $D_{lateral-lateral}$ or $D_{antero-posterior}$) must be carried out adopting the following steps and conditions:

1. Choose the axis that will be worked on;

2. The diameter of interest ($D_{cranial-caudal}$, $D_{latero-lateral}$ or $D_{antero-posterior}$) must be visible in at least one of the sections of the piece;

3. The diameter of interest must be parallel to one of the other axes studied;

4. The diameter measurement takes into account the extremes of each slice of each axis, which is the distance between the points in relation to the axis of interest.

This measurement of the diameter of a cut for a dimension of interest is already used in methods accepted in the literature. We simply extended the concept to all sections in the three axes available to the observer (axial, coronal and sagittal).

Deduction of the generic formula for calculating the volume of a hematoma

For a given axis, the CT provides us with 'n' slices filled by the lesion. Thus, we will have three values of 'n': $n_{sagittal}$, n_{axial} and $n_{coronal}$ (we used n_{axis} as a generic notation).

It is known that the distance between two consecutive slices is 'h'. Also, we will have three values of 'h': $h_{sagittal}$, h_{axial} and $h_{coronal}$ (we used h_{axis} as a generic notation).

Therefore, to estimate the volume of this lesion using our method, we do the following:

- o We identified the first image that shows the typical hyper-attenuation of a hematoma; this is our number 1 slice.
- o Then, for this slice number 1, we drew the contours of the lesion with the software "Polygon" tool. This gave us the value of the area of our drawing, so that the area of the lesion is equal to the highlighted area. Let us call the value of this area S1.
- o We admit that there is a very thin "straight prism" between two consecutive cuts, which base is equivalent to the contour drawn by us and which height is equal to the distance between the slices (h). Let us call it prism 1.
- o Using Cavalieri's principle, we calculate the volume of prism 1 (V1), using the formula:

$$V_1 = h * S_1 \quad (4)$$

We then repeat the procedure for slice 2, obtaining the value of S2 and V2, and so on, until the last slice (number 'n'), which eventually presents us the typical hyper-attenuation of the lesion, obtaining the value of Sn and Vn.

For the generic slice number 'z', the volume of this prism is calculated, taking into account Cavalieri's principle:

$$V_z = S_z * h. \quad (5)$$

Our solution ends when we add all the 'n' volumes obtained, obtaining the final volume value (V final):

$$V_{final} = \left(V_1 + V_2 + \ldots + V_n\right) = \sum_{z=1}^{n} V_z,\ z = 1,\ldots,n \quad (6)$$

However, there is a very interesting alternative to this method, and it is done as follows:

$$V_{\text{final}} = V_1 + V_2 + \cdots + V_n = \text{h} * S_1 + h * S_2 + \cdots + h * S_n = \text{h} * \left(\text{S}_1 + \text{S}_2 + \cdots + \text{S}_\text{n}\right) \quad (7)$$

To calculate the average distance between each slice, assuming that they are all parallel and equidistant, we must previously know the diameter of the part for a given axis (the values of $D_{cranial-caudal}$, $D_{latero-lateral}$ or $D_{antero-posterior}$, in millimeters) and the number of slices the tomography machine made for such axis (our 'n'). Thus, the ratio between these two factors should provide us with the distance between each slice 'h' (in millimeters/cut):

1) For a given axis, we must determine the diameter of the part for this particular axis, using a slice from another axis, orthogonal to the one being worked on (which can be obtained with the Ruler tool in XERO Viewer®). Like this:

- o By choosing the axial axis, we can obtain the measurements $D_{latero-lateral}$ or $D_{antero-posterior}$ to obtain $h_{latero-lateral}$ or $h_{antero-posterior}$, respectively ;
- o By choosing the coronal axis, we can obtain the measurements $D_{latero-lateral}$ or $D_{cranial-caudal}$ to obtain $h_{latero-lateral}$ or $h_{cranial-caudal}$, respectively ;
- o By choosing the sagittal axis, we can obtain the measurements $D_{crânio-caudal}$ or $D_{antero\ \ posterior}$ to obtain $h_{cranial-caudal}$ or $h_{antero-posterior}$, respectively.

2) The number of cuts, as already discussed, can be obtained by observing the first and last cuts that have the typical hyper-attenuation of bleeding (and these indices are shown by the XERO Viewer® itself).

3) The ratio previously described is made, using the generic formula:

$$h_{axis} = \frac{D_{axis}}{n_{axis}} \quad (8)$$

However, we know that:

$$V_{final_{axis}} = h_{axis} * \left(\text{S}_1 + \text{S}_2 + \ldots + \text{S}_\text{n}\right) \quad (9)$$

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Therefore, substituting II into I, we will have our final volume for an axis (V_{final}) :

$$V_{final_{axis}} = \frac{D_{axis}}{n_{axis}} * (S_1 + S_2 + \ldots + S_n) \quad (10)$$

Illustrations of the method for clarifications

As Figure 1 shows a real application of all things discussed so far, on an intraparenchymal hematoma in the axial section. In it, its contour is already circumscribed by the "Polygon" function and the area is displayed on the screen. The hematoma has a somewhat chaotic shape, making demarcating its contours a very challenging task. As for the estimation of a diameter, Figure 2 shows another example of an intraparenchymal hematoma, in which one of the diameters (the latero-lateral) is measured.

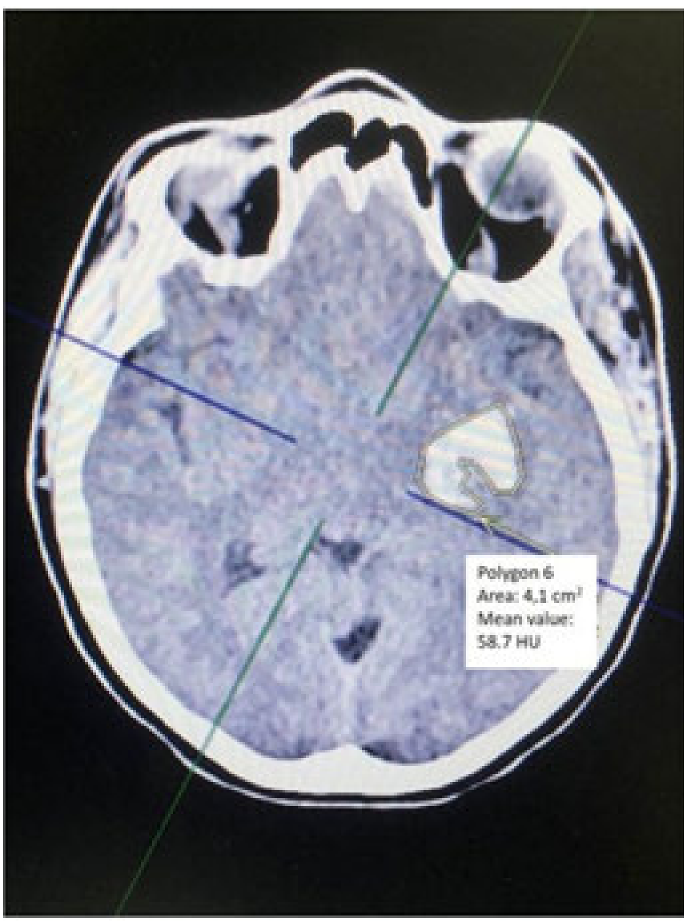

Figure 1. Demarcation of margins of the intraparenchymal hematoma using Polygon function. The software itself provides the delimited area in square centimeters. Yellow arrow highlights the 'polygon' and shows its informations (translated from Portuguese to English in the white square). Blue and green lines are auxiliary lines used by the software itself.

DISCUSSION

We proposed a mathematical model for hematoma volume estimation using three orthogonal CT axes, avoiding costly tools. Prior studies (Broderick et al.[3] suggest a correlation between pre-drainage hematoma volume and patient prognosis. Hematomas cause irreversible brain damage, requiring surgeons to gather comprehensive patient data (Peres et al.[4], Van Ornam et al.[5], Yu et al.[6], Bobeff et al.[7], Paranathala et al.[8], Kulesza et al.[9], Aromatario et al.[10], Ragaee et al.[11], Siddiq et al.[12] — age, history of the injury (whether traumatic or spontaneous), the existence of comorbidities (such as diabetes or Systemic Arterial Hypertension), whether there is a previous history of Cerebrovascular Accidents, the patient's continuous use of

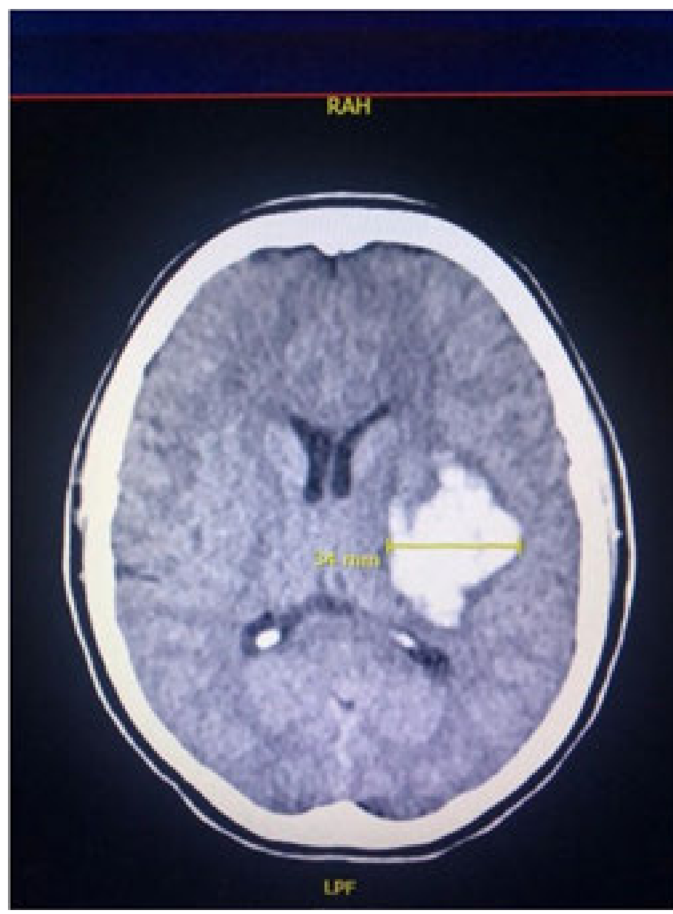

Figure 2. Yellow segment shows demarcation of one of the diameters of an intraparenchymal hematoma using 'Ruler'. The XERO Viewer software provides the measurement value in millimeters.

medications, intoxication by alcohol, tobacco or other drugs on admission, the patient's vital signs on admission, the patient's glycaemia at the time of admission, the Glasgow Coma Scale score at the time of admission or its worsening, the presence of focal deficits on examination neurological, the presence of active bleeding, the presence of signs of cerebral edema, the presence of coagulopathies, the blood ionic concentration, the presence of direct damage to the brain, the volume of the lesion, the location of the injury, the presence of skull fractures (and the types of fractures)—to inform decisions.

The team [3] notably isolated hematoma volume as a predictor, underlining the importance of precise measurement. However, direct drainage for measurement is flawed: manipulation risks re-bleeding, expansion, or leakage, distorting its true volume. Thus, imaging is preferred, particularly CT, given its availability and practicality for volumetric studies.

Additionally, we propose post-surgical application: comparing pre-drainage CT-based volume estimates with intraoperative measurements could help verify complete evacuation. Despite surgical removal potentially altering hematoma properties (expansion, shrinkage, re-bleeding), comparing estimated and actual volumes could guide final surgical decisions.

RESULTS

Tables 1 and 2 detail input data, and Table 3, volume calculations. Measurements across sagittal, coronal, and axial axes produced volume estimates using both traditional formulas (a.b.c/2 and 2/3 × a.b.c) and our three proposed methods: MED, POND, and SCA.

Formulas

[A] Literature formula (LIT):

Table 1. Data inputs part 1.

case	Sex/age (years old)	[SAG] sum area [cm 2]	[COR] sum area [cm 2]	[AXI] sum area [cm 2]	[SAG] number of cuts	[COR] number of cuts	[AXI] number of cuts
1	F/43	614.575	583.149	305.251	79	103	46
2	F/33	596.320	685.806	389.961	95	105	40
3	F/80	392.047	420.802	226.787	67	84	38
4	F/33	645.291	665.694	338.969	101	107	36
5	F/18	367.681	342.661	163.749	100	73	29
6	M/47	733.058	712.048	333.889	103	123	45
7	M/53	1264.441	1207.489	682.664	76	132	54
8	F/22	1573.155	1554.926	796.804	103	194	67
9	F/46	77.678	73.016	28.653	49	49	18
10	M/56	872.738	925.785	389.896	111	124	53
11	F/74	305.494	316.044	171.112	91	65	42
12	M/47	345.428	339.724	140.558	73	89	30
13	M/78	426.053	464.077	240.756	84	72	43
14	M/50	986.936	881.569	356.909	123	101	48
15	M/53	391.003	478.530	214.448	81	84	31
16	F/42	1422.712	1373.705	710.285	113	114	50

M = Male; F = Female; [SCA]: formula SCA; SAG: sagittal; COR: coronal; AXI: axial; 'a': dimension 'lateral-lateral'; 'b': dimension 'antero-posterior'; 'c': dimension 'cranial-caudal'; [ml]: milliliters.

Table 2. Data inputs part 2.

case	Sex/age (years old)	'a' l-l [mm]	'b' a-p [mm]	'c' c-c [mm]	[SAG] cut height [mm]	[COR] cut height [mm]	[AXI] cut height [mm]	[SAG] estimated volume [ml]	[COR] estimated volume [ml]	[AXI] estimated volume [ml]
1	F/43	**38.0**	**47.0**	**35.1**	0.481	0.456	0.763	**29.562**	**26.610**	**23.292**
2	F/33	**46.4**	**54.5**	**34.7**	0.488	0.519	0.868	**29.126**	**35.597**	**33.829**
3	F/80	**32.3**	**38.1**	**33.9**	0.482	0.454	0.892	**18.900**	**19.086**	**20.232**
4	F/33	**45.2**	**51.8**	**31.9**	0.448	0.484	0.886	**28.878**	**32.227**	**30.036**
5	F/18	**43.4**	**35.5**	**26.4**	0.434	0.486	0.910	**15.957**	**16.664**	**14.907**
6	M/47	**26.6**	**41.3**	**31.5**	0.258	0.336	0.700	**18.931**	**23.909**	**23.372**
7	M/53	**42.9**	**67.9**	**49.1**	0.564	0.514	0.909	**71.374**	**62.113**	**62.072**
8	F/22	**34.1**	**72.9**	**39.1**	0.331	0.376	0.584	**52.082**	**58.430**	**46.500**
9	F/46	**18.6**	**11.7**	**14.1**	0.380	0.239	0.783	**2.949**	**1.743**	**2.244**
10	M/56	**36.9**	**35.2**	**39.4**	0.332	0.284	0.743	**29.013**	**26.280**	**28.985**
11	F/74	**24.6**	**20.4**	**33.7**	0.270	0.314	0.802	**8.258**	**9.919**	**13.730**
12	M/47	**28.0**	**35.0**	**28.8**	0.384	0.393	0.960	**13.249**	**13.360**	**13.494**
13	M/78	**36.9**	**29.2**	**39.5**	0.439	0.406	0.919	**18.716**	**18.821**	**22.116**
14	M/50	**37.5**	**37.2**	**44.3**	0.305	0.368	0.923	**30.090**	**32.470**	**32.940**
15	M/53	**47.3**	**37.8**	**29.6**	0.584	0.450	0.955	**22.833**	**21.534**	**20.476**
16	F/42	**48.0**	**55.2**	**43.8**	0.425	0.484	0.876	**60.434**	**66.516**	**62.221**

M = Male; F = Female; [SCA]: formula SCA; SAG: sagittal; COR: coronal; AXI: axial; 'a': dimension 'lateral-lateral'; 'b': dimension 'antero-posterior'; 'c': dimension 'cranial-caudal'; [ml]: milliliters.

'a'— dimension 'l-l' (latero-lateral diameter)

'b' — dimension 'a-p' (antero-posterior diameter)

'c'— dimension 'c-c' (cranial-caudal diameter)

[LIT] $V = \frac{a*b*c}{2}$

[LIT] $V = \frac{2*a*b*c}{3}$

[B] Denominations of variables to the proposal of the formulas:

[SAG] number of slices — $n_{sagittal}$

[COR] number of slices — $n_{coronal}$

[AXI] number of slices — n_{axial}

[SAG] cut height [mm] — height of a slice on the sagittal axis — $h_{sagittal} = \frac{a}{n_{sagittal}}$

[COR] cut height [mm] — height of a slice on the coronal axis — $h_{coronal} = \frac{a}{n_{coronal}}$

[AXI] cut height [mm] — height of a slice on the axial axis — $h_{axial} = \frac{a}{n_{axial}}$

Table 3. Volume calculations.

case	Sex/age (years old)	[LIT] a.b.c /2 [ml]	[LIT] 2/3 x a.b.c [ml]	[MED] est volume [ml]	Rel Volume 1	Diff Volume 1	[POND] est volume [ml]	Rel Vol 2	Diff Vol 2	[SCA] est volume [ml]	Rel Volume 3	Diff Volume 3
1	F/43	31.344	41.792	26.488	18.33%	4.856	26.963	16.25%	4.381	26.244	19.43%	5.100
2	F/33	43.875	58.500	32.850	33.56%	11.024	32.741	34.01%	11.134	30.866	42.14%	13.008
3	F/80	20.859	27.812	19.406	7.49%	1.453	19.251	8.36%	1.609	19.061	9.43%	1.798
4	F/33	37.345	49.793	30.381	22.92%	6.964	30.518	22.37%	6.827	28.323	31.85%	9.022
5	F/18	20.337	27.116	15.843	28.37%	4.495	16.062	26.62%	4.275	14.752	37.86%	5.586
6	M/47	17.303	23.070	22.071	-21.60%	-4.768	21.928	-21.09%	-4.625	21.662	-20.12%	-4.359
7	M/53	71.512	95.349	65.186	9.70%	6.326	64.791	10.37%	6.721	63.868	11.97%	7.644
8	F/22	48.599	64.799	52.337	-7.14%	-3.738	54.438	-10.73%	-5.839	51.548	-5.72%	-2.949
9	F/46	1.534	2.046	2.312	-33.65%	-0.778	2.330	-34.16%	-0.796	2.248	-31.75%	-0.714
10	M/56	25.588	34.117	28.093	-8.92%	-2.505	27.831	-8.06%	-2.243	28.355	-9.76%	-2.767
11	F/74	8.456	11.275	10.636	-20.49%	-2.180	9.964	-15.14%	-1.508	10.771	-21.49%	-2.315
12	M/47	14.112	18.816	13.368	5.57%	0.744	13.339	5.80%	0.773	13.070	7.97%	1.042
13	M/78	21.280	28.374	19.884	7.02%	1.396	19.489	9.19%	1.792	20.261	5.03%	1.019
14	M/50	30.899	41.199	31.833	-2.93%	-0.934	31.476	-1.83%	-0.577	32.943	-6.20%	-2.044
15	M/53	26.462	35.282	21.614	22.43%	4.847	21.903	20.81%	4.558	20.776	27.37%	5.685
16	F/42	58.026	77.368	63.057	-7.98%	-5.031	63.260	-8.27%	-5.233	61.618	-5.83%	-3.591

Rel: Relative; Diff: Differential; M: Male; F: Female [LIT]: literature; [MED]: formula MED; [POND]: formula POND; [SCA]: formula SCA; SAG: sagittal; COR: coronal; AXI: axial; 'a': dimension 'lateral-lateral'; 'b': dimension 'antero-posterior'; 'c': dimension 'cranial-caudal'; [ml]: milliliters.

[SAG] area of each sagittal slice — $area_{sagittal\ slice}$

[COR] area of each coronal slice — $area_{corte\ coronal}$

[AXI] area of each axial slice — $area_{corte\ axial}$

[SAG] sum area [cm2] — sum of areas in the sagittal axis — $S_{sagittal} = \sum area_{sagittal\ slice}$

[COR] sum area [cm2] — sum of areas in the coronal axis — $S_{coronal} = \sum area_{coronal\ slice}$

[AXI] soma área [cm2] — sim of areas in the axial axis — $S_{axial} = \sum area_{axial\ slice}$

[SAG] vol est [ml] — sagittal estimated volume — $V_{sagittal} = h_{sagittal} * S_{sagittal}$

[COR] vol est [ml] — coronal estimated volume — $V_{coronal} = h_{coronal} * S_{coronal}$

[AXI] vol est [ml] — axial estimated volume — $V_{axial} = h_{axial} * S_{axial}$

[C] 'MED' formula:

[MED] vol est [ml] — estimated volume of hematoma — simple aritmetic mean

$$V_{final} = \frac{V_{sagittal} + V_{coronal} + V_{axial}}{3} \qquad (11)$$

[D] 'POND' formula:

[POND] vol est [ml] — estimated volume of hematoma — ponderated mean

$$V_{final} = \frac{V_{sagital} * n_{sagital} + V_{coronal} * n_{coronal} + V_{axial} * n_{axial}}{n_{sagital} + n_{coronal} + n_{axial}} \qquad (12)$$

[E] 'SCA' formula:

[SCA] vol est [ml] — estimated volume of hematoma — moderated mean

$$V_{final} = \frac{b * S_{sagittal} + c * S_{sagittal} + a * S_{coronal} + c * S_{coronal} + a * S_{axial} + b * S_{axial}}{2 * n_{sagittal} + 2 * n_{coronal} + 2 * n_{axial}} \qquad (13)$$

STATISTICAL ANALYSIS

Given the sample size (n=16) and variability, non-parametric tests were used. Only the a.b.c/2 formula was adopted for comparison, as the 2/3 × a.b.c formula showed greater overestimation between 8.53% and 29.3% by this work [1].

Tables 4 and 5 show the application of the Wilcoxon Signed-Rank Test to check possible differences between the Literature values and the proposed formulas, as well as between the proposed methods.

Findings: Literature formula I presents a statistically non-significant difference when compared with the three formulas proposed in this study; MED and POND showed no significant difference (p=0.679); there is a statistically significant difference between MED and SCA (p=0.026); There is a near-significant difference between POND and SCA (p=0.063).

Figures 3, 4 and 5 show representations and estimations of the regression equations between 'LIT' and 'MED', 'POND' and 'SCA'.

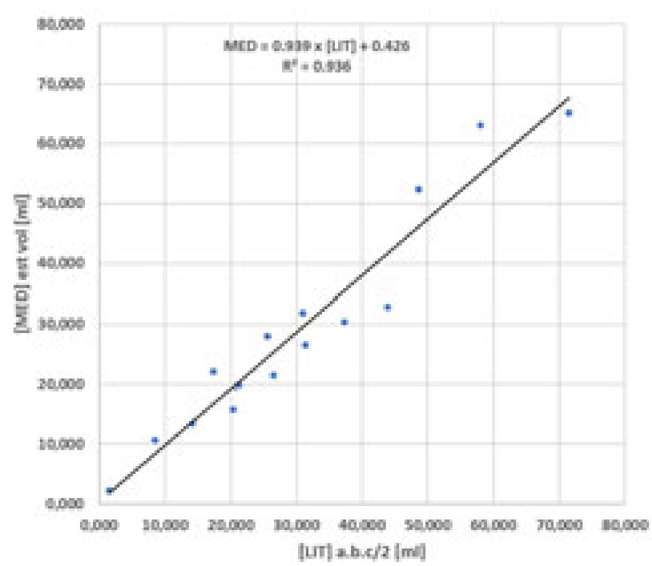

Figure 3. Regression analyses visualizing relationships between LIT and MED. [LIT]: literature; [MED]: formula MED; est vol – estimated volume; [ml]: milliliters.

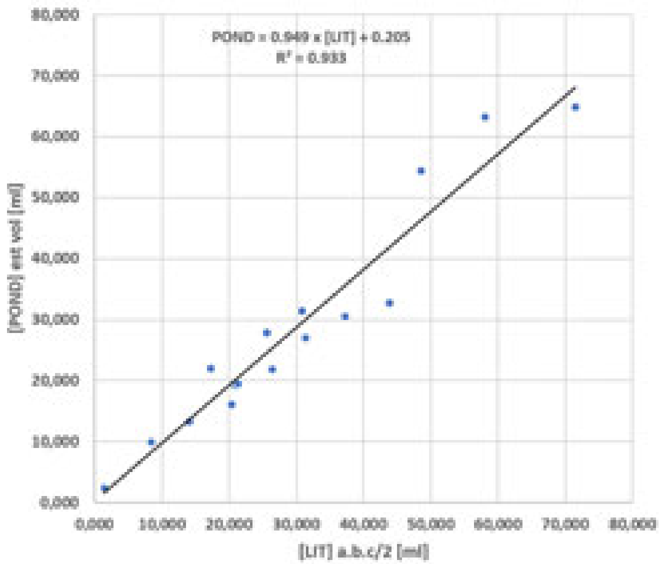

Figure 4. Regression analyses visualizing relationships between LIT and POND. [LIT]: literature; [POND]: formula POND; est vol – estimated volume; [ml]: milliliters.

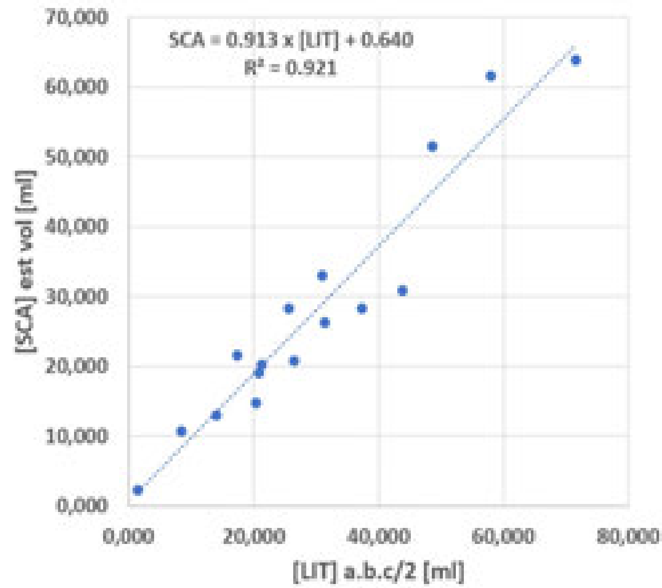

Figure 5. Regression analyses visualizing relationships between LIT and SCA. [LIT]: literature; [SCA]: formula SCA; est vol – estimated volume; [ml]: milliliters

Table 4. Statistical testing between literature formula and proposed methods.

Variable Pair	n	Mean	Standard deviation	Minimum	Maximum	25th percentile	50th percentile (Median)	75th percentile	Sig. (p)
[LIT] a.b.c/2 [ml]	16	29.846	18.396	1.534	71.512	18.061	26.025	42.242	0.326
[MED] est vol [ml]	16	28.460	17.862	2.312	65.186	16.733	24.279	32.596	
[LIT] a.b.c /2 [ml]	16	29.846	18.396	1.534	71.512	18.061	26.025	42.242	0.379
[POND] est vol [ml]	16	28.518	18.071	2.330	64.791	16.859	24.446	32.424	
[LIT] a.b.c /2 [ml]	16	29.846	18.396	1.534	71.512	18.061	26.025	42.242	0.255
[SCA] est vol [ml]	16	27.898	17.507	2.248	63.868	15.829	23.953	32.424	

[LIT]: literature; [MED]: formula MED; [POND]: formula POND; [SCA]: formula SCA; vol est – estimated volume; sig. – statistical significance; [ml]: milliliters.

Table 5. Statistical testing in-between our proposed methods.

Variable Pair	n	Mean	Standard deviation	Minimum	Maximum	25th percentile	50th percentile (Median)	75th percentile	Sig. (p)
[MED] est vol [ml]	16	28.460	17.862	2.312	65.186	16.733	24.279	32.596	0.679
[POND] est vol [ml]	16	28.518	18.071	2.330	64.791	16.859	24.446	32.424	
[MED] est vol [ml]	16	28.460	17.862	2.312	65.186	16.733	24.279	32.596	0.026
[SCA] est vol [ml]	16	27.898	17.507	2.248	63.868	15.829	23.953	32.424	
[POND] est vol [ml]	16	28.518	18.071	2.330	64.791	16.859	24.446	32.424	0.063
[SCA] est vol [ml]	16	27.898	17.507	2.248	63.868	15.829	23.953	32.424	

[MED]: formula MED; [POND]: formula POND; [SCA]: formula SCA; vol est – estimated volume; sig. – statistical significance; [ml]: milliliters.

CONCLUSIONS

Our new method estimates hematoma volume using mathematical and integral principles, enhancing precision through comprehensive CT slice analysis. The a.b.c/2 formula remains an effective, near-gold standard, but our method further reduces overestimation by 6.5% on average, and by 8.0% at the median, offering an alternative when automated volumetric tools are unavailable.

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CRediT

Luiz Fernando Cannoni: Collection of data, idealization of the project. Henrique Zuleta de Barros Couto: Idealization of the project. Euro de Barros Couto Junior: Statistics work. José Carlos Esteves Veiga: Idealization of the Project.

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Using Machine Learning to Predict Outcomes After Traumatic Brain Injury

Utilizando Aprendizado de Máquina para Prever Desfechos Após Trauma Cranioencefálico

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ABSTRACT

Introduction: *Traumatic Brain Injury (TBI) carries high morbidity and mortality. Traditional prognostic methods have limitations, and machine learning (ML) may improve predictive accuracy.* **Objective:** *To evaluate ML models for predicting in-hospital mortality in TBI patients.* **Methods:** *A retrospective study included 745 patients treated at HC-UFTM (2007–2017), with 169 deaths (22.7%). Six ML models were tested: Neural Network, Random Forest, XGBoost, Gradient Boosting, Logistic Regression, and Support Vector Machine (SVM). Performance metrics included accuracy, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the ROC curve (AUC), using 10-fold stratified cross-validation.* **Results:** *Gradient Boosting achieved the highest accuracy (0.820 ± 0.049), specificity (0.846 ± 0.091), and PPV (0.629 ± 0.147). Logistic Regression had the best sensitivity (0.805 ± 0.057) and NPV (0.931 ± 0.018). SVM achieved the highest AUC (0.863 ± 0.021), indicating superior discrimination. The Glasgow Coma Scale at admission was the strongest predictor, followed by hospital stay, age, creatinine, and leukocyte count.* **Conclusion:** *ML models demonstrated strong predictive performance for in-hospital mortality in TBI. Gradient Boosting excelled in accuracy and specificity, Logistic Regression in sensitivity, and SVM in AUC. Incorporating temporal data and biomarkers may further enhance predictions.*

Keywords: *Artificial intelligence; Brain injuries, traumatic; Hospital mortality; Logistic models; Machine learning; Random forest; Support vector machine*

RESUMO

Introdução: *O traumatismo cranioencefálico (TCE) apresenta alta morbimortalidade. Métodos prognósticos tradicionais têm limitações, e o aprendizado de máquina (ML) pode melhorar a acurácia preditiva. Objetivo: Avaliar modelos de ML na predição de mortalidade hospitalar em pacientes com TCE.* **Métodos:** *Estudo retrospectivo com 745 pacientes do HC-UFTM (2007–2017), dos quais 169 (22,7%) morreram. Foram testados seis modelos: Rede Neural, Random Forest, XGBoost, Gradient Boosting, Regressão Logística e Máquina de vetores de suporte (SVM). As métricas incluíram acurácia, sensibilidade, especificidade, valor preditivo positivo (VPP), valor preditivo negativo (VPN) e área sob a curva ROC (AUC), com validação cruzada estratificada (10 dobras).* **Resultados:** *O Gradient Boosting teve maior acurácia (0,820 ± 0,049), especificidade (0,846 ± 0,091) e VPP (0,629 ± 0,147). A Regressão Logística apresentou maior sensibilidade (0,805 ± 0,057) e VPN (0,931 ± 0,018). O SVM alcançou a maior AUC (0,863 ± 0,021), indicando melhor discriminação. A escala de coma de Glasgow na admissão foi o preditor mais relevante, seguida pelo tempo de internação, idade, creatinina e leucócitos.* **Conclusão:** *Os modelos de ML demonstraram bom desempenho na predição da mortalidade hospitalar no TCE. Gradient Boosting destacou-se em acurácia e especificidade; Regressão Logística, em sensibilidade; e SVM, na AUC.*

Palavras-Chave: *Inteligência artificial; Lesões cerebrais traumáticas; Mortalidade hospitalar; Modelos logísticos; Machine learning; Random forest; Máquina de vetores de suporte*

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INTRODUCTION

Traumatic Brain Injury (TBI) is defined as an alteration in brain function or other evidence of brain pathology caused by an external force. This injury can result from a violent blow or jolt to the head or body, or from an object penetrating the brain tissue, such as a bullet or shattered piece of skull. The severity of TBI ranges from mild, with temporary effects on brain cells, to severe cases involving bruising, torn tissues, bleeding, and other physical damage to the brain, potentially leading to long-term complications or death[1].

TBI is a significant public health concern both globally and in Brazil. Worldwide, the incidence of TBI is estimated at approximately 106 cases per 100,000 individuals annually, with higher rates observed in regions such as Latin America and Sub-Saharan Africa, where estimates range from 150 to 170 cases per 100,000 inhabitants[2].

In Brazil, data from 2008 to 2012 indicate an average of 125,000 hospital admissions due to TBI each year, corresponding to an incidence of 65.7 admissions per 100,000 inhabitants annually. The hospital mortality rate during this period was 5.1 per 100,000 per year, with a case fatality rate of 7.7%[3]. The demographic most affected comprises males under 60 years of age, with mild TBI being the most prevalent form. Falls are identified as the leading cause of TBI in Brazil, followed by motor vehicle accidents[4].

Conventional methods for TBI outcome prediction have included clinical scoring systems, neuroimaging modalities, and electrophysiological assessments. While these techniques offer valuable information, their predictive capabilities are often constrained by variability in patient responses and the complex nature of brain injuries. The integration of machine learning algorithms has been investigated to enhance predictive accuracy. Studies have demonstrated that models utilizing clinical data, imaging findings, and physiological parameters can improve the prediction of mortality and functional outcomes in TBI patients[5].

AI has been increasingly applied in various aspects of TBI management. Machine learning models have shown potential in prognostic estimation, aiding clinicians in making informed decisions regarding patient care. Additionally, AI-driven tools have been developed to analyze complex datasets, facilitating the identification of patterns that may not be discernible through traditional analysis. Despite these advancements, challenges remain in ensuring the generalizability and interpretability of AI models in diverse clinical settings[6].

The primary objective of this work is to evaluate the efficacy of machine learning models in predicting outcomes for patients with traumatic brain injury. By analyzing a combination of clinical and neuroimaging data, this study seeks to develop predictive models that can accurately forecast patient trajectories. The ultimate goal is to enhance clinical decision-making processes, tailor interventions more effectively, and improve overall patient outcomes in TBI care.

METHODS

In this study, a quantitative, retrospective, and documentary analysis of medical records for patients with TBI was conducted. The research was carried out at the Clinics Hospital of the Federal University of Triângulo Mineiro (HC-UFTM), located in Uberaba, Brazil, covering the period from January 2007 to December 2017[7]. The features of interest included the following:

- Demographic Data: Sex, Age;
- Clinical Measurements: Duration of Hospital Stay, Creatinine Levels, Leukocyte Count, Glasgow Coma Scale at Admission;
- Trauma Characteristics: Cause of Trauma, Specific Cause, Severity, CT Findings (Contusion, EDH, SDH, Hemoventricle, Lad, SAh, Brain Swelling, Pneumocephalus, Fracture, Fracture Location, Fracture Type, Altered CT), Neurosurgery Requirement, Associated Trauma, Number of Traumas, and Death Outcome.

Six classification models were employed: Neural Network (Multi-Layer Perceptron), Random Forest, XGBoost, Gradient Boosting, Logistic Regression, and Support Vector Machine (SVM). For each model, a randomized search for hyperparameters was conducted using RandomizedSearchCV to optimize model performance. The search was performed with 30 iterations and stratified cross-validation with 10 folds, ensuring a robust evaluation of hyperparameters. The metric used for optimization was the area under the ROC curve (AUC).

Model evaluation was performed using stratified cross-validation with 10 folds. For each model, performance metrics such as accuracy, sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and AUC were calculated. Additionally, Youden's J statistic was used to determine the optimal cutoff point on the ROC curve, maximizing the difference between sensitivity and specificity.

Feature importance was calculated using the permutation importance technique, which measures the drop in model performance when feature values are randomly permuted. This approach is robust and model-agnostic, providing a reliable assessment of each feature's contribution to the model's predictions.

All methods were implemented in Python, utilizing libraries such as scikit-learn, pandas, numpy, and matplotlib[8].

This research was approved based on the substantiated opinion of the Ethics and Research Committee on the Brazil Platform (CAAE: 79595924.0.0000.8667). Once it deals with the collection of medical records, the Informed Consent Form was waived.

RESULTS

After pre-selection, the original dataset of 1347 patients was reduced to 745. Among them, 169 patients died (22.7%), while 576 did not (77.3%). The training results for in-hospital patient deaths reveal various trends across different resampling methods. All results for each model are schematized in Table 1. Figure 1 compares ROC curves and Figure 2 compares the five most important features across the models.

DISCUSSION

The analysis of feature importance across different machine learning models provides valuable insights into the predictors of patient outcomes in neurotrauma. Our results indicate that Glasgow Coma Scale (GCS) is the most influential predictor across all models, followed by Length of Stay, Age, Creatinine, and Leukocytes. These findings align with previous literature emphasizing the role of neurological status at admission as a primary determinant of patient prognosis[9,10].

The dominance of Glasgow Admission Score in all models is consistent with existing studies on TBI prognosis[9]. Several large-scale studies, including those using the IMPACT and CRASH datasets, have identified GCS as the most significant predictor of mortality and long-term disability[10]. In our results, models like XGBoost and Support Vector Machine assigned the highest importance to this feature, supporting its well-established predictive value.

Length of Stay has emerged as an important factor, particularly in models such as Random Forest and XGBoost. Prior

Table 1. Performance Metrics of Machine Learning Models.

	Neural Network	Random Forest	XGBoost	Gradient Boosting	Logistic Regression	Support Vector Machine
Accuracy	0.781 ± 0.051	0.803 ± 0.059	0.799 ± 0.040	0.820 ± 0.049	0.774 ± 0.056	0.813 ± 0.022
Sensitivity	0.781 ± 0.107	0.776 ± 0.112	0.788 ± 0.067	0.734 ± 0.099	0.805 ± 0.057	0.781 ± 0.039
Specificity	0.781 ± 0.093	0.811 ± 0.109	0.802 ± 0.069	0.846 ± 0.091	0.766 ± 0.075	0.823 ± 0.035
PPV	0.536 ± 0.094	0.579 ± 0.101	0.557 ± 0.095	0.629 ± 0.147	0.516 ± 0.095	0.568 ± 0.046
NPV	0.927 ± 0.027	0.929 ± 0.029	0.929 ± 0.017	0.918 ± 0.021	0.931 ± 0.018	0.928 ± 0.011
AUC	0.838 ± 0.017	0.861 ± 0.014	0.855 ± 0.012	0.854 ± 0.011	0.836 ± 0.034	0.863 ± 0.021

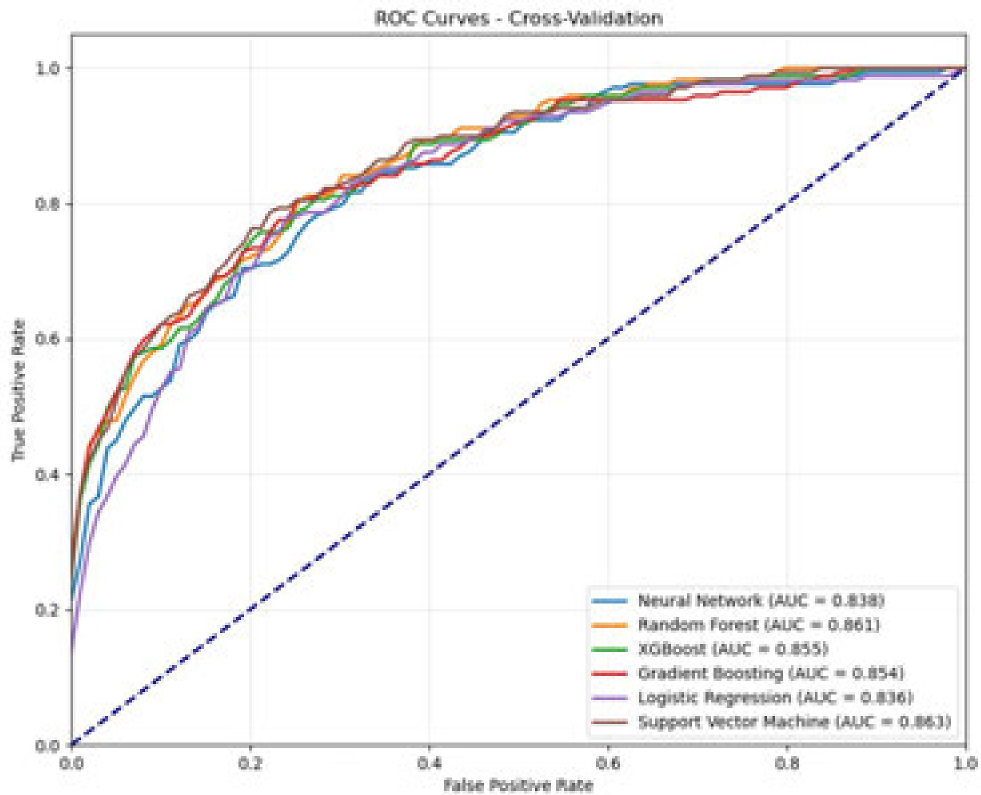

Figure 1. ROC-AUC curves.

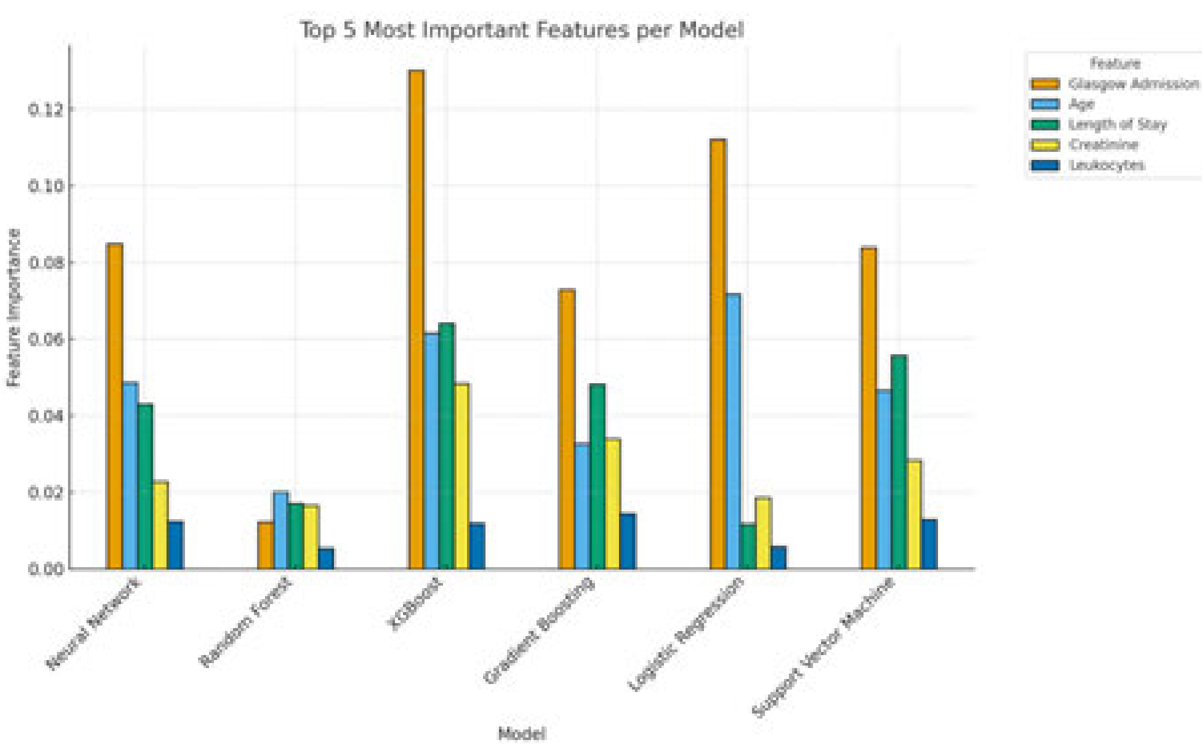

Figure 2. Top five most important features per model.

studies have linked prolonged hospitalization to increased post-discharge complications and mortality. Additionally, age remains a strong predictor in our models, a finding corroborated by several epidemiological studies showing that older patients exhibit worse functional outcomes and higher mortality following neurotrauma[11].

Interestingly, Creatinine appears as a moderately important feature in several models, notably Gradient Boosting and Logistic Regression. While renal function is not traditionally considered a primary predictor of neurotrauma outcomes, emerging studies suggest a link between acute kidney injury (AKI) and poor neurological prognosis[12-14]. Similarly, Leukocytes have been associated with systemic inflammatory responses following traumatic injury, which could influence secondary brain injury mechanisms[15].

Among the evaluated models, Gradient Boosting (Accuracy: 0.820 ± 0.049) and Support Vector Machine (Accuracy: 0.813 ± 0.022) achieved the highest predictive performance. The high feature importance assigned to Glasgow Admission Score and Length of Stay in these models suggests that these features are particularly crucial for high-accuracy predictions.

On the other hand, Random Forest (Accuracy: 0.803 ± 0.059) and XGBoost (Accuracy: 0.799 ± 0.040) displayed similar importance distributions, reinforcing the reliability of tree-based models in identifying key clinical predictors. Notably, Logistic Regression (Accuracy: 0.774 ± 0.056) assigned comparatively higher importance to Age and Creatinine, highlighting its sensitivity to linear relationships in the data.

In our study, we calculated AUC values for each model, with the highest being 0.863 (Support Vector Machine), followed by Random Forest (0.861), XGBoost (0.855), and Gradient Boosting (0.854). These values indicate that our models perform comparably to those reported in the literature. Neural Networks (AUC: 0.838) and Logistic Regression (AUC: 0.836) also demonstrated solid performance, reinforcing the robustness of our approach.

Our machine learning model for predicting in-hospital outcomes in TBI patients demonstrates competitive performance compared to recent studies. Utilizing Gradient Boosting, our model achieved an accuracy of 82.0% and an AUC of 0.854. In comparison, Matsuo et al.[16] reported an AUC of 0.901 using XGBoost, indicating a marginally higher predictive performance. Similarly, Song et al.[17] obtained an AUC of 0.940 with Gradient Boosting for mortality prediction, suggesting further potential for improvement, particularly in capturing severe cases. Additionally, Abujaber et al.[18] demonstrated a Support Vector Machine (SVM) model with 95.6% accuracy and an AUC of 0.96, significantly outperforming our SVM model (81.3% accuracy, AUC 0.863), likely due to the inclusion of additional clinical and imaging data.

These findings align with broader trends in the literature, where ensemble methods such as XGBoost and Gradient Boosting consistently outperform traditional logistic regression. Nevertheless, our results suggest that incorporating a broader range of clinical features could further enhance predictive performance, bridging the gap between our model and state-of-the-art approaches in TBI outcome prediction.

Variations in model performance can be attributed to differences in dataset size, population characteristics, and clinical outcomes considered. Additionally, feature selection and validation methodologies significantly impact predictive performance, therefore it is not possible to perform a direct comparison.

CONCLUSION

The machine learning models evaluated in this study demonstrated good predictive capability for in-hospital mortality in patients with traumatic brain injury. Support Vector Machine and Gradient Boosting achieved the best performance, reinforcing the applicability of these approaches in clinical settings. The Glasgow Coma Scale at admission consistently emerged as the most relevant predictor, highlighting its importance in risk stratification. Additionally, hospital length of stay, age, creatinine levels, and leukocyte count were identified as complementary factors in outcome prediction. Although our results align with previous findings in the literature, challenges such as model interpretability and the need for external validation must be considered. Future studies should explore the incorporation of temporal data and additional biomarkers to enhance model accuracy and facilitate its implementation in clinical practice.

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Epidemiological Profile and Immunohistochemical Analysis of Giant Pituitary Adenomas Treated at the Cristo Redentor Hospital

Perfil Epidemiológico e Análise Imuno-histoquímica dos Adenomas Pituitários Gigantes Tratados no Hospital Cristo Redentor

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ABSTRACT

Introduction: *Evaluate the epidemiological, radiological, and immunohistochemical profile and surgical outcomes of giant pituitary adenomas treated at the Cristo Redentor hospital.* **Methods:** *A retrospective cohort study was conducted by reviewing medical records from August 2011 to December 2022. Patients with giant pituitary adenomas operated on at the Cristo Redentor hospital during the analyzed period were included in the analysis. The primary objective was to analyze the epidemiological profile of the population. The secondary objectives were immunohistochemical analysis, radiological characteristics, and surgical results.* **Results:** *Eighteen patients were selected. The average lesion size was 47 mm. All presented visual symptoms and some hormone secretion disorder. Complete resection was possible in 16%, and 67% obtained visual improvement. Multiple surgical approaches were required in 44% of patients. No statistical associations were observed between immunohistochemical analysis and surgical outcomes, degree of invasion of adjacent structures, or multiple approaches.* **Conclusion::** *This study highlights the limited comparability between series due to heterogeneous definitions of giant adenomas and resection criteria. The high rate of invasive tumors and complex growth patterns often required combined surgical approaches. Radiotherapy played a key role in adjuvant treatment when surgical control was insufficient. The results are similar to those found in the literature and reflect the complexity of treating this pathology.*

Keywords: *Adenoma; Immunohistochemistry; Pituitary neoplasms*

RESUMO

Introdução: *Avaliar o perfil epidemiológico, radiológico, imuno-histoquímico e os desfechos cirúrgicos dos adenomas gigantes de hipófise tratados no Hospital Cristo Redentor.* **Métodos:** *Estudo de coorte retrospectivo realizado por meio da revisão de prontuários entre agosto de 2011 e dezembro de 2022. Foram incluídos na análise pacientes com adenomas gigantes de hipófise operados no Hospital Cristo Redentor durante o período analisado. O objetivo principal foi analisar o perfil epidemiológico da população. Os objetivos secundários foram a análise imuno-histoquímica, as características radiológicas e os resultados cirúrgicos.* **Resultados:** *Dezoito pacientes foram selecionados. O tamanho médio das lesões foi de 47 mm. Todos apresentaram sintomas visuais e algum distúrbio de secreção hormonal. A ressecção completa foi possível em 16% dos casos, e 67% apresentaram melhora visual. Abordagens cirúrgicas múltiplas foram necessárias em 44% dos pacientes. Não foram observadas associações estatísticas entre a análise imuno-histoquímica e os desfechos cirúrgicos, grau de invasão de estruturas adjacentes ou necessidade de múltiplas abordagens.* **Conclusão:** *O estudo evidencia a dificuldade de comparação entre as séries da literatura, dada a heterogeneidade nos critérios para definição de adenomas gigantes e de ressecção completa. A alta taxa de tumores invasivos e os padrões complexos de crescimento exigiram, com frequência, abordagens cirúrgicas combinadas. A radioterapia teve papel importante como tratamento adjuvante nos casos de controle cirúrgico insuficiente. Os resultados são semelhantes aos encontrados na literatura e refletem a complexidade do tratamento dessa patologia.*

Palavras-Chave: *Adenoma; Imuno-histoquímica; Neoplasias hipofisárias*

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INTRODUCTION

Pituitary adenomas are histologically benign lesions and represent the third most common intracranial neoplasm, accounting for approximately 10-25% of these tumors, with a prevalence of 16.7%[1]. Based on size classification, microadenomas are lesions <10 mm, while macroadenomas are lesions >10 mm. Large adenomas measure between 30 and 40 mm, whereas giant adenomas are >40 mm. The latter account for 6–10% of cases and are more prevalent in men[2].

Clinically, giant tumors present with compressive symptoms, such as visual impairment, headache, hydrocephalus, epilepsy, and symptoms due to compression of the cavernous sinus, as well as hormonal dysfunctions. These include hypogonadism (87%), hypothyroidism (55%), growth hormone deficiency (28%), adrenal insufficiency (17%), and panhypopituitarism (17-33%), and hormonal hypersecretion[2].

From a hormonal secretion perspective, adenomas are classified as functioning, when they cause a clinical syndrome due to hormonal hypersecretion, and non-functioning, when they do not produce hormones, or their secretion does not result in clinical manifestations. Approximately 70% of giant lesions are non-functioning, followed by prolactinomas (20%) and prolactin- and GH-secreting lesions (10%)[3].

Except for prolactinomas, treatment of macroadenomas and giant adenomas is usually surgical. The surgical access routes were transsphenoidal (using a microscope) and transcranial. However, since the 90s, with the improvement of the endoscopic technique, most reference centers began to use the transsphenoidal route associated with endoscopy as the first choice for treating pituitary adenomas, leaving the transcranial route as a complementary therapy for the remaining lesions and those inaccessible by the endoscopic route[3].

Although giant tumors do not metastasize, up to 35% are locally invasive, with the degree of local aggressiveness correlating with tumor size. Its treatment is associated with high complications rates, the need for multiple surgeries, combined surgical access routes, incomplete resection, pituitary dysfunction, and the need for complementary oncological treatments (radiotherapy and chemotherapy)[4].

In addition, some immunohistochemical markers, such as the oncogene PPTG and the nuclear antigen Ki-67, showed a relationship with the degree of invasion of adjacent structures and a tendency for tumor recurrence associated with treatment complications[5,6].

In this study, we aim to characterize the clinical and epidemiological profile of patients presenting giant adenomas and the imaging characteristics of these lesions, the treatment scheme instituted in our institution, complications related to the disease and its treatment, and immunohistochemical analysis of the tumors.

METHODS

This retrospective cohort study analyzes the electronic medical records of patients diagnosed with giant pituitary adenoma treated at the Cristo Redentor Hospital from August 2011 to December 2022.

Patients over 18 years of age, with an anatomopathological and immunohistochemical diagnosis of pituitary adenoma, with magnetic resonance imaging (MRI) showing a lesion >40 mm in at least one of its axes, and who were treated surgically were selected.

Patients with diagnoses other than pituitary adenoma and those who did not obtain follow-up in our hospital were excluded. Eighteen patients were initially selected.

The following variables were evaluated: gender, age, visual symptoms, neurological symptoms, clinical hormonal syndrome lesion size on MRI examination, degree of invasion of adjacent structures through the Knosp and Hardy scale[5,7]. We classify the shape of the tumors into 3 types: round, dumbbell and multilobular. Tumor extension to the lateral ventricles, third ventricle, temporal lobe and frontal lobe was also evaluated accordingly to Rahimli et al., 2021[8].

The study's primary objective was to describe the epidemiological profile of the studied population. The secondary objectives were the radiological evaluation, immunohistochemistry, and description of the methods and results of surgical treatments in our service.

Surgical technique
The surgical technique transsphenoidal endoscopy, binostril, with the otorhinolaryngologist team, was often used as the first choice.

The otolaryngologist team performed the nasal and sphenoid phases, and the neurosurgeon performed the sellar phase. An abdominal fat graft associated with the nasoseptal flap (previously prepared by the o otorhinolaryngology team) was used in cases where an intraoperative cerebrospinal leak was observed. In these cases, biological glue (fibrin) was also used at the final stage of the procedure associated with the insertion of an external lumbar drainage for three days. No sellar extended endoscopic accesses were performed in the present series. Transcranial surgical approaches were also performed in some cases using the subfrontal and pterional approaches and, in one patient, the transcallosal route.

Postoperative evaluation
Patients were evaluated concerning number and routes of surgical approach, resection rate (total and partial), ophthalmic complaints, need for complementary therapies to surgery, immunohistochemical analysis and postoperative complications. The study was submitted and approved by the Ethics and Research Committee of the Nossa Senhora da Conceição Hospital (HNSC). SPSS software was used for statistical analysis, and Fisher's exact test was used for correlation analysis between variables.

RESULTS

During the analyzed period, 18 patients with giant pituitary adenomas who met the study's inclusion criteria were found. Of these, 11 (61%) were male, with a median age at diagnosis of 54 years. All patients (100%) presented with visual symptoms, which were bilateral in 16 cases (88%). Additionally, 11 patients (61%) exhibited other neurological symptoms, with headaches being the most common (22%), followed by convulsive crisis and cranial nerve paresis. Regarding hormonal changes, all patients (100%) had a deficiency in at least one pituitary hormone, with central hypothyroidism being the most prevalent clinical syndrome (83%). However, 17 cases (94%) were non-functioning adenomas, with only one functioning adenoma (prolactin secretor) (Table 1). Regarding the size, the mean size of the lesions in their largest axis was 47 mm. From the perspective of invasion of adjacent structures (Knosp >2 or Hardy >2), 17 (94%) of the patients presented radiological evidence of involvement of some surrounding structure. Specifically, 8 patients (44%) showed possible cavernous sinus invasion (Knosp 2), 5 patients (28%) demonstrated probable invasion (Knosp 3), and 5 patients (28%) had definitive cavernous sinus invasion as indicated by preoperative MRI (Knosp 4) (Figure 1). In terms of the Hardy classification, 2 patients (11%) were classified as Hardy 2, characterized by a tumor ≥ 10 mm with an enlarged sella turcica but an intact floor. Hardy 3, marked by local erosion or destruction of the floor, was observed in 6 patients (33%). Hardy 4, indicating diffuse erosion or destruction of the entire sella floor, was found in 10 patients (56%) (Figure 2). Related to the shape of the tumors, 3 tumors were round (17%), 3 were dumbbell-shaped (17%), and 12 were multilobular (67%) (Figure 3). Invasion into the third ventricle was identified

Table 1. Clinical and demographic characteristics of patients with giant pituitary adenomas.

Characteristics	N	%
Patients	18	100%
Gender		
Men	11	61%
Women	7	39%
Average age	54y	
Average tumor size	47mm	
Symptoms		
Visual symptoms	18	100%
Neurological symptoms	11	61%
Cephalea	4	22%
Seizure	3	17%
Mental confusion	2	11%
III cranial nerve lesion	2	11%
V cranial nerve lesion	1	6%
VI cranial nerve lesion	2	11%
Hormonal deficits	18	100%
Hypothyroidism	15	83%
Hypogonadism	10	56%
Panhypopituitarism	4	22%
Tumor functionality		
Non-functional adenomas	17	94%
Functional adenomas	1	6%

in 3 cases (17%), with similar occurrences in the temporal fossa (3 cases, 17%) and the posterior fossa (3 cases, 17%). Notably, one case (6%) demonstrated simultaneous invasion of both the temporal fossa and the third ventricle. Additionally, 5 cases (28%) exhibited no signs of invasion (Figure 4).

Surgical results

The endoscopic transsphenoidal surgery for sellar region was performed in all patients. Nine patients underwent multiple procedures (50%). Two patients underwent reoperation via endoscopic transsphenoidal approach, while 7 patients underwent transcranial microsurgery. Considering these 7 patients, 9 transcranial microsurgeries were performed. In two cases, it was decided to perform TCM first and then ETSS. The tumor asymmetry was the determining factor for this choice (Figure 5).

Regarding the resection rate, we observed gross total resection (GTR) (Figure 6) in 3 patients (18%) out of 17, as one patient unfortunately passed away due to an unrelated cause, preventing the assessment of tumor resection level. Among the 14 patients with partial resection (Figure 7), 5 were referred for radiotherapy as a complementary treatment after undergoing multiple surgical approaches (transcranial and transsphenoidal). The remaining patients, whose tumor sizes remained stable in follow-up examinations, were monitored without additional intervention (Tables 2 and 3). After surgical treatment, 12 patients (67%) reported improvement in visual deficits and no patients suffered visual deterioration after postoperatively. The average postoperative follow-up period was approximately 34 months.

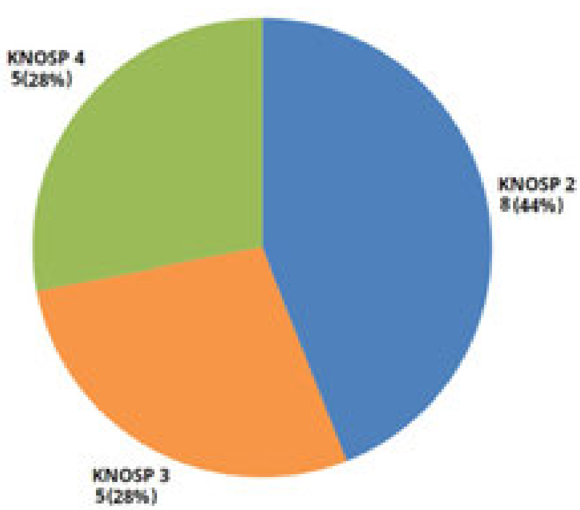

Figure 1. Distribution of patients by KNOSP score.

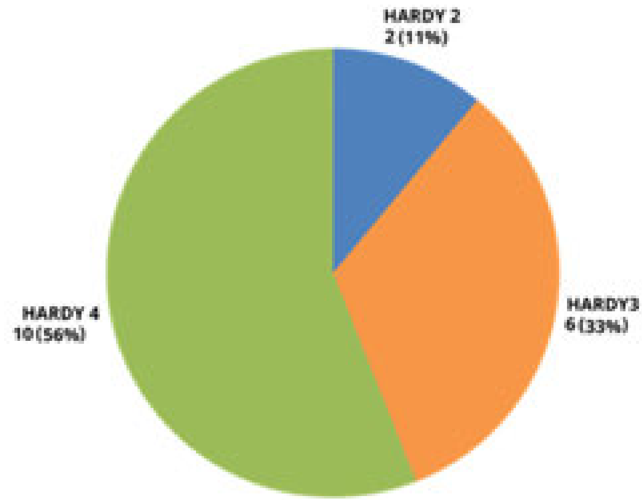

Figure 2. Distribution of patients by HARDY score.

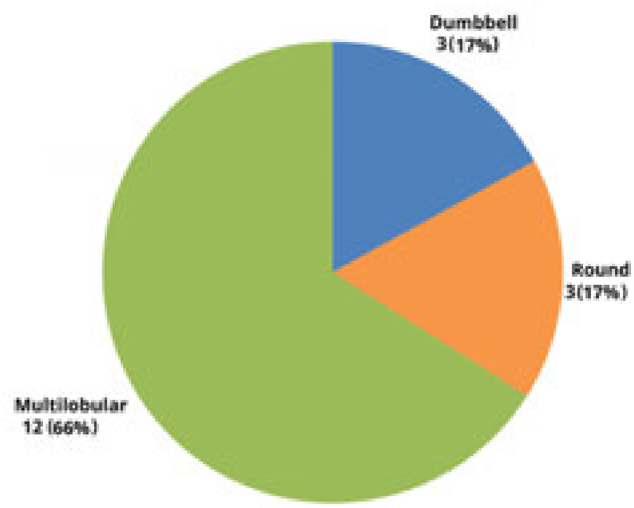

Figure 3. Distribution of tumor morphology.

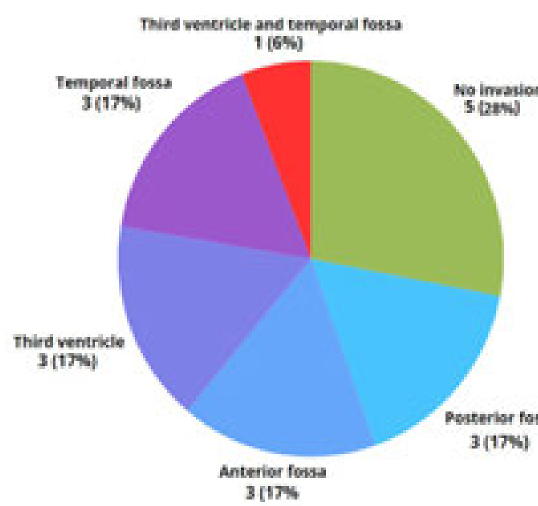

Figure 4. Frequency of tumor invasion into adjacent structures.

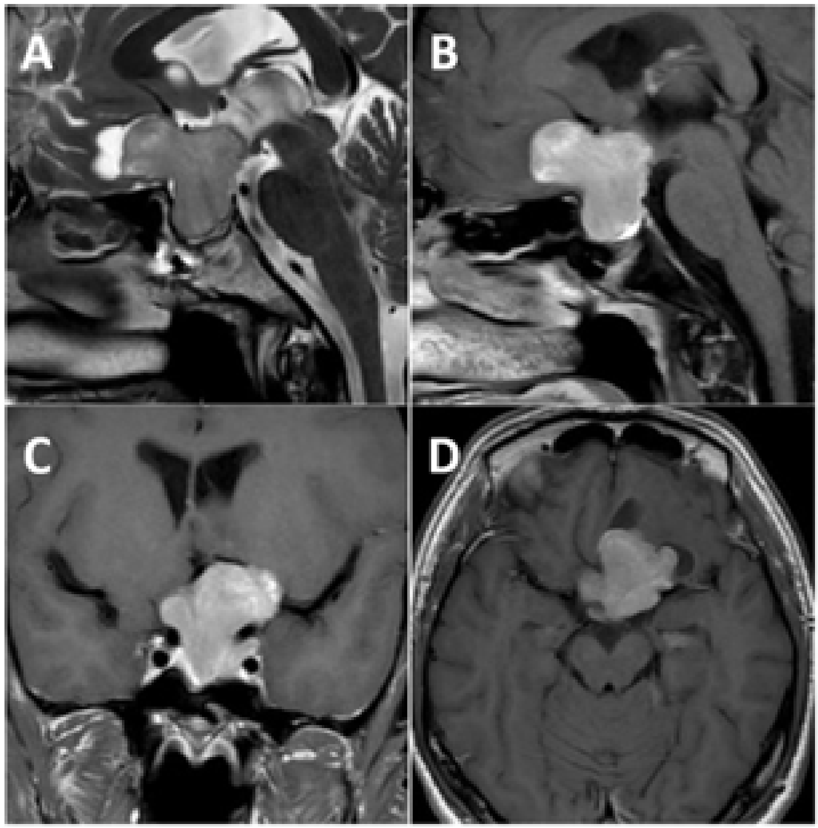

Figure 5. Preoperative MRI showing tumor asymmetry.

From the perspective of immunohistochemical analysis, six (33%) of the tumors presented prolactin expression, followed by "null cell" adenomas and those with gonadotropin expression in four (22%) and three (17%) cases, respectively (Figure 8). Quantification of Ki-67 values was not possible due to the limited number of tests that included marker analysis.

Regarding postoperative complications, two cases (11%) of sellar hematoma were observed in patients undergoing the endoscopic technique; both managed conservatively without neurological impairment or visual worsening. Installing an external lumbar drainage catheter in four patients (22%) was necessary due to transoperative observation of fluid outflow during the transsphenoidal approach. However, there was no evidence of postoperative fluid outflow. One patient (6%) presented postoperative meningitis, with good evolution after treatment with antibiotic therapy. Four patients (22%) presented temporary diabetes insipidus, and two patients (11%) presented SIADH. There was one death (6%) among the patients studied but without direct relation to the surgical procedure. The patient died due to acute obstructive abdomen, in the seventh postoperative day (Table 4).

DISCUSSION

Pituitary adenomas are benign, slow-growing lesions that are usually silent and often diagnosed incidentally[1,2]. Its prevalence has been described as around 16%[3]. However, giant lesions become rare neoplasms with few descriptions in the literature about their behavior, epidemiological data, treatment challenges, molecular analysis, and aggressiveness[2,3,9]. In general, such lesions are analyzed together with other pituitary adenomas or macroadenomas. There is still little information about this population in Brazil.

The data found in the present study are compatible with the results of other series concerning demographic data and neurological, visual, and hormonal deficits[1-3,9]. These findings reflect the complexity of managing these patients and reaffirm the need for a multidisciplinary medical approach, preferably in centers of large volume and experience with this patient profile.

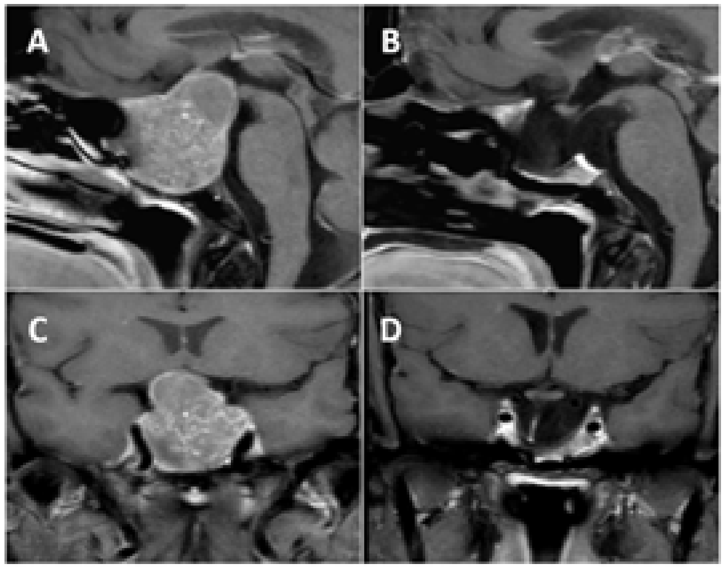

Figure 6. MRI showing complete resection of pituitary tumor.

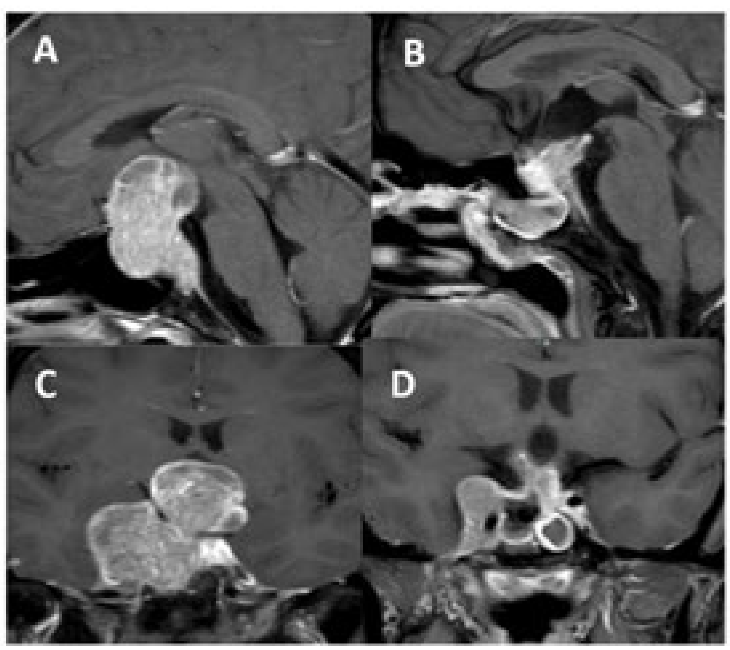

Figure 7. MRI showing partial resection of pituitary tumor.

Regarding imaging characteristics, average tumor size, and Knosp and Hardy scale values, the data again corroborate the complexity of the treatment of these tumors and justify the need for multiple approach routes and the rate of patients with incomplete resections. However, it is difficult to compare studies due to the heterogeneity of definitions of giant adenoma by imaging criteria (size x volume) found in the literature series[3,10-12].

Regarding surgical results, one of the primary goals of treatment is the recovery or stabilization of visual, neurological, and hormonal deficits with the lowest possible morbidity. Other studies show a rate of improvement of visual deficit around 70-80%[1,3,9,10,13]. In our series, we observed that almost 70% of patients reported improvement in visual deficit after surgical treatment, with a morbidity and mortality rate similar to that found in other studies.

Table 2. Summary of surgical approaches and results.

Patient	Approach	Degree of resection	Complications	Complementary therapy
1	ETSS 2011 + TCM 2015	Partial	None	None
2	ETSS 2014	Partial	Sellar hematoma, transoperative fistula	None
3	ETSS 2014 + TCM 2016, 2019	Partial	None	RTX
4	ETSS 2015	NA	Acute abdome, death (7 PO)	None
5	ETSS 2016	Total	None	None
6	ETSS 2017	Partial	None	None
7	ETSS 2017	Partial	Meningitis	None
8	ETS 2019, 2020 + TCM 2020, 2021	Partial	None	RTX
9	ETS 2019	Partial	None	None
10	TCM + ETSS 2021	Partial	Transoperative fistula, III CN lesion	RTX
11	TSM 2007 + ETSS 2021	Partial	None	RTX
12	ETSS 2021	Total	None	None
13	ETSS 2022	Partial	None	None
14	ETSS 2022	Total	None	None
15	ETSS 2022 + TCM 2023	Partial	III CN lesion	RTX
16	TCM 2013 + ETSS 2022	Partial	Transoperative fistula	None
17	ETSS + TCM 2022	Partial	Hemiparesis	None
18	ETSS 2022	Partial	III CN lesion	None

ETSS: endoscopic transsphenoidal surgery; TCM: transcranial microsurgery; TSM: transsphenoidal microsurgery; CN: cranial nerve; RTX: radiotherapy.

From our perspective, the transsphenoidal endonasal endoscopy should be the first choice for the initial approach and, if possible, for the second surgical intervention as well. In some centers, most, if not all, cases of giant adenomas are managed exclusively through the endoscopic technique[1,3,9,14]. At our hospital, whenever possible, the endoscopic technique was indicated in the first surgery. Considering that in the present series, no extended sellar endoscopic approaches were performed, complementary transcranial surgery (TCS) was necessary in almost 40% of cases.

Although the literature supports that the endoscopic technique is safer and presents fewer complications, we observed that it is difficult to perform adequate decompression of the optic pathways and neurological structures for this disease profile, especially for lesions with an hourglass appearance, retrochiasmatic, subfrontal, temporal growth. or extension of the posterior fossa. Many authors have defended the transcranial pathway for these cases[10,13-16].

Moreover, unlike the series shown by Gondin et al.[9], in which patients were treated only by the endoscopic technique, none of our patients

Table 3. Summary of postoperative results.

Postoperative results	N	%
Complete resection	3	17%
Visual improvement	12	67%
Complementary treatment	5	28%
Multiple approaches	7	39%

Table 4. Summary of postoperative complications.

Complications	N	%
Sellar hematoma	2	11%
Transoperative fistula	3	17%
Meningitis	1	6%
Cranial nerve lesion	3	17%
Motor deficit	1	6%
Diabetes insipidus	4	22%
Death*	1	6%

*Not directly related to the surgical procedure.

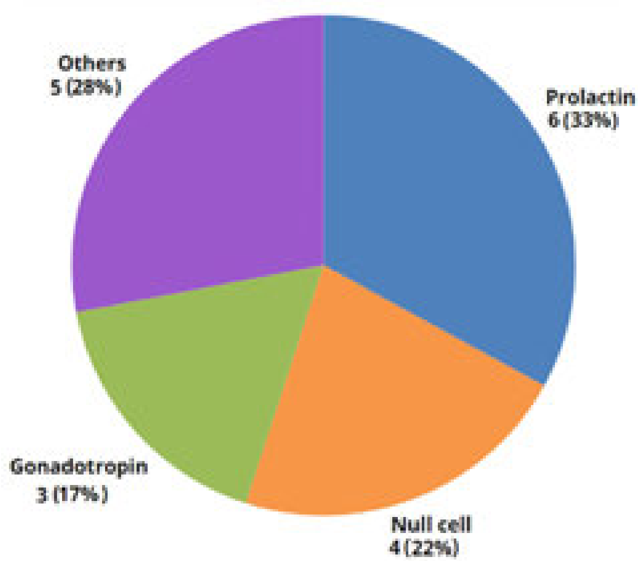

Figure 8. Immunohistochemical profile of tumor samples.

presented with Knosp lower than two. This finding is consistent with most published studies, in which most giant adenomas present evidence of possible invasion of the cavernous sinus (Knosp > 2) and that, in these cases, adequate management often requires multiple surgical techniques (endoscopic transsphenoidal and transcranial)[1,3,10,13-15,17].

From our perspective, the second main goal of treatment is controlling the lesion. When total resection is impossible without adding high morbidity, we choose the maximum possible reduction in tumor volume, followed by complementary treatment or not. The literature shows that total resection rates are quite variable, with results between 14.7% and 56.4%[2,10,11]. We also observed that the inclusion criteria of patients with giant adenomas vary significantly, with some studies considering giant tumors with a diameter greater than 3 cm, others using a diameter greater than 4 cm, and some using the volume > 10 cm[33,10-12]. Another important point is that most studies do not report the criteria used to consider complete resection, so it is difficult to compare the results. In our study, we considered complete resection only when there were no traces of lesions in postoperative MRI examinations (Figure 5). The remaining patients were considered partial resections (Figure 7). We obtained a total resection index of 16%, which is consistent with other authors who used similar criteria to those of our study, obtaining values between 14 and 38%[9,10,14].

Concerning postoperative complications, we obtained indices similar to the other series in the literature[1,3,9,10,13]. Only one patient presented postoperative meningitis. In addition, we obtained only one death in our sample, which was not directly associated with surgical treatment. No patient had postoperative cerebrospinal fluid leakage. Patients who had an intraoperative cerebrospinal fluid leak were treated according to the technique described and had a good postoperative evolution.

Adjuvant treatment with adenoma radiotherapy is already a defined topic in the literature. In our series, patients were referred to radiotherapy (27%) when surgical treatment alone was insufficient to achieve satisfactory disease control. All had undergone multiple approaches, including transsphenoidal and transcranial pathways. We believe that patients should be referred to radiotherapy when surgery is not enough to control these tumors due to the aggressiveness of these lesions and the low prospect of cure for these patients. According to Mortini et al.[10], patients with giant pituitary adenomas referred for radiotherapy presented better survival rates than those treated only with the surgical approach.

Regarding the immunohistochemical analysis, we found no association between the examination and surgical results, multiple surgical approaches, the need for adjuvant therapy, or the degree of invasion of adjacent structures. However, we observed no uniformity of the markers analyzed among the different patients due to the long period in which the cases were selected and the modifications of the method over the years.

CONCLUSION

There is still no consensus in the literature regarding the optimal treatment for giant pituitary adenomas, with approaches varying based on the institution's resources and the surgeon's expertise. In our study, we demonstrated that a combination of endoscopic transsphenoidal and transcranial approaches was often necessary due to the tumor's size and invasion of adjacent structures. We believe the objective should be the management of visual, neurological, and hormonal deficits, as well as effective disease control, even if adjuvant treatments such as radiotherapy or pharmacotherapy are required. However, the small sample size and retrospective nature of this study limit the generalizability of the findings, emphasizing the need for further research to refine management strategies for these challenging lesions.

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Bilateral Chronic Subdural Hematoma. Considerations on 26 cases

Hematoma Subdural Crônico Bilateral. Considerações de 26 casos

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ABSTRACT

Introduction: *Chronic subdural hematoma (CSDH) is a common disease in neurosurgical practice and especially in the elderly. It usually occurs after mild head trauma. Its occurrence is unilateral in most cases; between 3.5% to 25% of cases are bilateral.* **Objective:** *To analyze sex, age, predisposing factors, clinical picture, imaging findings, treatment and complications in prognosis of bilateral CSHD.* **Methods:** *This is a retrospective series of 26 cases of bilateral CSDH, studied in the neurosurgery service of the Hospital de Urgência (Aracaju-Sergipe, Brazil), from January 2009 to December 2012.* **Results:** *Predominance of males; average age of 72 years. Head trauma occurred in 50% of cases. Computed tomography (CT) was performed in all cases. All patients underwent a surgical procedure. There were eight complications and five deaths.* **Conclusion:** *Bilateral HSDC occurs in the elderly with a previous history of head trauma. It has been considered a surgical emergency. The prognosis is poor in relation to unilateral HSDC.*

Keywords: *Bilateral chronic subdural hematoma; Tomography; Complications; Mortality*

RESUMO

Introdução: *Hematoma subdural crônico (HSDC) é uma doença comum na pratica neurocirúrgica e em especial em idosos. Geralmente ocorre após um trauma craniano leve. Sua ocorrência é unilateral na maioria dos casos, entre 3,5% a 25% dos casos é bilateral.* **Objetivo:** *Analisar sexo, idade, fator de predisposição, quadro clínico, achados de imagem, tratamento e complicações em prognóstico de HSDC bilateral.* **Métodos:** *Trata-se de uma série retrospectiva de 26 casos de HSDC bilateral, estudados no serviço de neurocirurgia do Hospital de Urgência (Aracaju-Sergipe), durante o período de janeiro de 2009 a dezembro de 2012.* **Resultados:** *Predomínio do sexo masculino e a média das idades foi de 72 anos. Traumatismo craniano ocorreu em 50% dos casos. Tomografia computadorizada (TC) foi realizada em todos casos. Todos pacientes foram submetidos a procedimento cirúrgico. Houve oito complicações e cinco óbitos.* **Conclusão:** *O HSDC bilateral ocorre em idosos com história prévia de trauma craniano. Tem sido considerado uma emergência cirúrgica. O prognóstico é péssimo em relação ao HSDC unilateral.*

Palavras-Chave: *Hematoma subdural crônico bilateral; Tomografia computadorizada; Complicações; Mortalidade*

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INTRODUCTION

Chronic subdural hematoma (CSDH) is generally a consequence of a rupture of the bridge veins located in the subdural space, caused mainly by mild or moderate traumatic brain injury (TBI)[1]. It occurs more often in the elderly population[2-5]. The unilateral form is more common, occurring bilaterally between 3.5% to 25% of cases[5-13].

Twenty-six cases of bilateral CSDH are presented and discussed regarding etiology, clinic, imaging findings, treatment, complications and prognosis.

METHODS

The present work is a retrospective study on chronic bilateral subdural hematoma, from July 2009 to July 2012, at the neurosurgery service of Hospital João Alves Filho (Aracaju – Sergipe, Brazil). In this period, 172 cases of CSDH were treated; 26 of which were bilateral. Sex, age, predisposing factors, clinical picture, imaging findings, treatment and complications were analyzed. In the present study, we did not make a comparison with the cases of unilateral CSDH since this will be the subject of another article.

RESULTS

Of 172 (100%) patients with CSDH, 26 (15.7%) were bilateral. Males were affected in 19 cases (73.5%) and females, 7 (26.5%). The ages varied between 63 years and 95 years of age, with an average of 72 years. Previous histories of mild or moderate TBI were 13 cases, arterial hypertension (4), chronic alcoholism (4), diabetes mellitus (3), use of antiplatelet drugs (aspirin, heparin) were 2 patients. Cerebral atrophy was present in 22 (91.5%) cases. Clinical presentation of the pseudotumoral form was present in 62% of cases, followed by psychiatric disorders. A computed tomography exam was performed in all cases (Figures 1, 2, 3, 4, 5AB and 6AB). There was a predominance of volume in the right cerebral hemisphere and in the others, symmetrical ones. All were submitted to surgery, in 17 cases, with

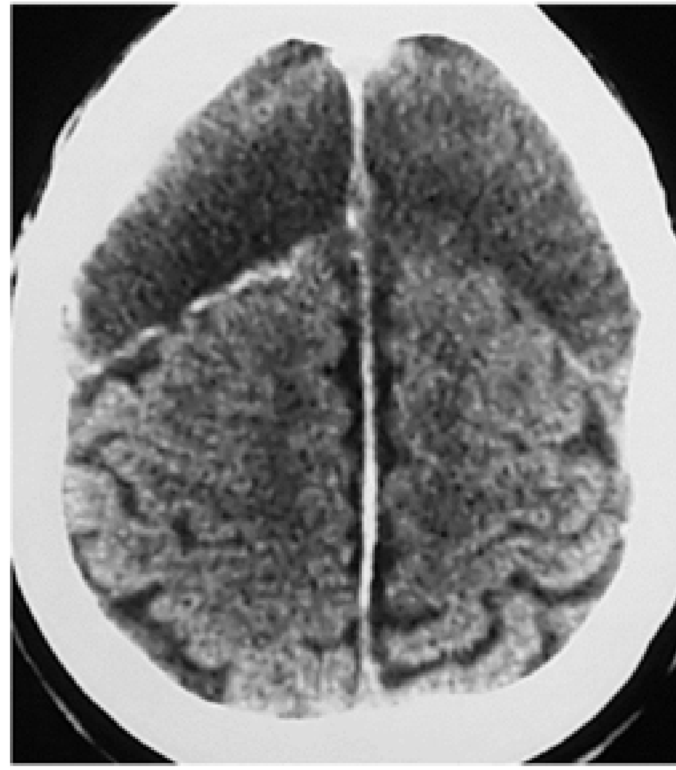

Figure 1. CT brain scan showing extensive bilateral chronic subdural hematoma involving frontal lobes.

Figure 2. CT brain scan showing bilateral chronic subdural hematoma. The right side was larger and there was a midline shift and absent right ventricle.

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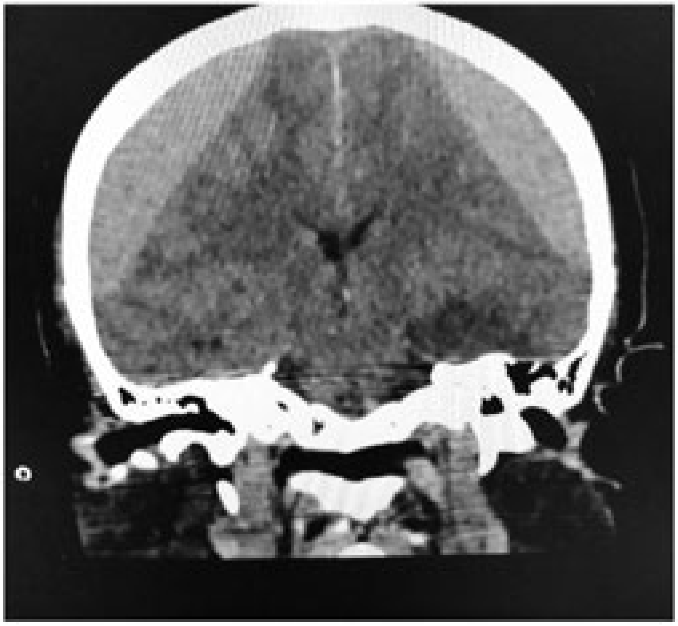

Figure 3. CT brain scan showing bilateral chronic subdural hematoma with hyperdensity.

Figure 4. CT brain scan in sagittal view demonstrating chronic subdural hematoma with double density.

two burr holes on each side, while in the others, one hole on each side. All patients were submitted to bed rest in the postoperative period for 72 hours. Anticonvulsant medication was used in 14 patients. Eight patients had complications: hematoma recurrence, four, and pneumocephalus, four cases. Postoperative death occurred in five patients, three due to previous cardiocirculatory conditions and two due to pulmonary complications.

DISCUSSION

CSDH usually occurs after mild and moderate TBI, as a consequence of the rupture of the bridge veins that are normally located in the subdural space. Premorbid conditions are important requirements in its development, such as: chronic alcoholism, cerebral atrophy, treatment with anticoagulant medication and antiplatelet agents[1,14-17]. The most frequent predisposing factors are: accidental falls, mild or moderate TBI, hemorrhagic diastasis, epilepsy, intracranial hypotension and hemodialysis[18]. Several authors have reported TBI as one of the factors most associated with the development of bilateral HSDC[3,4,12]. It has also been associated with the use of warfarin and antiplatelet drugs[19], spontaneous intracranial hypotension[20-22] and diabetes mellitus[5]. According to Agawa et al.[9], bilateral CSDH is more frequent in the elderly and patients with diabetes mellitus. Ahmed et al.[23] reported a case of probable idiopathic origin. In our series, there was a greater prevalence of mild and moderate TBI, followed by chronic alcoholism and the use of antiplatelet drugs. This fact was observed by other authors[3,4,12].

The male gender was the most affected (73.5%) of the cases, which is in agreement with other authors[3,13]. The average age of our patients was 72 years. In studies by Hima-Maiga et al.[3], it was 71 years old, Lee and Park[5], 77.8 years old and Min Xu[4], 69.5 years old. The preferred location is supratentorial; the infratentorial location has been rare[24,25]. All cases in the present series were located in the supratentorial portion.

Clinical presentation of bilateral CSDH varies and has been associated with the presence of unusual symptoms and signs[12]. For Mori and Maeda[26], most patients with CSDH present gait disorders, hemiparesis, headache, dementia, urinary incontinence or disturbances of consciousness. CSDH has been considered a great imitator because it simulates several neurological conditions such as stroke, dementia, parkinsonism and compressive spinal cord injury[1,27]. In bilateral CSDH, the global neurological deficit is more frequent than the focal deficit that occurs in a unilateral cases[18]. Okudera et al.[28] reported a case associated with divergent ocular paralysis. Several authors have reported a case with an initial presentation of involvement of the third cranial nerve[29,30]. Nagatomo et al.[31] described cases with initial symptoms of a depressive state. Suman et al.[32] described a case associated with Parkinson's disease. Other authors have described cases whose initial manifestation simulated spontaneous subarachnoid

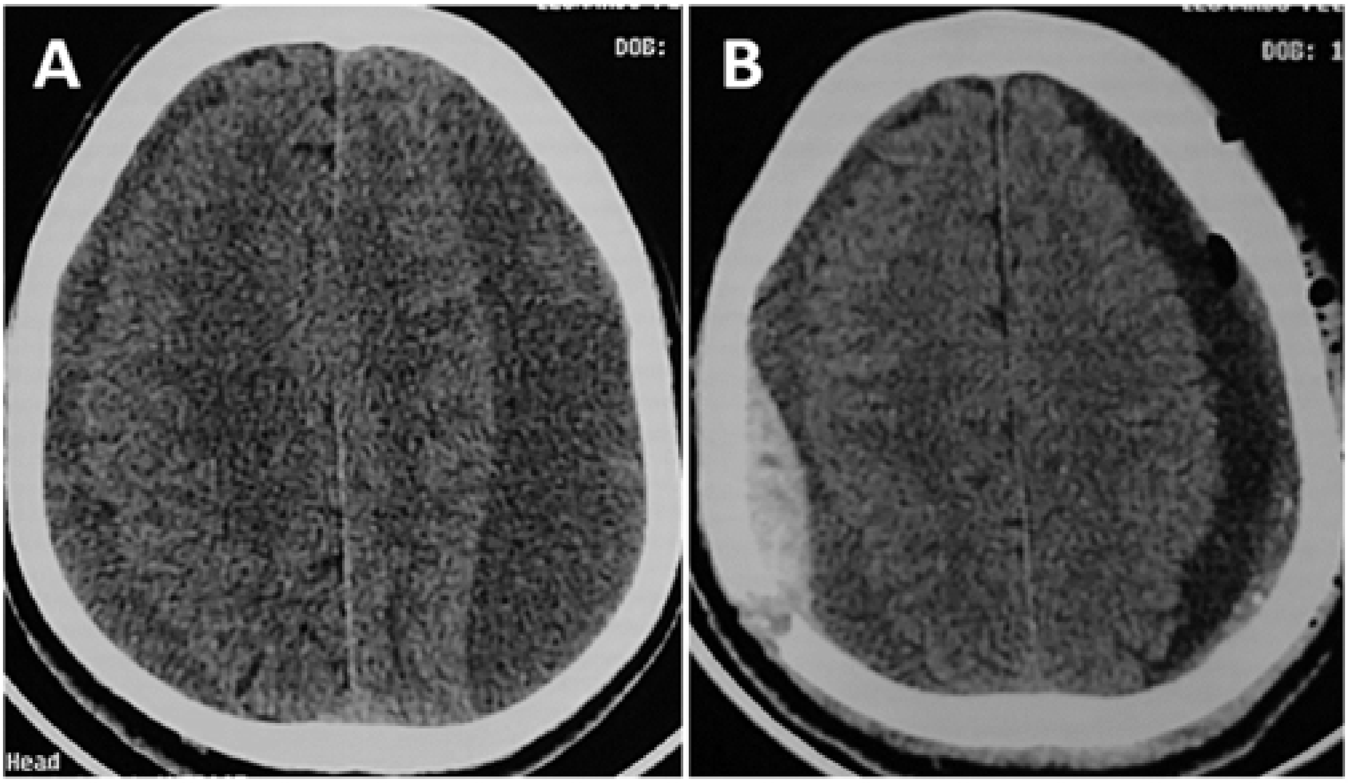

Figure 5. A. Preoperative computed tomography scans demonstrating bilateral chronic subdural hematoma. **B.** Post-operative computed tomography scans showing right parietal epidural hematoma.

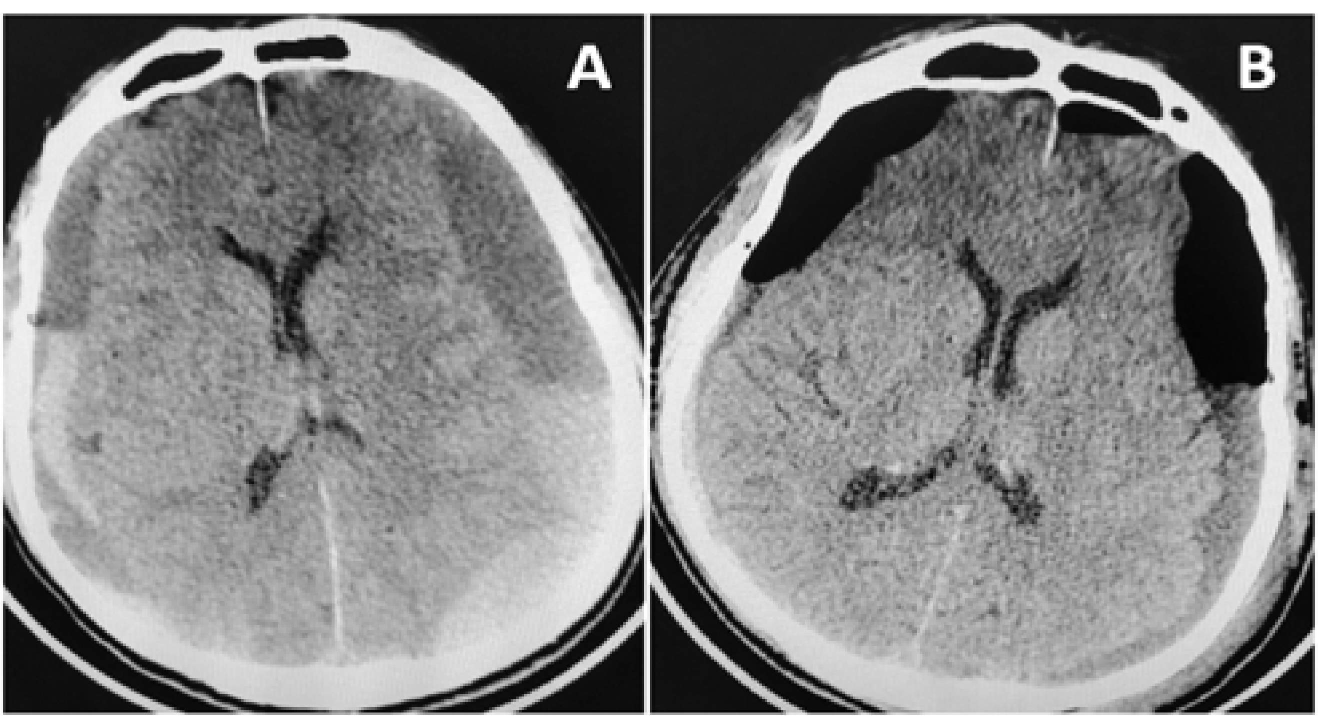

Figure 6. A. Preoperative CT brain scan showing bilateral chronic subdural hematoma with double density. **B.** Post-operative CT scan showing decompression of the brain.

hemorrhage[33,34]. Manifestation of paraparesis or paraplegia are rare[1,27,35,36]. According to Herath et al.[27], this could be due to direct compression of the motor cortex to the cerebral sickle or due to compression of the anterior cerebral artery due to subfalcic herniation. In their series, Lee and Park[5] found alteration of consciousness as the most common symptom. According to Huang et al.[12], most specialists consider that there is no difference between bilateral CSDH and unilateral CSDH in their clinical or strategic treatment manifestations. In our series, there was a predominance of the pseudotumoral form, with headache being the most common complaint. Presentation of psychiatric disorders was associated with previous history and use of drugs for anxiety and depression.

The cases in the present series were submitted to CT examination. There was a predominance of volume in the right cerebral hemisphere, mainly affecting males, similar to the findings of Hima-Maiga et al.[3]. In our cases, there was a predominance of findings on CT of isodense and hypodense hematoma, followed by mixed density. Cases of bilateral isodense CSDH can cause diagnostic difficulties on CT examination[37,38]. Other authors report that magnetic resonance imaging (MRI) is more sensitive than CT to determine the size and internal structures of the hematoma such as multiple loculations and membranes within the hematoma and capsule size[39,40]. For Kurokawa et al.[41], a clinical indicator of rapid progression of symptoms was reported through imaging exams, with CT on the fluid level (low density in the upper portion of the hematoma), MRI on hypodensity in T1 image sequence and hyper or hypodensity in the T2 images, as they indicate the presence of fresh blood, requiring surgical intervention.

Surgical treatment varies substantially according to the experience of the neurosurgeon or service. Among the most used procedures we have: burr-hole craniotomy with or without a continuous drainage system[42,43], wide craniotomy followed by drainage of the hematoma and membranectomy[44], endoscopic drainage through a small craniotomy[45]. Mersha et al.[13], in 195 cases, used a borehole and obtained 95.5% good results, 6.6% recurrence and four deaths. The literature has reported cases of spontaneous resolution in bilateral CSDH[46,47]. According to Agawa et al.[9], bilateral CSDH is indicated for urgent surgery. Min et al.[4] indicate the twist drill as an efficient and safe method of minimally invasive surgery in the surgical treatment of bilateral CSDH. Hsieh et al.[6], in cases of patients in good clinical condition, performed bilateral burr-holes. In our patients, two trephine holes were used bilaterally in 17 cases and, in the other case, on each side. This conduct was adopted according to the experiences of the professionals of that institution.

Hematoma recurrence is the main complication[48]. Agawa et al.[9] found that the bilateral recurrence rate was 14.2% and the unilateral recurrence rate was 11.3%. Other authors report the high incidence of recurrence[10,49]. Important factors in relapse are: residual presence of the external and internal capsule, blood in the subdural space, fibrin and degradation products, revascularization of the capsule and residual subdural space[50,51]. Rust et al.[52] reported a high rate of recurrence in patients using aspirin. Andersen-Ranberg et al.[53] reported that surgery being performed bilaterally reduces the risk of recurrence. Other complications are: epilepsy, pneumocephalus, subdural empyema, intracranial hemorrhage, pneumonia, pulmonary embolism, local or systemic infection and even death may occur[48]. Other authors have reported complications after hematoma drainage such as brain stem hemorrhage, oculomotor nerve disorder and prolapse of the brain tissue through the borehole[54-56]. According to Agawa et al.[9], it has a poor prognosis when associated with coagulation disorders due to the development of cerebral herniation. For Weigel et al.[57], the prognosis after surgery is often good due to advances in modern imaging techniques and surgical alternatives.

CONCLUSION

Bilateral CSDH is common in the elderly. It is usually associated with TBI, diabetes mellitus and antiplatelet drugs. The most frequent complaints are headache and consciousness disorders. The prognosis is worse in relation to unilateral CSDH.

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Classification of Ischemic Stroke Subtypes Using Machine Learning: insights from the International Stroke Trial dataset

Classificação de Subtipos de Infarto Cerebral Utilizando Aprendizado de Máquina: insights do International Stroke Trial dataset

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ABSTRACT

Introduction: *Ischemic stroke subtype classification supports prognosis and treatment but can be challenging in acute care.* **Objective:** *To develop and evaluate Machine Learning models for automated OCSP-based ischemic stroke subtype classification using clinical data.* **Methods:** *Using 13,056 IST cases, we trained Random Forest, XGBoost, Logistic Regression, Support Vector Machine, and k-Nearest Neighbors models. Performance was assessed by accuracy, sensitivity, specificity, PPV, NPV, and AUC-ROC using 10-fold stratified cross-validation.* **Results:** *Clinical variables were strongly associated with stroke subtypes ($p < 0.001$). RF and XGBoost achieved perfect performance (all metrics = 1.000 ± 0.000). Logistic Regression and SVM also performed near-perfectly (accuracy ≈ 0.998, AUC-ROC = 1.000). KNN showed lower sensitivity, especially for POCS (macro average sensitivity = 0.898).* **Conclusion:** *ML models, particularly RF and XGBoost, enable highly accurate ischemic stroke subtype classification using routine clinical data.*

Keywords: *Ischemic stroke; Machine learning; Random forest; Artificial intelligence*

RESUMO

Introdução: *A classificação de subtipos de AVC isquêmico é essencial para o prognóstico e tratamento, mas desafiadora na prática clínica.* **Objetivo:** *Desenvolver e avaliar modelos de aprendizado de máquina (ML) para classificação automatizada dos subtipos de AVC isquêmico (OCSP) usando dados clínicos.* **Métodos:** *Utilizando 13.056 casos do estudo IST, treinamos Random Forest, XGBoost, Regressão Logística, Support Vector Machine e k-Nearest Neighbors. Avaliamos acurácia, sensibilidade, especificidade, VPP, VPN e AUC-ROC com validação cruzada estratificada (10-fold).* **Resultados:** *Variáveis clínicas associaram-se fortemente aos subtipos ($p < 0{,}001$). Random Forest e XGBoost tiveram desempenho perfeito (todas as métricas = 1,000 ± 0,000). Regressão Logística e SVM tiveram desempenho quase perfeito (acurácia ≈ 0,998; AUC-ROC = 1,000). O KNN apresentou menor sensibilidade, especialmente para POCS (sensibilidade média = 0,898).* **Conclusão:** *Os modelos de ML, especialmente Random Forest e XGBoost, permitem classificar subtipos de AVC isquêmico com alta precisão usando dados clínicos rotineiros.*

Palavras-Chave: *Acidente vascular cerebral isquêmico; Machine learning; Random forest; Inteligência artificial*

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INTRODUCTION

Stroke remains a major global health issue, with ischemic stroke representing the majority of cases. Globally in 2021, there were about 69.9 million ischemic stroke cases, with an age-standardized prevalence rate of 819.5 per 100,000 individuals[1]. In the United States, ischemic stroke accounted for 67.5% of the 460,000 new stroke cases in 2019, with 310,000 incidents of ischemic stroke specifically. Although the age-standardized incidence, mortality, and disability-adjusted life years (DALYs) rates in the U.S. have declined, the absolute number of cases continues to grow, especially among younger adults aged 15–49 years in southern and midwestern states[2].

In Brazil, stroke is a leading cause of death, with ischemic stroke making up about 61.8% of all stroke deaths in 2016[3]. Encouragingly, there has been a 34.5% decrease in the age-standardized prevalence rate of ischemic stroke in Brazil from 1990 to 2019[4].

The Oxfordshire Community Stroke Project (OCSP) classification system, which categorizes strokes into Total Anterior Circulation Syndrome (TACS), Partial Anterior Circulation Syndrome (PACS), Posterior Circulation Syndrome (POCS), and Lacunar Syndrome (LACS), plays a critical role in guiding prognosis and treatment, as each subtype is associated with distinct patterns of recurrence and outcomes[5].

The International Stroke Trial (IST) was a large, randomized clinical study designed to assess the safety and effectiveness of early antithrombotic treatments — specifically aspirin and subcutaneous heparin — in patients with acute ischemic stroke. Conducted across 467 hospitals in 36 countries, it enrolled 19,435 patients and aimed to provide strong evidence on whether these treatments could reduce death and disability when started soon after stroke onset. The trial found that aspirin led to a small but real reduction in early death or recurrent stroke, while heparin offered no net benefit and increased the risk of bleeding[6]. The extensive data collected have since served as a valuable resource for planning future trials and conducting secondary analyses.

The IST dataset, encompassing a broad range of clinical variables such as neurological deficits, offers a valuable resource for developing automated subtype classification models. In this study, we leverage the IST dataset to develop and evaluate ML models for automated ischemic stroke subtype classification. We selected key clinical variables to train and compare multiple algorithms, including Random Forest (RF), Extreme Gradient Boosting (XGBoost), Support Vector Machine (SVM), Logistic Regression, and k-Nearest Neighbors (KNN). The objective of this paper is to identify the most effective machine learning approach for accurate ischemic stroke subtype classification using clinical data, thereby contributing to improved early diagnosis and personalized management strategies in stroke care.

METHODS

Variables

1. STYPE - Stroke subtype classification (TACS=Total Anterior Circulation Stroke, PACS=Partial Anterior Circulation Stroke, POCS=Posterior Circulation Stroke, LACS=Lacunar Stroke)
2. RDELAY - Time delay (in hours) between stroke onset and patient randomization
3. RCONSC - Consciousness level at randomization (F=Fully alert, D=Drowsy, U=Unconscious)
4. RSBP - Systolic blood pressure (mmHg) measured at randomization
5. RSLEEP - Whether symptoms were noticed upon waking
6. RDEF1 - Face deficit
7. RDEF2 - Arm/hand deficit
8. RDEF3 - Leg/foot deficit
9. RDEF4 - Dysphasia
10. RDEF5 - Hemianopia
11. RDEF6 - Visuospatial impairment
12. RDEF7 - Brainstem/cerebellar signs
13. RDEF8 - Other neurological deficits
14. RCT - Whether CT scan was performed before randomization

15. RVISINF - Whether infarct was visible on CT scan
16. RATRIAL - Presence of atrial fibrillation
17. RHEP24 - Heparin administration within 24 hours pre-randomization
18. RASP3 - Aspirin administration within 3 days pre-randomization
19. AGE - Patient age in years
20. SEX - Patient sex (M=Male, F=Female)

Data preprocessing (I)
We applied three exclusion criteria to ensure data quality:

1. Removed records where any neurological deficit (RDEF1-RDEF8) was coded as "C" (cannot assess)
2. Excluded cases classified as "other" stroke subtype (STYPE = "oth")
3. Dropped all records with missing values for any variable

Statistical evaluation
After exclusions, 13,056 complete cases were analyzed. Categorical variables were compared using χ^2 test. Due to non-normal distributions and unequal variances, continuous variables were analyzed using the Kruskal-Wallis test (reporting the H-statistic).

All analyses compared distributions across the four main stroke subtypes (LACS, PACS, POCS, TACS). Statistical significance was set at $p<0.05$.

Machine learning framework
We implemented a comprehensive machine learning pipeline using scikit-learn[7] library, consisting of data preprocessing, feature transformation, and model evaluation components.

1. Data Preprocessing (II)

The dataset was loaded from a CSV file, and missing values were inspected. Features were categorized into numerical and categorical variables. Numerical features were standardized using StandardScaler and subjected to variance thresholding (threshold = 0.01). Categorical features were encoded using one-hot encoding. The preprocessing steps were implemented using a ColumnTransformer within a scikit-learn pipeline.

2. Classification Algorithms

- Random Forest[8]

RF is a ML algorithm that combines multiple decision trees trained on random subsets of data and features, improving accuracy and reducing overfitting. Widely used in medical research, it handles complex datasets and identifies clinically relevant predictors.

- Extreme Gradient Boosting[9]

XGBoost is an advanced ML technique that sequentially builds decision trees, optimizing each new model to correct errors from previous ones. It is especially suitable for medical prediction tasks by handling complex, high-dimensional data and providing interpretable feature importance.

- Logistic Regression

Logistic Regression is a statistical model used for binary classification, estimating the probability of an outcome by fitting data to a logistic curve.

- Support Vector Machine[10]

SVM is a supervised learning algorithm that constructs a hyperplane or set of hyperplanes in a high-dimensional space to maximize the margin between classes.

- k-Nearest Neighbors[11]

KNN is a simple, instance-based learning algorithm that classifies data points based on the majority vote of their k closest training examples. It is particularly used when data distributions are unknown or complex.

3. Model Evaluation

- Performance Metrics

We computed standard classification metrics:

- Accuracy

- Sensitivity
- Specificity
- Positive Predictive Value (PPV)
- Negative Predictive Value (NPV)
- Area Under Curve - Receiver Operating Character (AUC-ROC)

- Cross-Validation

We used 10-fold stratified cross-validation maintaining class distributions.

RESULTS

χ^2 tests identified significant associations between several clinical and demographic categorical variables and ischemic stroke subtypes classified according to the OCSP system (Table 1). Altered level of consciousness at randomization (RCONSC), presence of visible infarct on computed tomography (RVISINF), atrial fibrillation (RATRIAL), presence of specific neurological deficits—including facial deficit (RDEF1), arm/hand deficit (RDEF2), leg/foot deficit (RDEF3), dysphasia (RDEF4), hemianopia (RDEF5), visuospatial disorder (RDEF6), brainstem or cerebellar signs (RDEF7), and other deficits (RDEF8)—were

Table 1. Association Between Clinical Variables and Stroke Subtypes (χ^2 Test Results).

Variable	Category	LACS	PACS	POCS	TACS	χ^2	p-value
RCONSC	D	0	814	150	531	1605.80	<0.001
	F	4401	4732	1508	899		
	U	0	3	10	8		
RCT	N	1561	1942	430	433	65.32	<0.001
	Y	2840	3607	1238	1005		
RVISINF	N	3254	3864	1180	811	158.95	<0.001
	Y	1147	1685	488	627		
RATRIAL	N	3994	4674	1489	1075	263.19	<0.001
	Y	407	875	179	363		
RHEP24	N	4295	5420	1637	1393	5.51	0.138
	Y	106	129	31	45		
RASP3	N	3522	4331	1308	1128	6.09	0.107
	Y	879	1218	360	310		
SEX	F	1914	2487	617	710	52.03	<0.001
	M	2487	3062	1051	728		
RSLEEP	N	2947	3912	1191	1021	20.35	<0.001
	Y	1454	1637	477	417		
RDEF1	N	1209	1692	897	103	822.02	<0.001
	Y	3192	3857	771	1335		
RDEF2	N	0	1253	777	0	2507,45	<0.001
	Y	4401	4296	891	1438		
RDEF3	N	451	2042	920	68	1944.43	<0.001
	Y	3950	3507	748	1370		
RDEF4	N	4401	2075	1298	614	4615.44	<0.001
	Y	0	3474	370	824		
RDEF5	N	4401	5032	1437	0	8265.14	<0.001
	Y	0	517	231	1438		
RDEF6	N	4401	4688	1506	448	3991.51	<0.001
	Y	0	861	162	990		
RDEF7	N	4401	5549	84	1438	12307.71	<0.001
	Y	0	0	1584	0		
RDEF8	N	4401	5033	1488	1384	486.68	<0.001
	Y	0	516	180	54		

all strongly associated with stroke subtype ($p < 0.001$ for all). Notably, altered consciousness was more common among patients with PACS and Total TACS, while preserved consciousness predominated in LACS. Infarcts visible on CT and atrial fibrillation were significantly more frequent in PACS and TACS. Conversely, prior heparin use within 24 hours (RHEP24) and aspirin use within 3 days prior to randomization (RASP3) were not significantly associated with stroke subtype ($p > 0.05$).

Analysis of continuous variables using analysis of variance (ANOVA) (Table 2) revealed significant differences in delay between stroke and randomization (RDELAY), systolic blood pressure at randomization (RSBP), and patient age across stroke subtypes ($p < 0.001$ for all). Patients with TACS tended to be older and experienced shorter delays from symptom onset to randomization compared to other subtypes.

The performance of the machine learning models for ischemic stroke subtype classification was evaluated across multiple metrics, including accuracy, sensitivity, specificity, PPV, NPV, and area under the receiver operating characteristic curve (AUC-ROC) (Table 3).

Both the RF and XGBoost classifiers achieved perfect performance across all classes—LACS, PACS, POCS, and TACS—with mean accuracy, sensitivity, specificity, PPV, NPV, and AUC-ROC of 1.000 ± 0.000. This indicates that these models correctly classified all samples without errors during cross-validation.

The Logistic Regression model also performed exceptionally well, with a macro average accuracy of 0.998 ± 0.002, sensitivity of 0.999 ± 0.001, and AUC-ROC of 1.000 ± 0.000. Minor deviations were observed in the PACS and TACS classes, where sensitivity was slightly below 1.000, but without significant compromise to overall classification performance. Similarly, the SVM classifier achieved high metrics, with a macro average accuracy of 0.998 ± 0.002 and AUC-ROC of 1.000 ± 0.000. Slight decreases in sensitivity were observed for PACS and POCS classes.

In contrast, the KNN classifier demonstrated comparatively lower performance, with a macro average accuracy of 0.914 ± 0.007 and macro AUC-ROC of 0.990 ± 0.007. While the LACS and TACS classes maintained high sensitivity and specificity, classification of the POCS subtype showed a notably reduced sensitivity (0.779 ± 0.026), indicating more frequent misclassifications in this group.

The confusion matrices (Figure 1) illustrate that Random Forest, XGBoost, Logistic Regression, and SVM achieved near-perfect classification across all subtypes, with minimal confusion between classes. In contrast, the KNN confusion matrix revealed some misclassifications, particularly between POCS and other subtypes.

The ROC-AUC curves (Figure 2) further corroborate these findings, with Random Forest, XGBoost, Logistic Regression, and SVM achieving curves close to the ideal top-left corner, corresponding to near-perfect separability. KNN exhibited slightly lower AUCs, particularly for the POCS and PACS classes.

DISCUSSION

This study demonstrated that ischemic stroke subtypes, classified according to the OCSP system, are strongly associated with distinct clinical and demographic profiles identifiable at presentation. Specifically, variables such as level of consciousness (RCONSC), presence of a visible infarct on computed tomography (RVISINF), atrial fibrillation (RATRIAL), and a detailed set of neurological deficits (RDEF1–RDEF8) were significantly different across stroke subtypes. These findings align with the foundational

Table 2. Comparison of Clinical Variables Across Stroke Subtypes (Kruskal-Wallis Test Results).

Variable	LACS (Mean)	PACS (Mean)	POCS (Mean)	TACS (Mean)	H-statistic	p-value
RDELAY	21.63	20.24	21.51	18.21	107.47	<0.001
RSBP	161.90	160.13	160.36	157.66	26.66	<0.001
AGE	69.48	71.17	68.93	72.91	157.37	<0.001

OCSP definitions, which emphasize clinical presentation as the basis for stroke syndrome classification[5].

Among continuous variables, shorter delays to randomization (RDELAY), lower systolic blood pressure (RSBP), and older age were characteristic of Total Anterior Circulation Syndrome (TACS), consistent with prior findings that TACS patients tend to be older and have more severe vascular pathologies[12].

The machine learning models employed for stroke subtype classification achieved outstanding performance. In particular, Random Forest and XGBoost attained perfect classification across all subtypes (accuracy, sensitivity, specificity, PPV, NPV, and AUC-ROC = 1.000 ± 0.000). Logistic Regression and SVM also performed near-perfectly, with only minor reductions in sensitivity for the PACS and POCS subtypes. In contrast, the KNN classifier, while still demonstrating strong overall

Table 3. Performance Metrics of Machine Learning Models for Ischemic Stroke Subtype Classification.

Model	Class	Accuracy	Sensitivity	Specificity	PPV	NPV	AUC-ROC
Random Forest	LACS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	PACS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	POCS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	TACS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	MACRO AVG	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
XGBoost	LACS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	PACS	1.000 ± 0.000	1.000 ± 0.001	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	POCS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	0.999 ± 0.002	1.000 ± 0.000	1.000 ± 0.000
	TACS	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	MACRO AVG	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
Logistic Regression	LACS	0.998 ± 0.002	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	PACS	0.998 ± 0.002	0.994 ± 0.004	1.000 ± 0.000	1.000 ± 0.000	0.996 ± 0.003	1.000 ± 0.001
	POCS	0.998 ± 0.002	1.000 ± 0.000	0.999 ± 0.001	0.995 ± 0.005	1.000 ± 0.000	1.000 ± 0.000
	TACS	0.998 ± 0.002	1.000 ± 0.000	0.998 ± 0.002	0.985 ± 0.013	1.000 ± 0.000	1.000 ± 0.001
	MACRO AVG	0.998 ± 0.002	0.999 ± 0.001	0.999 ± 0.000	0.995 ± 0.004	0.999 ± 0.001	1.000 ± 0.000
SVM	LACS	0.998 ± 0.002	1.000 ± 0.001	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000	1.000 ± 0.000
	PACS	0.998 ± 0.002	0.995 ± 0.004	0.999 ± 0.001	0.999 ± 0.001	0.997 ± 0.003	1.000 ± 0.000
	POCS	0.998 ± 0.002	0.997 ± 0.004	1.000 ± 0.001	0.997 ± 0.004	1.000 ± 0.001	1.000 ± 0.000
	TACS	0.998 ± 0.002	1.000 ± 0.000	0.998 ± 0.002	0.986 ± 0.014	1.000 ± 0.000	1.000 ± 0.000
	MACRO AVG	0.998 ± 0.002	0.998 ± 0.002	0.999 ± 0.001	0.996 ± 0.003	0.999 ± 0.001	1.000 ± 0.000
KNN	LACS	0.914 ± 0.007	1.000 ± 0.001	0.914 ± 0.007	0.855 ± 0.010	1.000 ± 0.001	0.995 ± 0.001
	PACS	0.914 ± 0.007	0.883 ± 0.013	0.963 ± 0.005	0.947 ± 0.007	0.918 ± 0.009	0.979 ± 0.002
	POCS	0.914 ± 0.007	0.779 ± 0.026	0.998 ± 0.001	0.984 ± 0.011	0.969 ± 0.004	0.988 ± 0.005
	TACS	0.914 ± 0.007	0.930 ± 0.016	0.993 ± 0.002	0.946 ± 0.017	0.991 ± 0.002	0.997 ± 0.001
	MACRO AVG	0.914 ± 0.007	0.898 ± 0.008	0.967 ± 0.003	0.933 ± 0.007	0.969 ± 0.003	0.990 ± 0.007

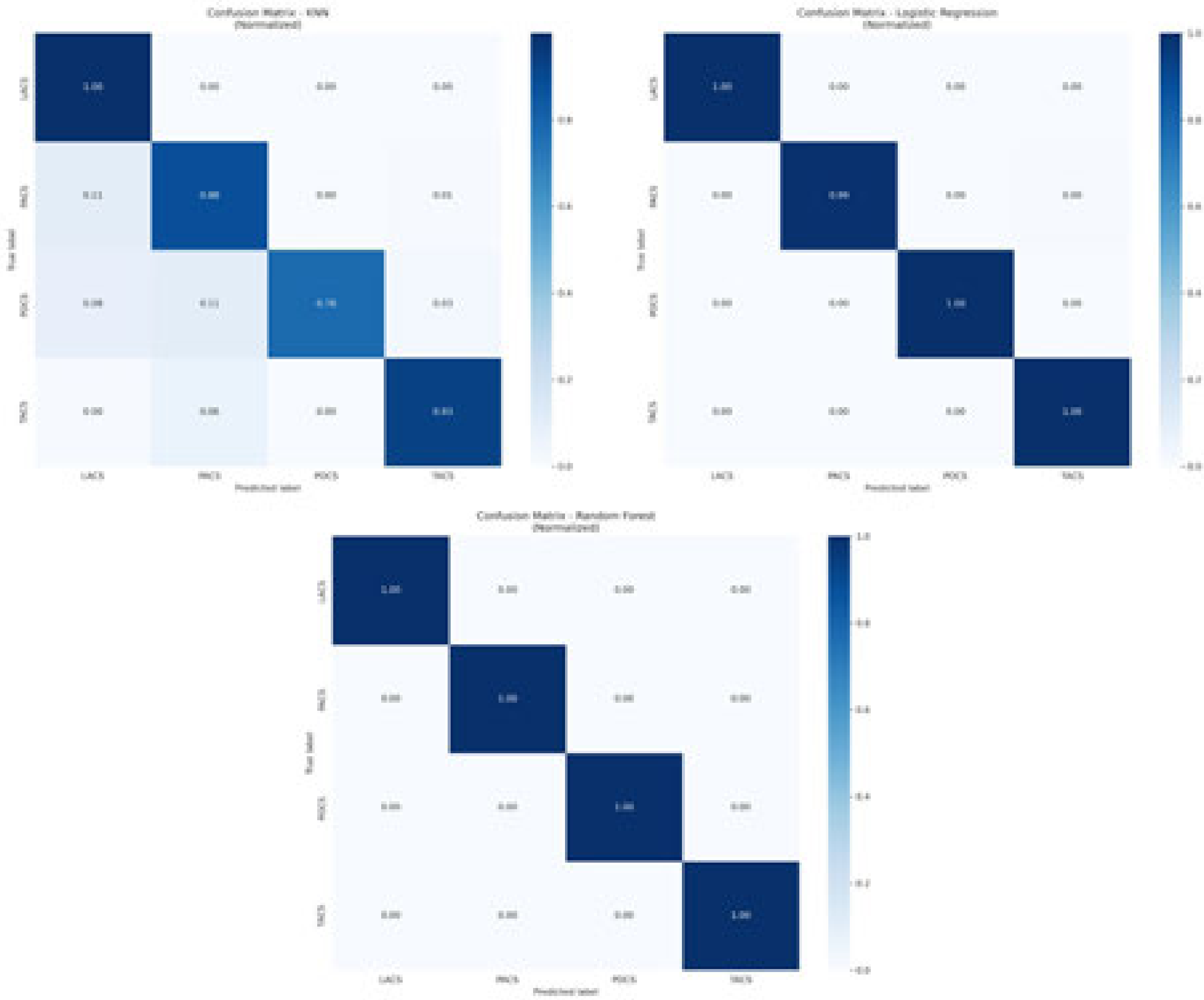

Figure 1A. Confusion Matrices of the Machine Learning Models for Stroke Subtype Classification.

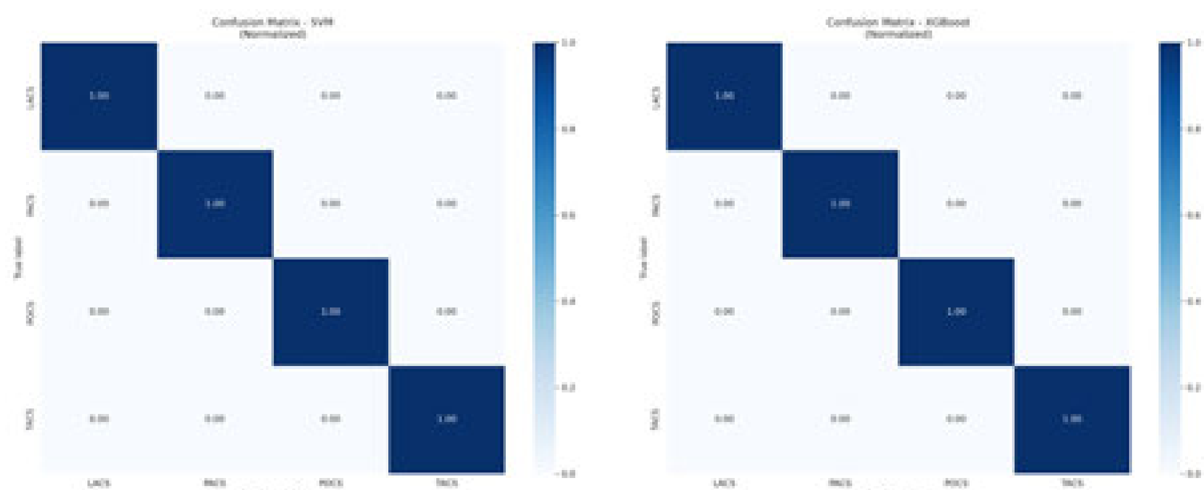

Figure 1B. Confusion Matrices of the Machine Learning Models for Stroke Subtype Classification.

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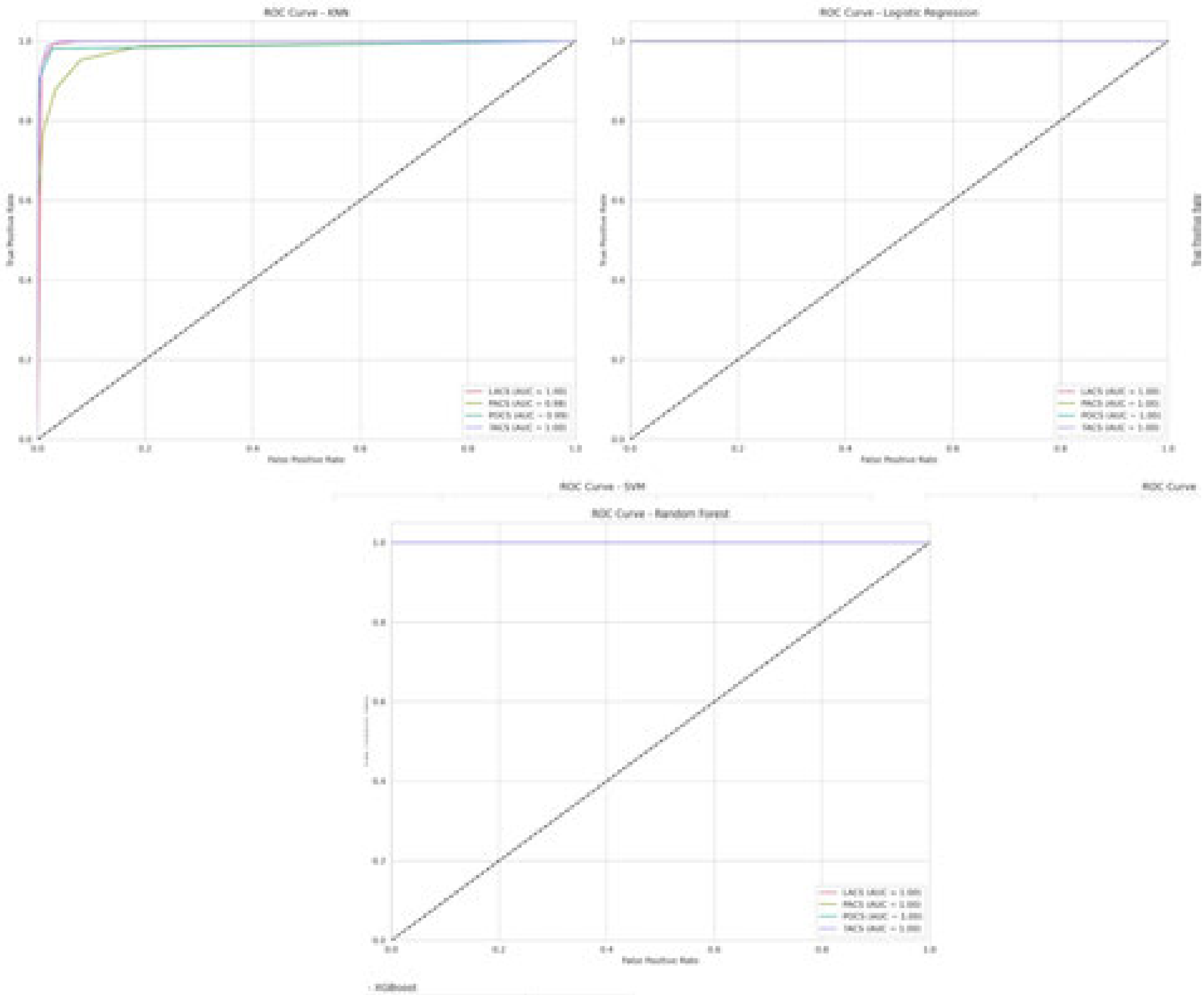

Figure 2A. ROC-AUC Curves for Machine Learning Models in Stroke Subtype Classification.

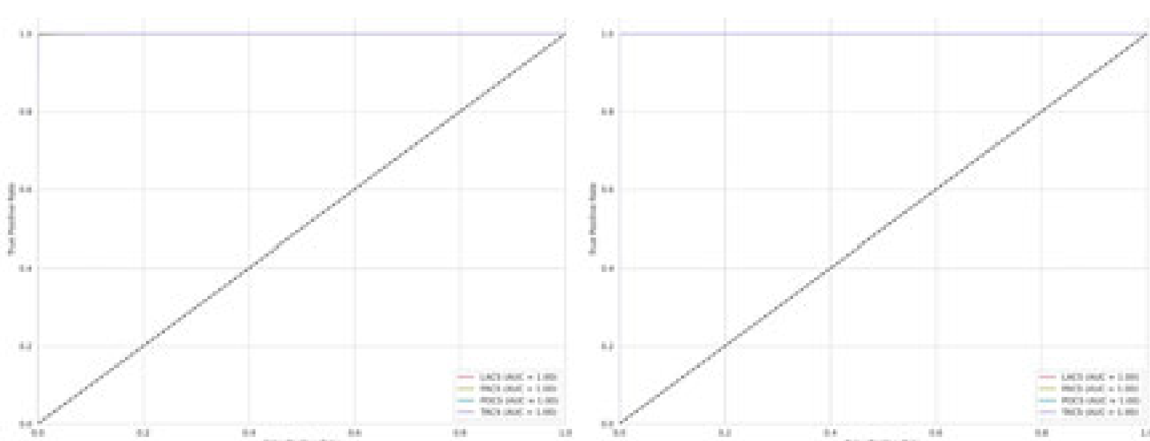

Figure 2B. ROC-AUC Curves for Machine Learning Models in Stroke Subtype Classification.

performance (macro AUC-ROC = 0.990 ± 0.007), showed a notable decline in sensitivity when classifying POCS strokes, highlighting potential limitations of nearest-neighbor approaches for more subtle clinical phenotypes.

In recent years, several studies have applied machine learning to ischemic stroke subtype classification, typically using either clinical features, imaging data, or both. The study by Andrade et al.[13] developed COMPACT, a decision-tree-based tool designed to assist neurology residents in applying the OCSP classification. Their findings showed that structured decision support significantly improved interrater agreement and classification accuracy, particularly for challenging subtypes such as TACS and PACS.

Our results significantly surpass performance reported in the current literature. For example, Fang et al.[14] applied an ensemble learning framework on the International Stroke Trial dataset and achieved high, though not perfect, classification performance. Similarly, a deep learning approach using diffusion-weighted imaging and atrial fibrillation data reported agreement levels with expert classification at 72.9%, with kappa scores around 0.57[15]. Garg et al.[16] utilized natural language processing and EHR data to automate TOAST subtyping, achieving moderate kappa values up to 0.57. Moreover, XGBoost-based models built on registry data reached AUC-ROC scores of 0.83 and classification accuracy around 62%, highlighting room for improvement even with enriched feature sets[17].

Although our results are promising, the disparity with existing literature suggests that our model may have been evaluated on a more homogeneous or limited dataset. As such, external validation on larger and more diverse populations is necessary to confirm generalizability and mitigate the risk of overfitting.

Furthermore, these findings reinforce the feasibility of using routine clinical variables—without relying on advanced neuroimaging—to automate stroke subtype classification with high precision. This approach may be particularly impactful in low-resource settings or during the early stages of stroke management, where access to imaging modalities is limited.

However, several limitations must be acknowledged. First, the dataset used for model training and evaluation was internally validated but not tested on independent cohorts. Moreover, this study represents an automation of the OCSP classification using machine learning rather than a validation of the classification system itself. Therefore, despite cross-validation, overfitting or dataset-specific biases cannot be entirely excluded. Second, the classification task was based on relatively clean clinical labels (OCSP-based), which may not fully reflect the variability encountered in real-world diagnostic settings.

Future studies should prioritize external validation across heterogeneous clinical populations and explore the incorporation of additional features—such as imaging biomarkers, laboratory results, and genetic information—to further refine classification accuracy.

CONCLUSION

This study confirms that machine learning models, especially ensemble-based approaches like Random Forest and XGBoost, are capable of achieving exceptionally high performance in classifying ischemic stroke subtypes using structured clinical data alone. These findings support the development of decision support tools that can assist clinicians in low-resource or time-sensitive contexts. However, external validation is essential to ensure broader applicability and to safeguard against dataset-specific biases.

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The Effect of Selenium Administration on the Outcomes of Patients with Moderate and Severe Traumatic Brain Injury

O Efeito da Administração de Selênio nos Resultados de Pacientes com Lesão Cerebral Traumática Moderada e Grave

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ABSTRACT

Introduction: *Traumatic brain injury (TBI) constitutes a major public health challenge globally. Oxidative stress, leading to secondary brain insult, remains a problem to be surmounted. The beneficial effect of selenium is still inconclusive as previous studies showed conflicting results.* **Objective***: The study aimed to determine the effect of selenium administration on the outcomes of moderate and severe TBI patients who presented to our hospital.* **Methods:** *The study consisted of 84 patients, with 42 patients in each category of moderate and severe TBI. Each category was further divided into two groups (A (selenium group) and B (non-selenium group)) with 21 patients in each group. Patients in group A had selenium administered while patients in group B served as the control group. Glasgow outcome score extended of patients in both groups at three months post trauma or at patient's demise were determined.* **Results:** *The mortality rate was the same in both groups of moderate TBI patients (9.5% each) while mortality rate was significantly higher in the non-selenium (90.5%) than in the selenium group (52.4%) of severe TBI patients (P=0.006).* **Conclusion:** *Selenium administration resulted in significantly reduced mortality rate among the severe TBI patients but not among moderate TBI patients.*

Keywords: *Antioxidant; Glasgow outcome score extended; Oxidative stress; Selenium; Traumatic brain injury*

RESUMO

Introdução: *A lesão cerebral traumática (LCT) constitui um grande desafio de saúde pública globalmente. O estresse oxidativo, levando a insulto cerebral secundário, permanece um problema a ser superado. O efeito benéfico do selênio ainda é inconclusivo, pois estudos anteriores mostraram resultados conflitantes.* **Objetivo:** *O estudo visou determinar o efeito da administração de selênio nos resultados de pacientes com LCT moderada e grave que se apresentaram ao nosso hospital.* **Métodos:** *O estudo consistiu em 84 pacientes, com 42 pacientes em cada categoria de LCT moderada e grave. Cada categoria foi dividida em dois grupos (A (grupo selênio) e B (grupo não-selênio)) com 21 pacientes em cada grupo. Os pacientes do grupo A receberam selênio, enquanto os pacientes do grupo B serviram como grupo controle. A pontuação da escala de resultado de Glasgow estendida dos pacientes em ambos os grupos foi determinada três meses após o trauma ou na morte do paciente.* **Resultados:** *A taxa de mortalidade foi a mesma em ambos os grupos de pacientes com LCT moderada (9,5% cada), enquanto a taxa de mortalidade foi significativamente maior no grupo não-selênio (90,5%) do que no grupo selênio (52,4%) de pacientes com LCT grave (P=0,006).* **Conclusão:** *A administração de selênio resultou em uma taxa de mortalidade significativamente reduzida entre os pacientes com LCT grave, mas não entre os pacientes com LCT moderada.*

Palavras-Chave: *Antioxidante; Escala de Glasgow estendida; Estresse oxidativo; Selênio; Lesão cerebral traumática*

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INTRODUCTION

Traumatic brain injury (TBI) is a significant cause of mortality and lifelong physical disability globally and it has been described as a silent pandemic[1]. Majority of poor outcome and deaths occur among individuals who are judged to have moderate or severe TBI[2]. Moderate and severe categories of TBI are responsible for the majority of poor outcome in patients who sustain TBI. A hospital-based study in India by Kamal et al.[3] showed that 34.58% of patients with moderate and severe TBI died while 67.21% of them had unfavorable outcome. Another hospital-based study in India by Deepika et al.[4] revealed that 60.7% of severe TBI patients had unfavorable outcome at 6 months post trauma while only 39.3% had favorable outcome. Tobi et al.[5] in Benin, South-South Nigeria reported 52.2% mortality rate among TBI patients admitted to the Intensive care unit (ICU) of whom 99.5% were moderate and severe; while in Ilorin, North-Central Nigeria, Tobi et al.[5] and Yusuf et al.[6] found that 88.4% of severe TBI patients died and none had good recovery. In order to secure maximum impact on alleviating the burden of TBI, the focus of care should therefore be predominantly directed at improving outcome in patients with moderate and severe injuries who constitute the poor risk group.

The most common cause of death and poor outcome following moderate and severe TBI among patients is secondary injury which results from oxidative stress, inflammatory changes and consequent cerebral oedema[7,8]. Over the years, cerebral oedema resulting from inflammatory changes has been managed by employing several means including elevation of patients' heads to improve venous return to the heart and the use of diuretics such as mannitol and furosemide while oxidative injury remains a problem. The imbalance between the production of scavenging anti-oxidant and free oxygen radicals constitutes the oxidative stress which triggers secondary brain injury that worsens outcome[7]. Following trauma to the brain, a mismatch occurs between the neuroprotective free radical scavenging system (antioxidant) and production of free oxygen radicals. The free radical production increases and as a result, the protective antioxidant system is overwhelmed, thus exposing the cerebral neurons to oxidative stress. It is expected that the administration of neuroprotective antioxidant agents may protect the injured brain and as such could lead to better outcome in TBI patients.

Certain agents such as Tirilazad and Dexanabinol have been tried to curb the oxidative stress in patients with TBI without any beneficial effect[9,10]. More recently, in further efforts to curb the effect of oxidative stress in TBI, selenium, an essential trace element with antioxidant, anti-inflammatory and immunomodulatory properties, has been tried. However, previous studies showed conflicting results[7,11]. Khalili et al. in a recent hospital-based prospective study in Iran found that selenium administration in patients with severe TBI significantly reduced the risk of unfavorable functional outcome as opposed to the control group[7]. However, Moghaddam et al. in another hospital-based prospective study in the same region found no difference in the functional outcome between the selenium treated TBI patients and the control group[11]. These results are conflicting and the debate continues as there is no consensus yet regarding the effect of selenium in the management of patients with traumatic brain injury.

OBJECTIVE

This study was conducted to determine the effect of selenium administration on the outcomes of adult patients who sustained moderate or severe TBI in our environment.

MATERIALS AND METHODS

The study was a single blind prospective randomized control trial, carried out over a period of 24 months at the division of Neurosurgery of the University of Ilorin Teaching Hospital, Ilorin. Ethical approval was obtained from the Health Research Ethics Committee of the hospital and informed consent was obtained from the caregiver of each of the patients. All patients with moderate or severe traumatic brain injury (based on Glasgow coma scale) who were aged 18 years old and above, admitted via the Accident and Emergency unit of the hospital presenting within 24 hours of the traumatic event and whose care givers consented their patients to take part in the study were included in the study. The following patients were excluded from the study; brain dead at admission or patient who died within 24 hours of admission, patients with poorly controlled diabetes mellitus and hypertension, patients with previous TBI, basal skull fracture, pregnant patients and patients who were known to have allergies to selenium sulfide shampoo in the past.

A total of 84 patients were enrolled into the study. A multistage sampling technique was utilized to allot the patients into different groups. participants were initially stratified into two strata; stratum 1 (moderate TBI group consisting of 42 patients) and stratum 2 (severe TBI group consisting of 42 patients). Subsequently, a simple random technique was employed to allocate the participants in each stratum into two study arms (group A-intervention/selenium group and group B-control/non-selenium group). Stratification was necessary so as to avoid confounding effect of different level of GCS, as severe TBI patients may generally fare worse than moderate TBI patients. Assignment into groups was done by stapled prelabelled slips; A1 to A21 for selenium treated group and B1to B21 for non-selenium treated group in an enclosed envelope for each stratum. Stapled prelabelled slips were hand-picked by the unit house officer or registrar at randomization and the envelope was reshuffled prior to each pick. The patients' caregivers were blinded as to whether or not their patients would take selenium.

Patients in group A (intervention group) in both moderate and severe TBI categories were administered 400μg of sodium selenite® (nature's field) via nasogastric tube (size 16). The first dose was administered within 24 hours of injury and this was repeated daily for 6 days, making a total of 7 days. The patients in group B served as the control group. All patients had standard TBI management protocol, with selenium administration being the only difference between the two groups. Patients who received selenium were monitored for presence of side effects of selenium such as nail discoloration, hair loss and garlic breath.

Glasgow Outcome Score Extended (GOS-E) of patients in both groups at discharge and monthly up to 3 months post trauma or till patient's demise were determined and recorded; this was dichotomized into favorable outcome defined as GOS-E of 5-8 and unfavorable outcome defined as GOS-E of 1-4 during analysis. Length of hospital stay for each patient was documented appropriately.

Data were collected using a predesigned proforma. The variables of interest were the GOS-E, mortality rate and length of hospital stay. The data were analyzed using Statistical Package for Social Sciences (IBM SPSS version 23.0) software (SPSS Inc., Chicago Illinois, USA). Tables and figure were used to represent descriptive statistics. Mann-Whitney U was used to analyze continuous variable (length of hospital stay), while chi square test and Fisher exact test were used to analyze categorical variables (GOS-E and mortality rate). Statistical significance was set at P value <0.05.

RESULTS

The mean age of all the patients was 36.60±12.97 years and majority of the patients (61.9%) were in the age range of 21-40 years (Table 1). Seventy-four patients (88.1%) were males, while 10 patients (11.9%) were females with male to female ratio of 7.4:1 (Table 1). Rider motorcycle road traffic crash accounted for the majority of the injuries, 44 (52.4%), followed by passenger motorcycle crash, 17 (20.2%) (Figure 1).

The socio-demographics, mechanisms of injury, computed tomographic scan findings and management of cases (ICU admission, surgical operation and administration of mannitol and lasix) were comparable between the selenium and non-selenium arms of severe TBI (P >0.05) (Table 2). Among the moderate group of TBI patients, both arms of selenium and non-selenium were comparable in terms of sex, mechanism of injury, CT scan findings, management (surgical intervention and administration of mannitol and lasix), however patients in the selenium arm were older (41.95±14.40 years) than the patients in the non-selenium arm (32.62±9.98 years) (P= 0.019) (Table 3).

The proportions of patients who had favorable outcome (GOS-E 5-8) at 3 months post trauma were the same in both selenium and non-selenium arms of moderate TBI group while among the severe

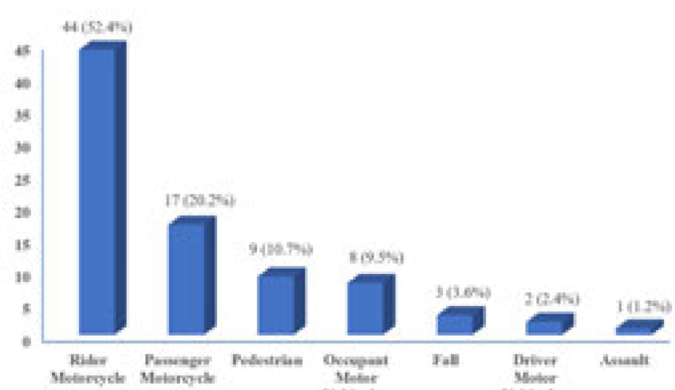

Figure 1. Mechanisms of injury of 84 patients in the study.

Table 1. Socio-demographics and clinical features of 84 patients who sustained traumatic brain injury.

Variables	Frequency	Percentage
Age groups (years)		
18-20	5	6.0
21 – 40	52	61.9
41 – 60	25	29.7
> 60	2	2.4
Mean ± SD	36.60 ± 12.97	
Gender		
Male	74	88.1
Female	10	11.9
Clinical features		
Immediate PTS	12	14.3
Early PTS	8	9.5
Vomiting	18	21.4
Long Tract Deficit	22	26.2

SD= Standard Deviation, PTS= Posttraumatic seizure.

TBI group, the proportion of patients with favorable outcome was insignificantly higher (28.6%) among those who received selenium than those who did not (4.8%) at 3 months post trauma (Tables 4 and 5). Although the mortality rate was the same in the selenium and non-selenium groups of moderate TBI patients (9.5% each), mortality rate was significantly higher in the non-selenium (90.5%) than in the selenium group (52.4%) of severe TBI patients (P=0.006) (Table 6). The median length of hospital stay in the selenium arm of moderate TBI patients was 12 days while it was 11 days in the non-selenium group (P=0.086). These were 34 days and 42.5 days respectively among the severe TBI patients (P=0.667). None of the patients who had selenium developed side effects related to selenium.

DISCUSSION

Even though selenium administration did not benefit patients who sustained moderate TBI in this study, it however led to reduced mortality rate among the severe TBI patients and also better favorable Glasgow outcome score (GOS) though this did not get to significant level. The small sample size of patients studied could have been the reason for this insignificant better favorable GOS-E observed among the severe TBI patients.

The majority (61.9%) of patients in this study were young adults (between 21 and 40 years of age). This is similar to a study by Yusuf et al. in Ilorin who reported that young adults within the age range of 15 and 44 years constituted 70.2% of patients with motorcycle-related head injuries[12]. Adam et al. in Ghana similarly reported highest incidence (29.66%) among young people with age ranging between 21 and 30 years[13].

Most of the patients were males (88.1%), which is in consonance with reports by many authors who reported male preponderance among patients who sustained TBI[2,12,14,15]. This study and previous studies found that traumatic brain injury occurs mostly in young male adults who represent the most active and adventurous members of the community and in many instances, the bread winners of their families. They are thus more exposed and vulnerable due to their involvement in many rigorous and risky activities. Although TBI is commoner among males, the outcome may not be affected by the gender of the patients as this study revealed that the gender was comparable between the selenium and non-selenium group of severe TBI patients despite the fact there was difference in the outcome (mortality rate) between the two groups. Rather, age may be a better socio-demographic determinant of outcome in TBI patients[16].

Road traffic crash accounted for most of the injuries in this study, representing 95.2% of all the causes of injury. Dewan et al.[2] reported similar findings of road traffic crash being the leading cause of TBI in Africa, while Adam et al. in Ghana reported cases of TBI to be due to road traffic crash in 91.21%, which is similar to the findings of this study[13]. Among the road traffic crashes, rider motorcycle crash was the highest (52.4%) followed by passenger motorcycle crash (20.2%) in the current study whereas Adeolu et al.[17] found that passenger motor vehicular crash was the leading cause of TBI in Ibadan, Southwestern, Nigeria. The discrepancy in the particular mode of road traffic crash between the current study and that of Adeolu et al. may be due to the fact that more recently, motorcycle riding is becoming the most common means of intra-state and sometimes, inter-state transportation. In contrast to the findings of this study, Rutland-Brown et al.[18] in the United States and Jonsdottir et al.[19] in Iceland reported fall as the leading cause of

TBI. Compared with the report from the United States and Iceland, predominance of road traffic crashes as mechanism of injury in the current study and many parts of Africa may be due to poor road networks and less adherence to traffic regulations than in the developed countries. Head trauma in particular is on the increase in our setting because of an increasing rate of road traffic crashes due to careless and unlicensed driving, bad roads and road designs, bad vehicles and illiteracy as reported by Odebode and Abubakar[20].

Table 2. Comparison of socio-demographics, mechanisms of injury and CT scan findings between selenium and non-selenium arms of patients with severe TBI.

Variables	Severe TBI		χ^2/t	*p* value
	Selenium (%)	Non-Selenium (%)		
Age groups(years)				
18-20	2 (9.5)	1 (4.8)	2.175^f	0.666
21 – 40	13 (61.9)	13 (61.9)		
41 – 60	6 (28.6)	5 (23.8)		
> 60	0 (0.0)	2 (9.5)		
Mean ± SD	33.67 ± 11.28	38.14 ± 14.33	-1.124	0.268
Gender				
Male	18 (85.7)	19 (90.5)	0.227^f	1.000
Female	3 (14.3)	2 (9.5)		
Mechanism of Injury				
Rider motorcycle RTC	10 (47.6)	11 (52.4)	3.164^f	0.610
Passenger motorcycle RTC	4 (19.0)	7 (33.3)		
Driver motor-vehicular RTC	0 (0.0)	0 (0.0)		
Occupant motor-vehicular RTC	4 (19.0)	1 (4.8)		
Pedestrian	2 (9.5)	1 (4.8)		
Fall	1 (4.8)	1 (4.8)		
Assault	0 (0.0)	0 (0.0)		
CT Findings				
Cerebral oedema				
Yes	13 (61.9)	14 (66.7)	0.104	0.747
No	8 (38.1)	7 (33.3)		
Intracranial hematoma				
Yes	4 (19.0)	9 (42.9)	2.785	0.095
No	17 (81.0)	12 (57.1)		
Cerebral Contusion				
Yes	16 (76.2)	12 (57.1)	1.714	0.190
No	5 (23.8)	9 (42.9)		
tSAH				
Yes	5 (23.8)	2 (9.5)	0.686^y	0.408
No	16 (76.2)	19 (90.5)		
Others				
Yes	2 (9.5)	0 (0.0)	0.525^y	0.469
No	19 (90.5)	21 (100.0)		

X^2= Chi square test, y= Yate corrected chi square test, f=Fisher exact test, t= independent student test, CT= computed tomographic, tSAH= traumatic subarachnoid hemorrhage, RTC= Road traffic crash.

Table 3. Comparison of socio-demographics, mechanisms of injury and CT scan findings between selenium and non-selenium arms of patients with moderate TBI.

Variables	Moderate TBI		χ^2/t	*p* value
	Selenium (%)	Non-Selenium (%)		
Age groups (years)				
18-20	1 (4.8)	1 (4.8)	7.177[f]	**0.020**
21 – 40	9 (42.9)	17 (81.0)		
41 – 60	11 (52.4)	3 (14.3)		
> 60	0 (0.0)	0 (0.0)		
Mean ± SD	41.95 ± 14.40	32.62 ± 9.98	2.441	**0.019**
Gender				
Male	17 (81.0)	20 (95.2)	2.043[f]	0.343
Female	4 (19.0)	1 (4.8)		
Mechanism of Injury				
Rider motorcycle RTC	12 (57.1)	11 (52.4)	8.942[f]	0.101
Passenger motorcycle RTC	1 (4.8)	5 (23.8)		
Driver motor-vehicular RTC	0 (0.0)	2 (9.5)		
Occupant motor-vehicular RTC	2 (9.5)	1 (4.8)		
Pedestrian	5 (23.8)	1 (4.8)		
Fall	1 (4.8)	0 (0.0)		
Assault	0 (0.0)	1 (4.8)		
CT scan findings				
Cerebral oedema				
Yes	6 (28.6)	4 (19.0)	0.525	0.469
No	15 (71.4)	17 (81.0)		
Intracranial haematoma				
Yes	2 (9.5)	7 (33.3)	2.263[y]	0.132
No	19 (90.5)	14 (66.7)		
Cerebral contusion				
Yes	18 (85.7)	14 (66.7)	2.100	0.147
No	3 (14.3)	7 (33.3)		
tSAH				
Yes	3 (14.3)	0 (0.0)	1.406[y]	0.230
No	18 (85.7)	21 (100.0)		
Others				
Yes	1 (4.8)	2 (9.5)	0.000[y]	1.000
No	20 (95.2)	19 (90.5)		

X^2= Chi square test, t= independent student test, y= Yate corrected chi square test, f=Fisher exact test, SD= standard deviation, CT=computed tomographic, tSAH= traumatic subarachnoid hemorrhage, RTC=Road traffic crash TBI=Traumatic brain injury.

Table 4. Comparison of outcomes between the selenium and non-selenium groups of moderate TBI patients.

Variables	Moderate		χ ²/u	*p* value
	Selenium (%)	Non-Selenium (%)		
Length of hospital stay (Days)				
Median (IQR)	12.00 (10.0, 15.0)	11.00 (7, 12)	122.000[u]	0.086
GOS-E at Discharge				
Favorable	17 (81.0)	17 (81.0)	0.001[f]	1.000
Unfavorable	4 (19.0)	4 (19.0)		
GOS-E at 3 months				
Favorable	19 (90.4)	19 (90.4)	0.026	0.872
Unfavorable	0 (0.0)	0 (0.0)		
Median (IQR)	8.00 (8, 8)	8.00 (8, 8)	171.000[u]	0.680

X^2=Chi-square test, u= Mann-Whitney U, y= Yate corrected, f=Fisher Exact test, GOS-E= Glasgow Outcome Score Extended, IQR= Interquartile Range.

Table 5. Comparison of outcomes between the selenium and non-selenium groups of severe TBI patients.

Variables	Severe		χ ²/u	*p* value
	Selenium (%)	Non-Selenium (%)		
Length of hospital stay (Days)				
Median (IQR)	34.00 (16.75, 83.50)	42.50 (15.00, -)	8.000[u]	0.667
GOS-E at Discharge				
Favorable	6 (28.6)	1 (4.8)	4.679[f]	0.093
Unfavorable	15 (71.4)	20 (95.2)		
GOS-E at 3 months				
Favorable	6 (28.6)	1 (4.8)	0.068[f]	1.000
Unfavorable	4 (19.0)	1 (4.8)		

f-Fishers Exact test, Yates Corrected chi-square test, [u]- Mann-Whitney U, GOS-E-Glasgow Outcome Score Extended, IQR-Interquartile Range.

Table 6. Mortality rate among 84 patients with moderate and severe TBI in both selenium and non-selenium groups.

Variables	Mortality		χ ²	*p* value
	Yes (%)	No (%)		
Severity of TBI				
Moderate	4 (9.5)	38 (90.5)	33.402	**0.001**
Severe	30 (71.4)	12 (28.6)		
Moderate TBI				
Selenium	2 (9.5)	19 (9.5)	0.276	0.599
Non-selenium	2 (9.5)	19 (19.5)		
Severe TBI				
Selenium	11 (52.4)	10 (47.6)	7.467	**0.006**
Non-Selenium	19 (90.5)	2 (9.5)		

X^2=Chi-square test.

The management of patients in both the intervention and control groups of moderate and severe TBI were similar with administration of selenium in the intervention group, being the only difference. No patient in both arms of the moderate TBI group was admitted into the intensive care unit, while 25 patients (59.5%) in the severe group were admitted into the ICU (12 patients and 13 patients in the selenium and non-selenium groups respectively). Moderate TBI patients are not routinely admitted into the ICU except otherwise indicated, such as patients with concomitant respiratory problems with hypoxia needing intubation and ventilation. However, severe TBI on its own is an indication for ICU admission for endotracheal intubation and mechanical ventilation due to inability to control airway and possible inadequate oxygen saturation. All patients with severe TBI in the current study could not be admitted into the ICU due to various reasons including lack of ICU bed spaces and financial constraint on the part of patients' caregivers. Balogun et al.[21] reported a slightly higher ICU admission rate (68.9%) in Ibadan but however admitted that there was delay in admission and the commonest reason identified was lack of ICU bed spaces. The low rate of ICU admission in the current study (due to various reasons such as lack of available bed space and financial constraints on the part of the patients' relatives) could have affected functional outcome of patients in the severe TBI group generally. A study by Mathias et al. in Calabar showed that ICU admission reduced mortality rate from 45.8% to 37.0% among patients who sustained severe TBI[22]. Although there was low rate of ICU admission among the severe TBI patients generally, there was no significant difference between the selenium, 12 patients (57.1%) and non-selenium, 13 (61.9%) groups.

There was no difference in the outcome of patients between the selenium and non- selenium groups of moderate TBI patients in this study as GOS-E at 3 months post trauma were the same in both groups, whereas there was a difference in the GOS-E between the selenium and non-selenium groups of severe TBI group in the favor of severe group, though non-statistically significant. Among the severe TBI patients, 28.6% and 4.8% had favorable outcome at discharge in the selenium and non-selenium groups respectively. These proportions remained the same at 3 months post trauma, although one of the patients with lower severe disability in the non-selenium group had improved to upper severe disability by 3 months post trauma. These findings are in contrast to those of Khalili et al. who reported improving unfavorable outcome from discharge to 6 months post trauma[7]. The progressive improvement in GOS-E noted by Khalili et al. at 6 month post trauma as against the current study which exit point was at 3 months post trauma may be due to difference in the time of GOS-E assessment as improvement is expected to continue for varying period of time post trauma. If the patients in this study were followed up for 6 months, probably the same trend would have been noted.

The mortality rate was significantly higher in the non-selenium group (90.5%) of severe TBI patients than in the selenium group (57.1%), whereas the mortality rate was equal for both selenium and non-selenium groups (9.5% in each group) among the moderate TBI patients. Moghaddam et al.[11] reported higher mortality rate in control group than selenium group; 19.6% and 15.8% respectively, although this difference was not statistically significant. In contrast Khalili et al.[7] reported almost the same mortality rate of 15.2% and 15.4% for selenium and non-selenium groups respectively among severe TBI patients. The observed difference in mortality rate between this study and those of Moghaddam and Khalili could be due to difference in the methodology. Whereas Moghaddam et al. studied both moderate and severe TBI patients together without stratification (difference in severity of injury could have affected their result), Khalili et al. commenced selenium administration at 48 hours post trauma as against this study which commenced selenium administration within 24 hours of trauma at which period oxidative stress is considered maximal.

The fact that selenium administration resulted in significant reduced mortality rate among severe TBI patients and not the moderate TBI group may be due to higher oxidative stress in the severe group compared to the moderate group due to the severity of injury and hence the effect of the anti-oxidant agent. Ogunleye et al. reported that oxidative stress correlates with severity oh head injury in rats, being highest in severe injury and lowest in mild head injury.

As against this study, Moghaddam et al.[11] reported that age of patients in both selenium and non-selenium groups of the studied patients was similar (p=0.38). Even though the age of patients in both selenium and non-selenium arms of severe TBI category in the current study was also comparable (p=0.268), the patients in non-selenium group were significantly older than the patients in the non-selenium group (p=0.019). This might probably account for the no difference in the outcomes (GOS-E and mortality rate) between the intervention and control groups of moderate TBI patients, as age has been found to be one of the prognostic factors in TBI patients[16,23,24]. Age matching between the two groups would have probably given the true picture of effect of selenium administration among the moderate TBI patients.

In this study, patients in the severe TBI group spent significantly longer time on hospital admission than the patients in the moderate TBI group (p=0.001). This may be due to severity of injury in the former group and longer time to recovery. The patients in the selenium arm of moderate TBI group spent a longer time on hospital admission while in the severe TBI group, the patients in the non-selenium arm spent a longer time on admission. However, these differences were not statistically significant (p values were 0.086 and 0.667) respectively. The finding of shorter hospital stay among the severe TBI patients who were administered selenium in this study is in keeping with the systematic review by Huang et al.[25], who reported that selenium supplementation was associated with shorter ICU and hospital length of stay. In contrast, Khalili et al.[7] reported that patients in the selenium arm of severe TBI group spent 19 days on hospital admission versus 15 days in the control group.

CONCLUSION

The study revealed that selenium administration significantly reduced mortality rate and insignificantly improved favorable Glasgow Outcome Score-Extended and length of hospital stay among the severe TBI patients. These findings were not however reproducible among patients who sustained moderate TBI. Therefore, selenium administration may be beneficial in the management of severe TBI patients in whom oxidative stress is expected to be higher due to the severity of injury compared to the moderate group.

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Interlaminar Endoscopic Lumbar Discectomy: analysis of pain improvement and clinical outcomes

Discectomia Lombar Endoscópica Interlaminar: análise da melhora da dor e resultados clínicos

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ABSTRACT

Introduction: *The lumbar interlaminar endoscopic technique is a minimally invasive approach that allows access to the lumbar spine through the interlaminar space, aiming for neural decompression and disc herniation removal. This technique has gained attention for minimizing tissue trauma, reducing recovery time, and effectively relieving symptoms in patients with lumbar disc herniation. It is particularly indicated for central or centro-lateral herniations at the L4-L5 and L5-S1 levels..* **Objective:** *To report our team's experience with the interlaminar endoscopic lumbar discectomy (IELD) technique in Brazil, describing and quantifying postoperative clinical outcomes in patients indicated for lumbar disc herniation.* **Methods:** *This retrospective study included 112 patients who underwent IELD between May 2021 and November 2024. Patient data were collected from an institutional surgical database. Primary outcomes included postoperative complications such as paresthesia, epidural hematoma, infection, and reoperation, as well as pain improvement assessed by the Visual Analog Scale (VAS). Secondary outcomes included operative time and the occurrence of dural sac or nerve root injuries. Patients were followed for at least six months and up to two years. Statistical analysis was conducted using paired t-tests or Wilcoxon signed-rank tests, considering p < 0.05 as statistically significant.* **Results:** *The mean patient age was 50.06 years (SD 8.80), with a balanced sex distribution. The most commonly operated levels were L5-S1 (46.4%) and L4-L5 (26.8%). The mean operative time was 116.78 minutes (SD 31.28), with no intraoperative nerve root or dural sac injuries. The mean preoperative VAS score of 9.18 (SD 0.47) significantly decreased to 3.02 (SD 1.06) postoperatively (p < 0.001). No postoperative complications or reoperations were reported. The mean hospital stay was 0.26 days (SD 0.68).* **Conclusion:** *The lumbar interlaminar endoscopic technique is a safe and effective approach for L4-L5 and L5-S1 disc herniations, ensuring pain reduction, early recovery, and no severe complications.*

Keywords: *Endoscopic discectomy; Lumbar vertebrae; Intervertebral disc displacement; Minimally invasive surgical procedures; Pain management; Treatment outcome*

RESUMO

Introdução: *A técnica endoscópica lombar interlaminar é uma abordagem minimamente invasiva que permite o acesso à coluna lombar pelo espaço interlaminar, com o objetivo de descompressão neural e remoção da hérnia discal. Essa técnica tem ganhado destaque por minimizar o trauma tecidual, reduzir o tempo de recuperação e proporcionar alívio sintomático eficaz em pacientes com hérnia de disco lombar. É especialmente indicada para hérnias centrais ou centro-laterais nos níveis L4-L5 e L5-S1.* **Objetivo:** *Relatar a experiência de nossa equipe com a técnica de discectomia lombar endoscópica interlaminar (IELD) no Brasil, descrevendo e quantificando os desfechos clínicos pós-operatórios em pacientes com indicação para hérnia de disco lombar.* **Métodos:** *Este estudo retrospectivo incluiu 112 pacientes submetidos à IELD entre maio de 2021 e novembro de 2024. Os dados dos pacientes foram obtidos a partir de um banco de dados cirúrgico institucional. Os desfechos primários incluíram complicações pós-operatórias, como parestesia, hematoma epidural, infecção e necessidade de reoperação, além da melhora da dor avaliada por meio da Escala Visual Analógica (EVA). Os desfechos secundários incluíram o tempo operatório e a ocorrência de lesões ao saco dural ou à raiz nervosa. Os pacientes foram acompanhados por um período mínimo de seis meses e máximo de dois anos. A análise estatística foi realizada utilizando testes t pareados ou o teste de Wilcoxon, considerando-se p < 0,05 como estatisticamente significativo.* **Resultados:** *A média de idade dos pacientes foi de 50,06 anos (DP 8,80), com distribuição equilibrada entre os sexos. Os níveis mais frequentemente abordados foram L5-S1 (46,4%) e L4-L5 (26,8%). O tempo operatório médio foi de 116,78 minutos (DP 31,28), sem ocorrência de lesões intraoperatórias às raízes nervosas ou ao saco dural. A pontuação média na EVA pré-operatória de 9,18 (DP 0,47) apresentou redução significativa para 3,02 (DP 1,06) no pós-operatório (p < 0,001). Não foram registradas complicações pós-operatórias ou reoperações. O tempo médio de internação foi de 0,26 dias (DP 0,68).* **Conclusão:** *A técnica endoscópica interlaminar lombar mostrou-se segura e eficaz para o tratamento de hérnias discais nos níveis L4-L5 e L5-S1, proporcionando redução da dor, recuperação precoce e ausência de complicações graves.*

Palavras-Chave: *Discectomia endoscópica; Vértebras lombares; Deslocamento do disco intervertebral; Procedimentos cirúrgicos minimamente invasivos; Controle da dor; Resultado do tratamento*

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INTRODUCTION

The lumbar interlaminar endoscopic technique is a minimally invasive procedure that allows access to the lumbar spine through the interlaminar space, aiming for neural decompression and disc herniation removal[1]. This approach has been highlighted for minimizing tissue trauma, reducing recovery time, and providing effective symptom relief in patients with lumbar pathologies[2]. The evolution of endoscopic techniques in spine surgery began in the 1970s with the development of flexible endoscopes and refined instrumentation. Over the years, technological advancements and a deeper understanding of spinal anatomy have led to the refinement of these techniques, culminating in the application of the interlaminar approach for the treatment of lumbar disc herniations[3].

The most frequently used endoscopic approaches are the interlaminar and transforaminal techniques. In general, foraminal and extraforaminal herniations are preferably treated using the transforaminal route or the extreme lateral approach. Conversely, the interlaminar technique is more suitable for the treatment of centrally or centro-laterally located disc herniations. At the L5-S1 level, the presence of the iliac crest can hinder transforaminal access, making the interlaminar approach the most appropriate option for this segment[4].

Currently, the lumbar interlaminar endoscopic technique is primarily indicated for the treatment of lumbar disc herniations, particularly those at the L4-L5 and L5-S1 levels. Additionally, it may also be indicated in cases of spinal canal stenosis, allowing for neural structure decompression[5]. Recent studies suggest that this technique is effective in symptom relief and improving patients' quality of life. For instance, a study involving 132 patients who underwent interlaminar endoscopic discectomy demonstrated significant clinical improvement, with a low complication rate and early return to daily activities[6].

Given the increasing adoption of this technique worldwide, this study aims to report our experience in Brazil with the lumbar interlaminar endoscopic technique by describing the surgical procedure and evaluating intraoperative and postoperative morbidity parameters.

METHODS

General information

Patient data were retrospectively collected from the database of the Fundação de Neurologia e Neurocirurgia – Instituto do Cérebro between May 2021 and November 2024. The database was updated as each procedure was performed, serving as a secure surgical record rather than a dataset specifically designed for this research. Furthermore, this manuscript was written in accordance with the Preferred Reporting of Case Series in Surgery (PROCESS)[7] guidelines. It also received approval from the Ethics Committee (CAAE: 88271225.2.0000.5028).

All patients who underwent DLEI surgery for lumbar disc herniation were included. The only exclusion criterion was age under 18 years. The primary outcomes of this study included postoperative complications such as paresthesia (assessed using the Leeds Assessment of Neuropathic Symptoms and Signs – LANNS scale), sympathetic changes, epidural hematoma, infection, reoperation, and pain improvement based on the Visual Analog Scale (VAS). Injuries were defined as any impairment of these structures, whether due to accidental incision or inadequate mobilization, leading to intraoperative or postoperative consequences. Secondary outcomes included dural sac and nerve root injuries, as well as operative time, which was measured from the initial skin incision to closure. Pain improvement was evaluated using the VAS, comparing preoperative and postoperative scores.

Additional information, including the number of patients, sex, mean age, body mass index (BMI), year of surgery and history of prior spine surgery; presenting symptoms and operated levels was also collected. Furthermore, all patients were retrospectively followed for a minimum of six months and up to two years. Follow-up was conducted through routine medical consultations after the procedure, assessing potential complications and pain progression. These follow-ups were performed according to institutional protocol at 1 week, 1 month, 6 months, 1 year, and 2 years postoperatively. Although not all patients completed 1- or 2-year follow-ups, all had at least six months of follow-up. All data, including intraoperative records, had been previously documented in the institutional database.

Surgical technique

All procedures were conducted under general anesthesia with the patient positioned laterally and the hips flexed to optimize exposure of the interlaminar space. The entirety of the surgical series was performed by the senior author, a surgeon with extensive experience in microsurgical and microendoscopic discectomy techniques. Intraoperative fluoroscopy (posteroanterior and lateral views) was employed to accurately localize the interlaminar window at the L4–L5 or L5–S1 levels.

A minimal skin incision was made (Figure 1), followed by progressive soft tissue dilation to establish a working corridor through which the endoscopic surgical system and working cannula were introduced. All operative steps were conducted under continuous saline irrigation, providing clear endoscopic visualization.

Initial exposure targeted the inferior margin of the cranial lamina on the symptomatic side and the adjacent ligamentum flavum, both visualized endoscopically. A 5-mm fenestration of the ligamentum flavum was performed using a laminectomy rongeur, allowing direct access to the spinal canal. For interlaminar spaces with a diameter less than 7 mm, enlargement was performed to accommodate the working cannula (Figure 2).

At the L4–L5 level, partial resection of the cranial lamina was accomplished using a direction-variable drill to sufficiently widen the interlaminar window. At L5–S1, the ligamentum flavum was dissected to expose the spinal canal; in select cases with narrow anatomy, further bone resection was also conducted using the variable-angle drill.

Subsequently, the herniated nucleus pulposus was carefully identified and excised to achieve decompression of the affected nerve root (Figure 3). Before concluding the procedure, meticulous inspection ensured the absence of residual disc fragments, cerebrospinal fluid leakage, or active hemorrhage. No surgical drains were placed.

Statistical analysis

The statistical analysis was conducted to systematically evaluate the collected data and interpret the study outcomes with scientific rigor. Descriptive statistics were initially calculated for all collected variables, including means, standard deviations, medians, and interquartile ranges for continuous variables, as well as absolute and relative frequencies for categorical variables. To compare pre- and postoperative VAS scores, a paired t-test was used for normally distributed data, while the Wilcoxon signed-rank test was applied otherwise. Normality was assessed using the Shapiro-Wilk test. A significance level of 5% ($p < 0.05$) was adopted, and all confidence intervals were reported with 95% reliability. Statistical analyses were performed using R software (version 4.3.1), ensuring the reproducibility and accuracy of the results.

Figure 1. Skin incision approximately 1 cm in length.

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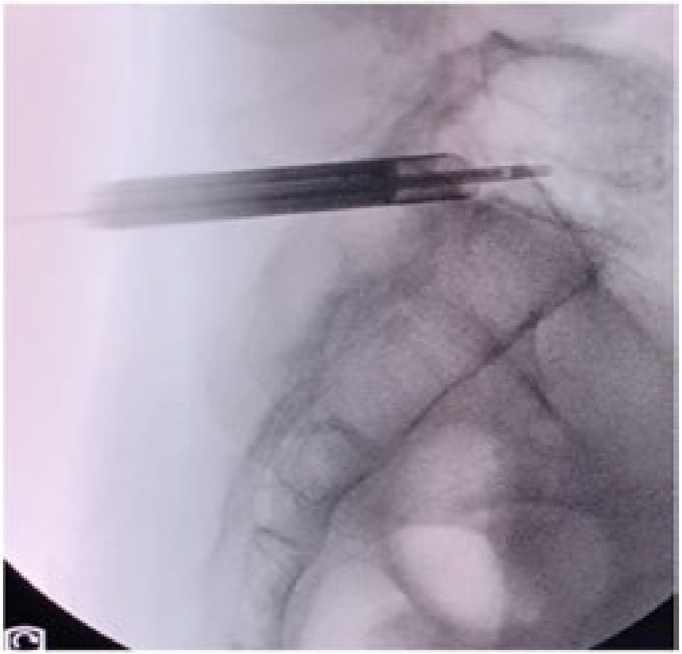

Figure 2. Intraoperative image of endoscopic decompression.

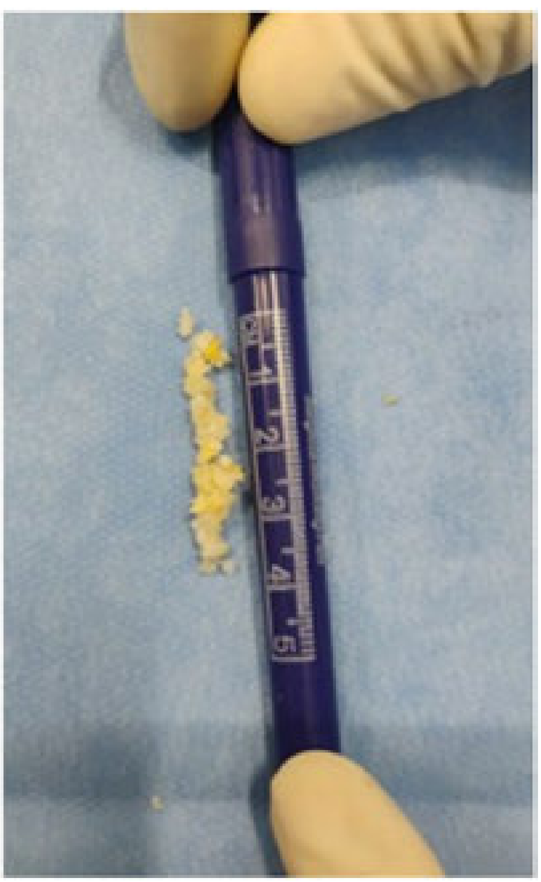

Figure 3. Resected herniated content.

RESULTS

A total of 112 patients were included in this case series (Table 1), with a mean age of 50.06 years (SD 8.80) and a BMI of 25.21 kg/m^2 (SD 2.08). The sex distribution was balanced (52 males and 60 females), and most procedures were performed in 2023 and 2024, representing 83.0% of the cases.

The most frequently operated levels were L5-S1 (46.4%) and L4-L5 (26.8%), with a predominance of right-sided access (55.4%) (Table 2). No intraoperative nerve root or dural sac injuries were recorded. The mean operative time was 116.78 minutes (SD 31.28).

Follow-up was complete for all patients up to six months, with 37.5% and 5.35% available at one and two years, respectively (Table 3). The mean preoperative VAS score was 9.18 (SD 0.47), which significantly decreased to 3.02 (SD 1.06) postoperatively ($p < 0.001$). No postoperative complications, including paresthesia, sympathetic changes, epidural hematoma, infection, or reoperation, were observed. The mean hospital length of stay was 0.26 days (SD 0.68).

Table 1. Demographic Data.

General characteristics	
Number of Patients, n	112
Mean age, y (SD)	50.06 (8.80)
Age range, y	32 - 74
Median age, y	49
Sex (male/female), n	52/60
Mean BMI, kg/m2 (SD)	25.21 (2.08)
Year of Surgery	**n**
2021	9
2022	10
2023	59
2024	34

Description: BMI = Body Mass Index; SD = Standard Deviation.

Table 2. Intraoperative Parameters.

Operated Levels	
L1-L2-L3	1
L2-L3-L4	1
L3-L4	3
L4-L5	30
L4-L5-S1	25
L5-S1	52
Access in relation to the patient	**n**
Left-sided	50
Right-sided	62
Intraoperative injury	
Nerve root involvement, n (%)	0
Dural sac injury, n (%)	0
Operative time, min (SD)	116.78 (31.28)

Description: SD = Standard Deviation.

Table 3. Postoperative Parameters.

Follow-up	n (%)
1 week	112 (100)
1 month	112 (100)
6 months	112 (100)
1 year	42 (37.5)
2 years	6 (5.35)
VAS Scale	
Before surgery, SD	9.18 (0.47)
After surgery, SD	3.02 (1.06)
p-value	< 0.001
Postoperative complications	**n (%)**
Paresthesia	0
Lanns Scale	-
Sympathetic changes	0
Epidural hematoma	0
Infection	0
Reoperation	0
Length of stay, days (SD)	0.26 (0.68)

Description: VAS = Visual Analog Scale; SD = Standard Deviation. We defined $p < 0.05$ as the threshold for statistical significance.

DISCUSSION

The results of the present study demonstrated that the lumbar interlaminar endoscopic technique is a safe and effective approach for the treatment of lumbar disc herniations, particularly at the L4-L5 and L5-S1 levels. The significant reduction in postoperative pain, as reflected by the decrease in Visual Analog Scale (VAS) scores, is consistent with previous studies that have reported substantial pain relief and improved quality of life in patients undergoing this technique[8].

This study stands out for reporting the Brazilian experience with the interlaminar endoscopic technique, contributing to the understanding of the feasibility and safety of this procedure within a national context. The absence of significant intraoperative and postoperative complications reinforces the safety of the technique. Although previous studies have reported complication rates ranging from 5% to 12%, with disc herniation recurrence rates of up to 9.8%[9], our study did not observe such events. This may be attributed to the expertise of the surgical team.

Another relevant aspect is the mean surgical duration of 116.78 minutes. This duration is comparable to recent studies that have reported similar average surgical times, such as that of Kim et al.[10], which found a mean time of 107 minutes in patients undergoing the interlaminar technique[10], and the study by Morale et al.[11], which compared different approaches and found similar average times for the interlaminar technique[11]. These variations may be associated with factors such as anatomical characteristics of the studied population, institutional protocols, and the level of experience of the surgical team.

The high patient satisfaction rate and early return to daily activities are also in agreement with findings in the literature. A retrospective analysis of 545 patients found that 81% reported significant symptom improvement and resumed their usual activities within similar timeframes to our results[12].

Finally, the findings of this study reinforce that the lumbar interlaminar endoscopic technique can be considered a viable alternative to conventional microdiscectomy, yielding equivalent or superior clinical outcomes with lower complication rates[13]. The consolidation of this minimally invasive approach will depend on the widespread dissemination of specialized surgical training and the expansion of evidence supporting its safety and efficacy.

TIPS AND TRICKS

One of the key contributors to the favorable outcomes observed in this study was the meticulous surgical strategy employed during the endoscopic interlaminar discectomy procedures. The combination of precise fluoroscopic targeting and minimally invasive access allowed for effective decompression with minimal disruption to surrounding anatomical structures. Accurate localization of the interlaminar window using posteroanterior and lateral fluoroscopy ensured that the working cannula was positioned with optimal precision, reducing the need for excessive tissue manipulation.

The use of soft tissue dilators and a working cannula through a small skin incision, along with continuous saline irrigation, provided a stable and clear endoscopic field. In cases with narrow interlaminar spaces (<7 mm), selective bony decompression using a direction-variable drill allowed safe expansion of the window, particularly at L4–L5 and L5–S1 levels. This approach enabled targeted access to the herniated disc without compromising spinal integrity or increasing the risk of dural tears.

An essential element in enhancing patient safety and minimizing neurological complications was the implementation of intraoperative neurophysiological monitoring (IONM). Multimodal IONM—including motor evoked potentials (MEPs), somatosensory evoked potentials (SSEPs), and electromyography (EMG)—was employed to monitor the integrity of neural structures in real time. The decision to incorporate IONM aligns with recent recommendations from professional societies such as the North American Spine Society (NASS), which recognize its value in procedures with potential risk of nerve root injury, especially when performed in anatomically constrained areas.

Importantly, IONM provided continuous feedback during critical stages of the surgery, enabling the surgical team to make immediate adjustments upon detecting changes in neurophysiological signals. This strategy likely contributed to the absence of new postoperative neurological deficits in our cohort. Moreover, the interpretation and supervision of IONM by certified neurophysiology professionals further reinforced the reliability of intraoperative alerts, ensuring timely and informed surgical responses.

In summary, the integration of refined surgical techniques with advanced neuromonitoring protocols not only enhanced surgical precision but also played a critical role in preventing neural injury, thus supporting the safety and efficacy of the endoscopic interlaminar approach.

STRENGTHS AND LIMITATIONS

This study has some limitations. The retrospective design may be subject to selection bias and limitations in data standardization, which could impact the generalizability of the results. Although the sample of 112 patients is relevant, larger studies could strengthen the conclusions, particularly regarding long-term safety and efficacy. Additionally, despite a minimum follow-up period of six months, only 5.35% of patients completed two years of follow-up, limiting the analysis of herniation recurrence.

However, the study also presents several strengths. There was a significant reduction in postoperative pain without severe intraoperative complications, reinforcing the safety of the technique. The mean surgical time of 116.78 minutes is consistent with international studies, and the average hospital stay of 0.26 days supports rapid recovery. The retrospective follow-up ranging from six months to two years allows for a more comprehensive assessment of clinical outcomes. These findings confirm the feasibility of the interlaminar endoscopic technique as a safe and effective alternative for treating lumbar disc herniations, contributing to its broader adoption in the national setting.

CONCLUSION

The lumbar interlaminar endoscopic technique has proven to be a safe and effective approach for the treatment of disc herniations. The present study, by analyzing the Brazilian experience with this technique, confirmed its feasibility by demonstrating a significant reduction in postoperative pain, the absence of severe intraoperative complications, and early patient recovery. The mean surgical time of 116.78 minutes was consistent with international studies, reinforcing the applicability of this approach in different clinical settings.

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Evaluation of Arteriography Time in Non-Thrombosed Intracranial Aneurysms Completely After Endovascular Treatment: a systematic review

Periodicidade da Arteriografia em Aneurismas Intracranianos Não Trombosados Após Tratamento Endovascular: uma revisão sistemática

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ABSTRACT

Intracranial aneurysms are common and frequently seen by neurologists. This is an anomalous dilation of a cerebral artery, which results in the formation of a sac or balloon located in the wall of the blood vessel. This research aims to study and analyze the frequency of arteriographies in patients with intracranial aneurysms that have not completely thrombosed by selecting appropriately preselected original articles. This integrative, fundamental, observational and descriptive systematic review results in the idea that intracranial aneurysms imaging in the endovascular era enables surveillance and post-treatment follow-up, prejudging possible future undesirable risks. In conclusion, there is a need for medical follow-up using arteriographies in these specific patients with personalized treatment. Additionally, no exact period was determined for monitoring with the use of imaging, only its relevance to avoid undesirable progression of the pathology.

Keywords: *Angiography; Endovascular procedures; Follow-up; Intracranial aneurysm*

RESUMO

Os aneurismas intracranianos são comuns e frequentemente vistos por neurologistas. Trata-se de uma dilatação anômala de uma artéria cerebral, que resulta na formação de um saco ou balão localizado na parede do vaso sanguíneo. Esta pesquisa tem como objetivo estudar e analisar a frequência de arteriografias em pacientes com aneurismas intracranianos que não sofreram trombose completa, selecionando artigos originais pré-selecionados adequadamente. Esta revisão sistemática integrativa, fundamental, observacional e descritiva resulta na ideia de que a imagem de aneurismas intracranianos na era endovascular permite a vigilância e o acompanhamento pós-tratamento, prejulgando possíveis riscos indesejáveis futuros. Em conclusão, há necessidade de follow-up médico por meio de arteriografias nesses pacientes específicos com tratamento personalizado. Além disso, não foi determinado um período exato para o acompanhamento com o uso de imagens, apenas sua relevância para evitar a progressão indesejável da patologia.

Palavras-Chave: *Angiografia; Procedimentos endovasculares; Follow-up; Aneurisma intracraniano*

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INTRODUCTION

The description of the medical term "Intracranial Aneurysm (IA)" has undergone a lot of analysis and study until a concept that fits the medical question was reached. This pathology is common in society and its recurrence is directly linked to various factors, presenting a significant risk of mortality and morbidity when ruptured. Genetic factors, demographic and environmental risks, infectious and autoimmune factors, an increase in proteolytic enzymes and mechanical factors are some of the factors that influence the development of an aneurysm, according to Antonio Carlos Lopes in his book *Tratado de Clínica Médica*[1] .

To this day, there is still a great deal of study and dedication on the part of health professionals to achieve better treatment for IAs. That said, there is a need for a better understanding of neuroimaging tests that can facilitate the prognosis of patients with intracranial aneurysms. Therefore, it is worth highlighting the importance of studies on the time needed to perform and/or redo arteriographies in cases of non-thrombosed aneurysms completely after intravenous treatment.

Arteriography is a type of imaging test used to visualize the body's arteries, assessing their functions and structures. Thus, when an aneurysm occurs, there is a dilation of the arterial wall which suffers alterations to its integrity, becoming thinner and more fragile, forming a "pocket" in its wall which, if left untreated, can rupture, leading to numerous consequences[2] . Perhaps one of the most important is hospitalization for aneurysmal subarachnoid hemorrhage. Therefore, although the arteriography procedure is crucial for diagnosing and monitoring various vascular conditions and is important in the treatment of intracranial aneurysms, the frequency of this neuroimaging test after intravenous treatment in IAs is still a matter of debate and deserves to be discussed.

The risk of ruptured IAs is notorious and depends on the location, size, characteristics and factors of the patient, including age, gender, ethnicity and additional risk factors (hypertension, previous SAH, smoking)[3] .

METHOD

This study was designed and conducted to analyze and review the periodicity of arteriography in patients with non-thrombosed aneurysms after endovascular treatment. This is an integrative, fundamental, observational and descriptive systematic review.

The research was based on the question of how long it takes and how often to carry out the imaging test described as arteriography in patients with intracranial aneurysms that have completely thrombosed after endovascular treatment. The medical literature on this subject was reviewed from 2000 to August 2024. The databases used were PubMed and the keywords used were: "Intracranial Aneurysm"; "Endovascular Procedures"; "Angiography" and "Follow-Up Studies".

The inclusion criteria for the studies reviewed were studies carried out from the 2000s onwards that provide information on the subject and answer the question of the appropriate regularity and whether it is necessary to carry out arteriography in intracranial aneurysms after endovascular treatment. In addition, it is important to report on patients with intracranial aneurysms that have not completely thrombosed and to document neurological complications during follow-up.

The articles excluded for evaluation were those classified as systematic reviews and studies carried out before the year 2000. In addition, studies that do not show the use and frequency of arteriography and studies that do not address the subject adequately, i.e. abandon the main point of the study were also excluded (Figure 1).

RESULTS

According to the study on Robotic-Assisted Intracranial Aneurysm Treatment, neuroimaging exams are necessary for a one-year follow-up (average time), since 4 of the 6 aneurysms investigated in this study were completely obliterated and the remaining two were occluded, according to arteriography. All the patients selected underwent clinical follow-up for an average of 10.0 + 1.6 months and reported good health, i.e. there were no problems related to the procedure. However, angiography was pertinent for categorizing

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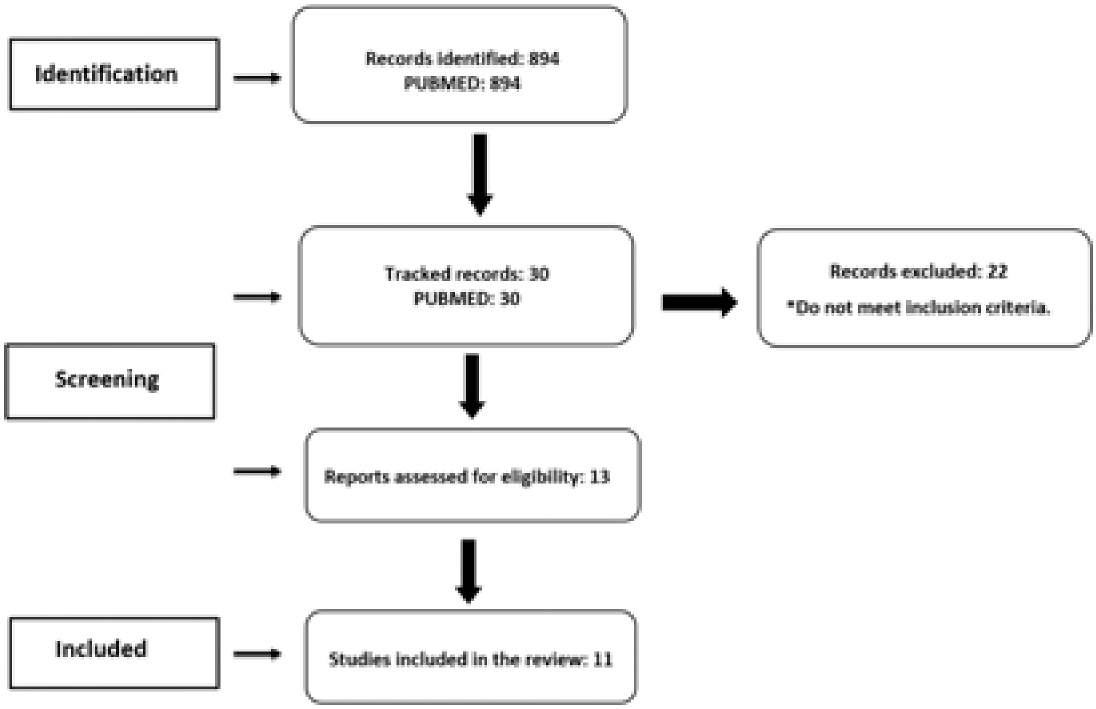

Figure 1. PRISMA, research search strategy flow diagram showing the identification, screening, eligibility, inclusion and exclusion processes.

the Raymond-Roy Occlusion Classification (RROC) and negative incidents[4]. In addition, patients with unruptured aneurysms were discovered incidentally. The evaluation of IAs using angiography after intravenous treatment to portray clinical results and prognosis at a more recent mean follow-up of 10.0 ± 1.6 months[4].

Despite being an asymptomatic pathology throughout life, aneurysms that rupture can cause significant consequences for the patient's life. This being the case, greater attention is needed for this group of people in whom the cases of AIs are not completely thrombosed, i.e. not all the space in the wall of the artery in which the aneurysm was formed is filled with the blood clot, which can have hemorrhagic impacts.

A study on imaging intracranial aneurysms in the endovascular era states that there has been an increase in the use and quality of neuroimaging in the medical environment, especially in cases of patients with Intracranial Aneurysms[3]. Arteriography has made it possible to identify unruptured aneurysms and has promoted the monitoring and management of these lesions. Furthermore, the discovery of accidentally unruptured IAs is recurrent, making it possible to treat them appropriately in order to prevent future rupture. In line with the thinking of Charlotte Y. Chung, one item that is increasingly being used in medical practice to monitor cases of intracranial aneurysm after intravenous treatment is neuroimaging, i.e. angiography, which is considered the gold standard for characterizing and planning IAs. However, it can be said that advances in angiography are visible in the form of CT (cranial tomography) and MRI (magnetic resonance imaging). The author states that these exams show improvements and precision in diagnosis so that they occur earlier and earlier, in addition to providing a surveillance role, i.e. it is possible to analyze the prognosis and detect possible complications in the face of treatment[3].

Those who specialize in diagnosing and treating diseases and conditions by interpreting medical images (radiologists) have the power to interpret the images common to Intracranial Aneurysms, as well as the image expected after treatment, says Charlotte Y. Chung in her research. It's worth noting that, in general, IAs can change over the years, making follow-up necessary. Hence, depending on the treatment chosen for the pathology and its respective device and the structures adjacent to the problem, there are other factors evaluated in imaging exams to confirm the blockage of the aneurysm, as well as the ability to identify possible complications in a short or long period after treatment[3].

It is known that endovascular treatment techniques for intracranial aneurysms currently have a successful recanalization rate. However, depending on the method chosen, there can be a drop in the success rate, especially when it is associated with "primary coiling", which is a minimally invasive treatment using a catheter in the target[5].

One set of authors states that, following a study involving 23 patients, 15 of whom were women and 8 of whom were men, the consequences of endovascular treatment were minimal. However, it is worth noting that 19 of the patients underwent angiographic follow-up for an average period of 15.3 months, in which only one of the selected patients required recanalization of the aneurysm during treatment. Therefore, few recanalizations were observed in the medium term, reporting better treatment durability. The study also reports that it is necessary to evaluate periodic thromboembolic events, which are seen in almost all endovascular treatments, either during or after treatment, making adequate angiography necessary.

Follow-up exams, especially imaging exams, have a periodicity of around 4.9 months and a maximum of 13.5 months, according to a study on interventional neuro-radiology. Another aspect to be highlighted is that angiography can objectively report whether the method chosen to treat the intracranial aneurysm was appropriate or not, and can classify the method, after a long study of several cases, as effective or invalid, building a "funnel" of more relevant options[6]. Since the consequences after treatment need to be minimal in order to improve the patient's symptoms.

DISCUSSION

In light of the analysis of the selected studies, it is clear that there is a need to improve studies relevant to IAs in the current medical field (Table 1). The best strategy or the definition of the appropriate time for the treatment of non-thrombosed intracranial aneurysms is defined entirely with the crucial help of arteriography. In addition, it is important to analyze the characteristics of the IA, such as size, location, orientation and proportion[3].

In this way, imaging techniques have evolved in the face of advances in treatment strategies, advocating the best prognosis for the patient[7]. One of the emerging options for angiography is magnetic resonance angiography, since it can play an excellent role in diagnosis, treatment and patient follow-up, offering the ability to perform tests repeatedly[8].

Angiography was performed in 2/3 of the patients selected for the study of endovascular treatment of aneurysms, which, when multiple, are very difficult to treat. Thus, imaging was useful at an average of 49 months after embolization therapy, allowing comparisons and progression of the aneurysms[9].

Aboukaïs reported that follow-up imaging was effective in analyzing the recurrence of aneurysms after treatment, showing the need for post-operative care focused on additional treatment by microsurgery[10].

Table 1. The references, year of publication, authors, title of the study, periodicity of arteriography, prognosis and consequences, results and conclusions of the articles selected for the project.

Reference and year	Title of the study	Periodicity of Arteriography	Prognosis and consequences	Result	Conclusion
Cancellière et al.[2] (2022)	Robotic-assisted intracranial aneurysm treatment: 1-year follow-up image and clinical results	Average follow-up time between 10.0 + 1.6 months	Patients with no comorbidities or possible health problems.	A study was carried out on six patients with AIs, 4 of whom were completely obliterated and the remaining two were occluded, according to arteriography over a period of one year. It is worth noting that over a period of 10.0 + 1.6 months (average) all the patients underwent a follow-up process, reporting good health.	Angiography is pertinent for categorizing adverse events and enabling the discovery of aneurysms that were not ruptured accidentally.

Table 1. Continued...

Reference and year	Title of the study	Periodicity of Arteriography	Prognosis and consequences	Result	Conclusion
Chung et al.[3] (2022)	Imaging of intracranial aneurysms in the endovascular era: surveillance and post-treatment follow-up.	Acute post-procedural and short-term post-treatment period	By monitoring and managing the lesions, it is possible to prevent future subarachnoid hemorrhages, as well as making it easier to tailor treatment.	There was a growing use of arteriographies, as well as their quality, since they made it possible to identify unruptured aneurysms.	Despite the low chances of ruptures, the accuracy of image markers shows possible instabilities.
Bender et al.[7] (2018)	Small aneurysms account for the majority and an increasing percentage of aneurysmal subarachnoid hemorrhages: a 25-year study in a single institution	25-year period	Subarachnoid hemorrhage.	Over a 5-year period, it can be said that there has been a reduction in ruptured IAAs. In addition, small aneurysms are one of the main causes of subarachnoid hemorrhage.	Proper analysis of risk factors
Tan et al.[8] (2023)	Diagnostic performance of silent magnetic resonance angiography for follow-up of endovascularly treated intracranial aneurysms: a prospective study	N \ A	Analysis of aneurysms using imaging tests without causing harm.	Magnetic resonance angiography can visualize treated sites and the state of occlusion of the aneurysm.	MRA is considered an option for repeat examinations.
Wang et al. (2023)[9]	Endovascular treatment of multiple intracranial aneurysms	6 to 90 months (average 49)	Predicting undesirable risks.	The study analyzed 116 multiple IAAs in which angiography was performed immediately after embolization. Among them, complete occlusion was achieved in 50 aneurysms, almost complete occlusion in 26 and incomplete occlusion in 8.	Investigation of the effect and safety of endovascular treatment for intracranial aneurysms.
Aboukaïs et al.[10] (2014)	Clinical and imaging follow-up after surgical or endovascular treatment in patients with non-ruptured carotid-ophthalmic aneurysms	Long-term imaging follow-up was carried out 3 years after treatment.	Clinically appropriate.	Conventional arteriography revealed multiple intracranial aneurysms in 26 selected patients, 6 of whom showed aneurysm recurrence on imaging after endovascular treatment.	Arteriography made it possible to analyze undesirable risks after endovascular treatment in patients with intracranial aneurysms.

Table 1. Continued...

Reference and year	Title of the study	Periodicity of Arteriography	Prognosis and consequences	Result	Conclusion
Murakami et al.[11] (2019)	Long-term results and follow-up examinations after endovascular embolization for non-ruptured cerebral aneurysms	The average follow-up period for the clinical case was considered to be 7 +- 1.4 years, the periodicity of which is not well-known.	Among the aneurysms analyzed in this case, embolization was observed over a period of 2 years during an average follow-up of 7 years.	The average follow-up period for the clinical case was 7 +- 1.4 years.	The appropriate period for the use of neuroimaging was useful for monitoring aneurysms.
Hua-Qiao Tan et al.[12] (2010)	Reconstructive endovascular treatment of intracranial aneurysms with a Willis-coated stent: mid-term clinical and angiographic follow-up	3 months, in 6-12 months and annually after endovascular treatment.	Analysis of efficacy and safety after medium- and long-term endovascular treatment.	30 patients underwent angiographic analysis at a mean time of 17.5 +/- 9.4 months. Of these, 28 patients showed incomplete occlusion in 2 aneurysms. Clinical follow-up showed complete recovery, and 14 patients improved. There were no adverse events.	The importance of arteriography and the analysis of AIs after treatment.
Acik et al.[5] (2019)	Endovascular Treatment of Superior Cerebellar Artery Aneurysm	Average angiographic follow-up time of 15.3.	After endovascular treatment, the few bad consequences can be assessed by imaging in a suitable timeframe.	Low percentage of need for recanalization seen by angiography.	Good endovascular treatment techniques rule out a worse prognosis.
Kimchi et al.[6] (2007)	Endovascular treatment of intracranial aneurysms with matrix springs: immediate post-treatment results, clinical evolution and follow-up	Periodicity between 4.9 months and 15.3 months.	Post-treatment makes it possible to classify the method used as effective or ineffective.	Treatment with matrix springs proved effective.	The right method minimizes the consequences for the patient.

Angiographic follow-up for one year demonstrates the safety of the treatment. When the exam shows, for example, immediate total occlusion of the aneurysm, it is extremely important to consider neuroendovascular tools to treat the aneurysm correctly, avoiding consequences such as possible rebleeding[5].

Furthermore, the use of state-of-the-art techniques and instruments that are easy to handle can reduce the consequences of non-thrombosed aneurysms completely, since durability improves occlusion in the long term. In this sense, after the procedure has been performed (around 24 hours), angiography makes it possible to analyze the patient's improvement or worsening[13].

The vascular images allow for clinical follow-up between two months and 12 months after treatment. Depending on the time chosen for the arteriography, different results and changes are observed in each time period. For example, an American study based on a case study reports that the imaging tests carried out at 2 months did not show any significant changes, classifying the surgery as having minimal harmful consequences for the patient. At six-month follow-up, the patient recovered completely and without sequelae. At one year, the clinic showed an asymptomatic patient[13].

This study therefore analyzed the results of various published neuroscience texts on the subject of totally non-thrombosed aneurysms and the use of imaging, especially angiography. The search that statistically combines the data from a study to produce a quantitative estimate was not relevant, but rather a qualitative one, excluding the need to carry out a meta-analysis.

Furthermore, a study on the embolization of aneurysms, in which 1257 patients with 1556 aneurysms were selected, deliberated that the dimensions of the aneurysm were measured with the aid of imaging tests, with emphasis on three-dimensional angiography. This implies numerous results, among which the most special were the analysis of symptomatic complications, the presence of transient ischemic attacks (TIAs) and the discovery of ruptured aneurysms. In addition, angiography enabled screening by finding carotid artery stenosis greater than 50% without the patient showing any symptoms and accidental aneurysms. Along another line of thought, this study also states that treatment was indicated for small aneurysms that were not ruptured by including risk factors for aneurysmal rupture, such as: images showing an increase in size, family history of subarachnoid hemorrhage and others[14].

In addition, despite being safe, endovascular treatment for non-thrombosed aneurysms can be problematic, especially when they are very small. Frequent interventions are often necessary to complement the treatment, making analysis and affinity with neuroimaging exams necessary, allowing for insightful follow-up[15].

Immediate follow-up angiography was a resource used by the researchers in the study on the treatment of large vertebral artery dissection aneurysms, reporting, in this case, intra-aneurysmal contrast stasis. In addition, angiography was present for at least six months in some selected patients showing a possible clinical outcome, confirming the need for follow-up imaging of aneurysms after endovascular treatment[16].

Clinical follow-up using angiography was carried out in a study of 30 ruptured aneurysms in patients receiving endovascular treatment. The imaging exam allowed analysis of the aneurysm occlusion, which was then classified using the Raymond Classification - an angiographic scheme that classifies the occlusion of endovascularly treated intracranial aneurysms. Imaging was present for an average period of between 5 and 10 months[17].

Medium-term follow-up of an aneurysm was effective and safe in a study of consecutive patients who were hospitalized at the endovascular intervention center in October 2004. Treatment outcomes included rupture rates, i.e. hemorrhage, neck embolization rate and recurrent aneurysm. Angiography was performed on all patients at an average of 9 months for follow-up purposes. This made it possible to ensure that no bleeding or ruptured aneurysms were found in these particular cases[18].

A treatment carried out on 11 female patients of average age 65 allowed for a one-year follow-up, which showed complete occlusion, i.e. "Raymond Class 1" in 55% of the patients selected. Imaging allowed us to obtain the result of each aneurysm treated. Initially, it is known that the resulting data was promising, although follow-up over a slightly longer period allows for a more succinct analysis[19].

Another study, focused on the safety and effects of the endovascular treatment of aneurysms performed on specific patients who had a common disease (in this case, "Moyamoya disease"), was effective in reporting that, immediately after embolization, it was possible to analyze the degree of Raymond classification. In addition, intra-procedural complications were also possible to analyze, which occurred in 10% of patients, including aneurysm rupture and failure of one of the patients included in this percentage. Follow-up was carried out from 6 to 26 months on 27 patients, and angiography enabled Raymond's analysis to be carried out on them; in addition, other clinical complications were noted. The research states that the data was possible due to the angiography referred to as adequate follow-up after endovascular treatment[20].

Still in this perspective of valuing neuroimaging exams, one study showed an average follow-up time of 21 months, in which the first exam was carried out between 3 and 6 months after treatment of the aneurysm, which revealed complete occlusion in 85% of cases. Occlusion was also noted at the last follow-up, which was carried out at an average of 26 months in 87% of cases. The authors state that the angiography showed zero morbidity in this study[21].

CONCLUSION

It is possible to conclude from this research that imaging tests are present in the medical scenario in order to improve and help monitor intracranial aneurysms. Thus, emerging techniques for assessing aneurysms, such as MRI imaging of the vascular wall, can complement conventional neurological imaging techniques in assessing the risk of aneurysm rupture[8]. In the face of a neurological pathological scenario, no effort should be spared to obtain the best diagnosis and treatment for patients with intracranial aneurysms.

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Endoscopic Posterior Cervical Foraminotomy for Radiculopathy Management: review and technique description

Foraminotomia Cervical Posterior Endoscópica para o Manejo de Radiculopatia: revisão e descrição da técnica

Matheus Felipe Borges Lopes[1]
Karla Emily Masotti[1,2]
José Ronaldo de Sousa Junior[3]

ABSTRACT

Posterior cervical foraminotomy has been described as a safe and effective technique since 1944, so ever since, the development of less invasive techniques demonstrated advantages. This study aimed to assess the current benefits of endoscopic posterior cervical foraminotomy for pain relief in patients with radiculopathy. The research was performed using the terms: full-endoscopic, posterior, cervical, foraminotomy, decompression, discectomy. The included articles contained descriptions of clinical outcomes after full endoscopic posterior foraminotomy. The decrease in neck pain within the VAS-assessed groups ranged from 5.9% to 90.1%, in the NRS-assessed groups, the values varied from 50% to 87.2%. Arm pain reduction ranged from 60.0% to 91.6% for VAS-assessed patients and NRS-assessed groups demonstrated a variation of 65.7% up to 69.7%. Full-endoscopic approaches are effective for treating cervical disc herniations, offering similar outcomes to traditional methods with less trauma and quicker recovery. Studies show comparable pain relief and complication rates between minimally invasive and open procedures. Full endoscopic posterior cervical foraminotomy should be incorporated into the therapeutic repertoire of spine surgeons to relieve chronic pain considering his indications.

Keywords: *Pain; Arm pain; Neck pain; Decompression discectomy; Foraminotomy; Full-endoscopic, microsurgery; Posterior, Radiculopathy*

RESUMO

A foraminotomia cervical posterior tem sido descrita como uma técnica segura e eficaz desde 1944, portanto, desde então, o desenvolvimento de técnicas menos invasivas demonstrou vantagens. Este estudo teve como objetivo avaliar os benefícios atuais da foraminotomia cervical posterior endoscópica para o alívio da dor em pacientes com radiculopatia. A pesquisa foi realizada utilizando os termos: endoscópica completa, posterior, cervical, foraminotomia, descompressão, discectomia. Os artigos incluídos continham descrições dos desfechos clínicos após foraminotomia endoscópica posterior completa. A diminuição da dor cervical nos grupos avaliados pelo EVA variou de 5,9% a 90,1%, nos grupos avaliados pela NRS, os valores variaram de 50% a 87,2%. A redução da dor no braço variou de 60,0% a 91,6% para os pacientes avaliados pelo EVA e os grupos avaliados pelo NRS demonstraram uma variação de 65,7% até 69,7%. As abordagens endoscópicas completas são eficazes no tratamento de hérnias discais cervicais, oferecendo resultados semelhantes aos métodos tradicionais com menos trauma e recuperação mais rápida. Estudos mostram taxas comparáveis de alívio da dor e complicações entre procedimentos minimamente invasivos e abertos. A foraminotomia cervical posterior endoscópica deve ser incorporada ao repertório terapêutico dos cirurgiões da coluna para aliviar a dor crônica, considerando suas indicações.

Palavras-Chave: *Dor; Braço, dor; Cervical, dor; Discectomia de descompressão; Foraminotomia; Microcirurgia Endoscópica; Radiculopatia posterior*

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INTRODUCTION

Patients presenting with cervical disc herniations or foraminal stenosis, when deemed suitable candidates for surgical intervention, are frequently managed through the anterior approach involving discectomy and fusion (ACDF). Although this approach provides favorable clinical outcomes, it is associated with certain inherent drawbacks. These include complete disc replacement with subsequent arthrodesis which results in the immobilization of the affected spinal segment necessitating the utilization of various implants such as cages with or without plates and screws. Furthermore, the anterior cervical dissection exposes critical anatomical structures including the carotid artery, internal jugular vein, recurrent laryngeal nerve, trachea, and esophagus, to potential risks of injury. Additionally, there exists a risk of implant-associated infections and the development of adjacent-level pathology. The accelerated disc degeneration occurring at the adjacent levels following arthrodesis may necessitate further surgical interventions in the subsequent years. The reported incidence of this condition ranges from 3% to 8% annually with a 25.6% increase over a 10-year period[1]. Less invasive treatment options have been investigated and documented in the literature[2].

First described by Spurling and Scoville in 1944, posterior cervical foraminotomy has proven to be a safe and effective method for addressing foraminal stenosis resulting from disc herniations or osteophytes[3]. Since then, the indications have remained consistent. The development of less invasive techniques, such as endoscopy have demonstrated significant utility in the cervical spine as well. Previous studies on posterior cervical laminoforaminotomies have reported good or excellent outcomes in relieving cervical radiculopathy comparable to anterior cervical decompression with fusion (ACDF) or open cervical foraminotomy techniques[4,5]. Ruetten et al.[6] published a randomized controlled trial of fully endoscopic posterior cervical foraminotomy (PECF) versus ACDF for cervical disc herniations and concluded that PECF may serve as an effective alternative to conventional surgery in appropriately selected patients.

There are two commonly described forms of endoscopy in the literature and the terminology can often be confusing. One form utilizes a tubular system measuring 16 to 24mm in diameter, with an attached endoscope and is referred to as microendoscopy. The other form described as full-endoscopic employs a system with an outer sheath of approximately 7-8mm in most systems along with a continuous irrigation channel for physiological saline. This channel can be connected to a pressure-controlled irrigation pump or operate using gravity. Full-endoscopy has several benefits: a smaller incision, less muscle dilation, clearer view with frequent irrigation, and reduced bleeding due to saline pressure. Furthermore, the instrumentation used in full-endoscopy typically operates through a working channel ranging from 3.5 to 6.3mm in systems designed for stenosis procedures[7]. In all these systems, it is possible to utilize drills or shaver motor as well as Kerrison instruments, which facilitate bone decompression procedures.

Technical description of full endoscopic posterior cervical decompression

For the performance of posterior cervical foraminotomy, in addition to precise indications, we rely on preoperative imaging studies. These include **static** and dynamic X-rays to assess potential instability criteria. Oblique X-rays may also be employed to evaluate foraminal dimensions. Additionally, non-contrast cervical spine computed tomography (CT) scans (Figure 1) are utilized to gather additional information regarding foraminal stenosis, osteophytes, or calcified herniations. The gold standard for diagnosis, however, is magnetic resonance imaging (MRI) (Figure 2).

MRI provides a more comprehensive assessment of root compression, neural structures, foraminal and canal diameter and the presence of any signs of myelopathy, among other factors.

Figure 1. Sagittal CT scan of the spine reveals right-sided foraminal stenosis at C5-C6.

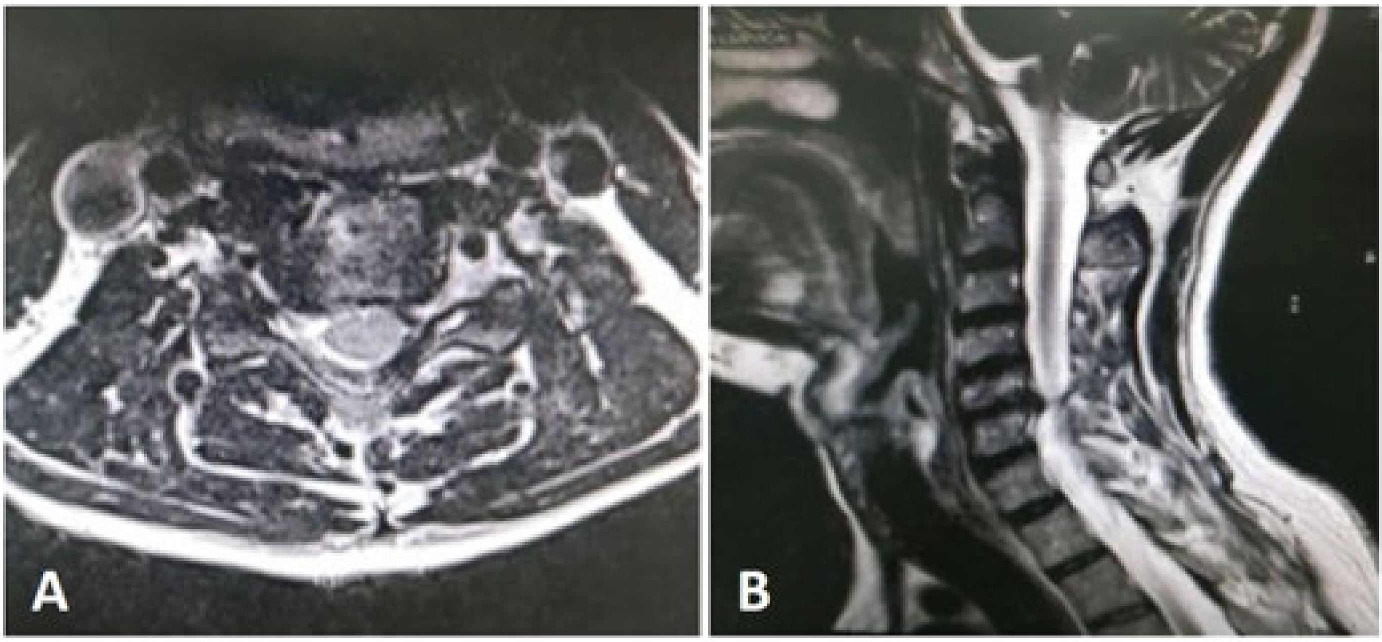

Figure 2. MRI of the cervical spine. **A.** Axial. **B.** Sagittal view confirming right-sided foraminal **stenosis at C5-C6**.

Step-by-step process for full-endoscopic posterior cervical spine foraminotomy performed in our surgical service is presented here: First, the procedure is performed under general anesthesia. The patient is placed in a prone position (lying face down), high cushions are positioned under the chest and iliac crests to provide support and comfort for the patient. A facial support or a 3-pin Mayfield head holder is used to secure the patient's head in flexion and in a slightly inclined position to facilitate venous return. The shoulders are moderately pulled to enhance access to the surgical site.

his carefully planned positioning allows the surgeon to safely and effectively access the posterior cervical spine during the full-endoscopic foraminotomy (Figure 3).

Figure 3. Positioning in prone position.

After the placement of sterile drapes, marking is performed with the assistance of radioscopy in both anterior-posterior (AP) and lateral views. The objective of these markings is to identify the target, referred to as the "V" point, which is the junction of the laminae and facets. In the lateral view, the angle of the disc is also marked (Figure 4).

Local anesthesia with a vasoconstrictor is administered followed by an incision of the skin and fascia. A dilator is then inserted at the designated target area mentioned earlier.

After the placement of the working sleeve and endoscope, irrigation with physiological saline is initiated. The "V" point is meticulously dissected through coagulation and grasping forceps, facilitating the exposure of bone and the yellow ligament (Figure 5).

Foraminotomy is performed using drills and Kerrison rongeurs until a maximum of 50% of the articular facets is removed to prevent instability (Figure 6).

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Figure 4. Marking in AP - Placement of the dilator at the 'V' point.

Figure 5. Endoscopic view of the exposure of the 'V' point.

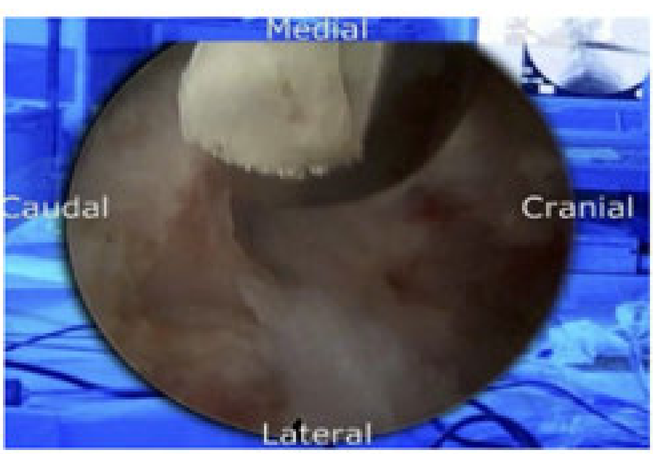

Figure 6. Utilization of Kerrison rongeurs to complete the foraminotomy, with the surgeon's position in the background.

Flavectomy is carried out using Kerrison rongeurs and dissectors until the nerve root is exposed at its point of origin and extracted through the foramen. Typically, this is performed from pedicle to pedicle in a cranio-caudal direction. When there is a soft or extruded fragment in the foraminal region, careful discectomy and decompression of the nerve root can be performed. Confirmation of the level and limits of decompression (Figure 7) is then performed followed by a thorough review of hemostasis and finally, closure of the incision.

MATERIALS AND METHODS

This systematic review of the literature aimed to assess the current benefits of endoscopic posterior cervical foraminotomy for pain relief in patients with radiculopathy secondary to foraminal stenosis or disc herniation. The research was performed on PubMed in January 2024, using the terms: full-endoscopic, posterior, cervical, foraminotomy, decompression, discectomy in the title/abstract fields and using combinations 'and' and 'or' (search structure: (((FULL-ENDOSCOPIC[Title/Abstract]) AND (POSTERIOR[Title/Abstract])) AND (CERVICAL[Title/Abstract])) AND (FORAMINOTOMY[Title/Abstract] OR DECOMPRESSION[Title/Abstract] OR DISCECTOMY[Title/Abstract]) . There was no time or language restriction.

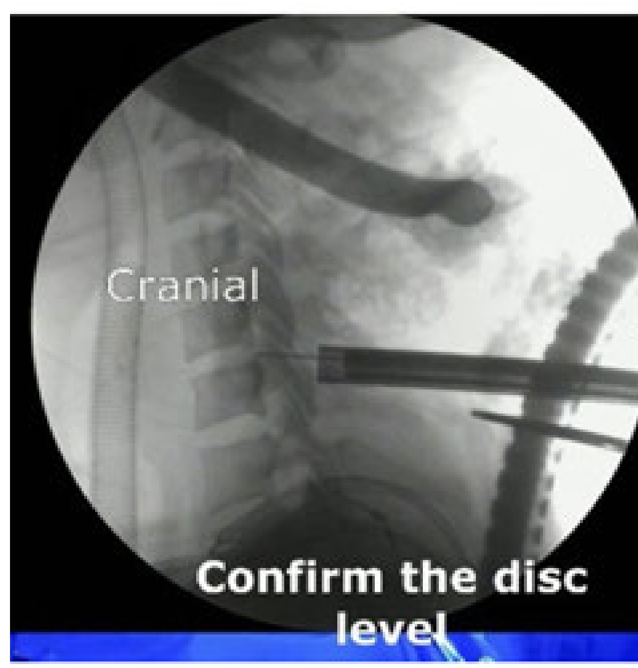

Figure 7. Level confirmation and radioscopic control.

Eligibility criteria

We included articles that contained descriptions of the clinical outcomes of patients with foraminal stenosis or disc herniation who underwent treatment using the full endoscopic posterior foraminotomy regardless of the type of study. Articles were excluded if they focused on other surgical techniques or did not contain information about pain improvement, or if they were about patients with other neurological diseases. Cadaver studies, technical notes and other reviews were also excluded.

The year of publication, study design, pain intensity, surgery-related complications, adverse events, number of reoperations, and negative outcomes were the data considered in this study.

Due to the heterogeneity and the small sample of the studies included in this review, a meta-analysis was not conducted. Therefore, the data were summarized and described in a narrative format. We assessed the percentage of pain reduction reported by comparing the pain presented in the preoperative period with the pain at the end of the follow-up.

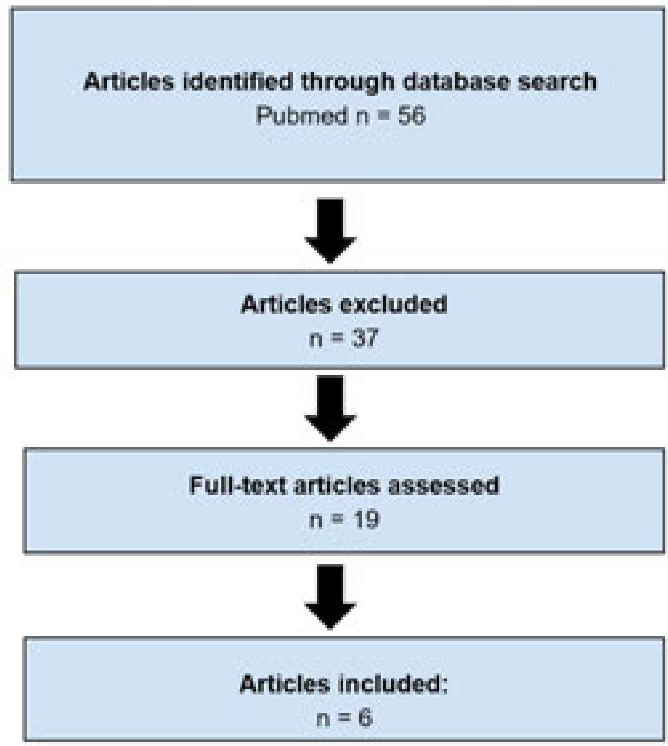

Figure 8. Flowchart according to PRISMA guidelines.

RESULTS

This search strategy resulted in 56 articles, published between 2007 and 2024. After screening by titles and abstracts, according to the inclusion and exclusion criteria, we excluded 37 articles. Out of the remaining 19 studies, we obtained 6 for analysis (Figure 8).

In all studies examined, patients presented with pain attributed to disc herniation or foraminal stenosis, with 85.7% exhibiting involvement of only one level and 14.3% displaying involvement of one to two levels. The follow-up time exhibited ranged from 12 to 60 months, with a mean duration of 22.8 months (Standard Deviation - SD - 11.569).

The visual analog scale (VAS) was the most utilized method for pain assessment, being present in 85.7% of cases. Numerical rating scale (NRS) was employed in only 14.3% of instances. As a result, in all evaluated studies, there was a significant reduction in pain reported by the patients, as described in Table 1.

Table 1. Pain levels in the samples of the observed studies.

Study	Neck pain (initial pain / endpoint pain)	Arm pain (initial pain / endpoint pain)
Paik et al.[8]	NRS for DH group: 6.7 / 2.5 NRS for FS group: 5.6 / 3.0	NRS for DH group 7.6 / 2.3 NRS for FS group: 5.8 / 2.0
Gatam et al.[9]	VAS: 1.2 / 0.6	VAS: 5.0 / 2.0
Luo et al.[10]	VAS: 7.8 / 1.0	VAS: 7.8 / 1.0
Ye et al.[11]	Not available	VAS: 7.89 / 1.11
Ruetten et al.[6]	VAS: 17.0 / 16.0	VAS: 84.0 / 7.0
Ruetten et al.[12]	VAS: 81.0 / 8.0	VAS: 15.0 / 18.0

DH = disc herniation; **FS** = foraminal stenosis; **NRS** = numerical rating scale; **VAS** = Visual Analogue Scale.

The decrease in neck pain within the VAS-assessed groups ranged from 5.9% to 90.1%, with an average reduction of 58.3% (SD 34.1%); conversely, in the NRS-assessed groups, the values varied from 50% to 87.2%, with an average of 54.6% (SD 8.1%).

In terms of arm pain, the VAS-assessed groups that showed pain reduction ranged from 60.0% to 91.6%, with an average reduction of 81.4% (SD 12.5%). Meanwhile, in the NRS-assessed groups, the level of pain reduction ranged from 65.7% to 69.7%, with an average of 67.6% (SD 2.1%). Ruetten et al.[12], in 2007, was the sole observer of an increase in arm pain level within the assessed sample with an increment of 20.0%.

DISCUSSION

Firstly, the application of standardized terminology is essential due to the extensive array of terms in use. In a recent consensus published by AOSPINE, the proposed term for this approach in the cervical spine is "Posterior endoscopic cervical foraminotomy (PECF) or Discectomy (PECD)," with the objective of the surgery being the direct visualization and decompression of the exiting root from its origin to the lateral margin at the caudal pedicle[13].

When comparing the prospective shift from the traditional anterior approach to subsequent methodologies encompassing open, tubular, or full-endoscopic procedures, it is prudent to underscore that various scholarly investigations have already substantiated the efficacy of the posterior cervical approach for osseous decompressions and foraminal disc herniations. As described in our results, pain reduction can reach up to 91.6% concerning arm pain and 90.1% concerning neck pain.

Notably, an example can be found in the randomized controlled clinical study by Ruetten et al.[6]. This study compared the outcomes of posterior cervical full-endoscopic discectomy versus the conventional anterior microsurgical technique conjoined with fusion (commonly known as ACDF). The study included 175 patients who were followed for 2 years. After surgery, 87.4% of the patients no longer experienced arm pain, while 9.2% reported sporadic pain, resulting in a cumulative favorable outcome rate of 96.6%. Clinical outcomes were similar in both groups, including complication rates and reoperation rates. However, the full-endoscopy group had the advantages of preserving mobility, early rehabilitation, and reduced surgical trauma due to its less invasive nature[6].

Platt et al. conducted an analysis of five studies comparing posterior open surgery versus microendoscopic procedures. Among these studies, two reported a significant increase in postoperative neck pain scores in patients who underwent open cervical foraminotomies. However, it's worth noting that both studies indicated that these differences lost statistical significance with long-term follow-up and the technique wasn't fully endoscopic as we described. There were no statistically significant differences observed in complications and reoperations between the open and minimally invasive surgery (MIS) groups, showing that MIS techniques demonstrate no inferiority when we discuss the results. A retrospective cohort study was included in the analysis, comparing MIS-PCF and FE-PCF. At the 24-month postoperative assessment, the average neck and arm scores were significantly lower in the FE-PCF group compared to the MIS-PCF group. There was no significant difference in arm pain scores between the two groups. It's important to note that the number of direct comparative studies between MIS-PCF and open cervical foraminotomy is limited. While there is significant heterogeneity among studies comparing open and MIS-PCF, there appears to be a trend towards reduced hospital stay and the use of postoperative analgesic in the minimally invasive cohort[14].

In a meta-analysis conducted by Wu et al.[15], in 2019, comparing posterior full-endoscopic cervical foraminotomy (FE-PCF) with microendoscopy (tubular system coupled with an endoscope) for cervical radiculopathy, a total of 26 articles comprising 2,003 patients (FE-PCF, 377; MI-PCF, 1,626) were included. The pooled clinical success rate was 93.6% for the full-endoscopy group and 89.9% for the Microendoscopy group, with no statistically significant difference noted (p = 0.908). These findings align with those outlined in this review, wherein most patients reported a significant reduction in pain. The overall complication rates were 6.1% for the FE group and 3.5% for the MI group, respectively, but without significant differences (p = 0.128). Regarding the pooled reoperation rate, it was 4.8% for the FE group and 5.3% for the MI group, also demonstrating no statistically significant difference (p = 0.741). The pooled complication rate for the treatment of single-level radiculopathy showed no statistical difference (FE, 4.5%; MI, 3.5%; p=0.471). Notably, while relatively low, the described complications included transient root paralysis and dural injury, which were observed in both techniques[15].

The entirely endoscopic technique serves as a sufficient, safe, and alternative to the previously conventional microsurgical approach[6]. Although the indications, in general, do not encompass patients with cervical myelopathy, there are studies in the literature demonstrating that the endoscopic technique can also be employed in these patients however further research is required[16]. The studies mentioned above yielded results comparable to those found in this research, characterized by favorable clinical outcomes with low rates of complications and reoperations. This reinforces the efficacy and safety of the posterior full-endoscopic technique.

Clinical outcomes of posterior full-endoscopic cervical foraminotomy, regarding improving cervicobrachialgia symptoms, are comparable to those achieved with conventional anterior microsurgical decompression and fusion. The transition towards posterior approaches can be accomplished through open posterior decompression, microsurgery, tubular endoscopic techniques, or more recently, full-endoscopic procedures, provided that the learning curve for this procedure is respected.

CONCLUSION

The use of posterior full-endoscopic cervical foraminotomy has proven to be effective in pain reduction, safely delivering satisfactory results. Considering its advantages and effectiveness, the author believes this technique should be added to the spine surgeons' therapeutic repertoire for treating chronic pain from foraminal stenosis and lateral disc herniations without needing fusion. Surgeons can selectively choose patients who would benefit from this less invasive approach. The number of articles found was the primary limitation of this research; but considering that full-endoscopic technique is being increasingly adopted, and the publication curve is rising each year, this is the appropriate time to discuss what is currently available in the literature.

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Congenital Inclusion Dermoid Cyst in the Anterior Fontanel: case report and integrative literature review

Cisto Dermoide de Inclusão Congênita em Fontanela Anterior: relato de caso e revisão integrativa de literatura

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ABSTRACT

Congenital Inclusion Dermoid Cysts (CIDCs) are rare, benign lesions commonly found over the anterior fontanel. These cysts are typically soft, mobile, painless, and may progressively enlarge, with most cases diagnosed in early childhood. A review of 24 studies highlighted key clinical, laboratory, histopathological, and neuroradiological findings of CIDCs. The average age at diagnosis is 5.3 years. Laboratory analysis often reveals clear or turbid fluid containing keratin and sebaceous material, sometimes resembling cerebrospinal fluid (CSF), which aids in differentiating CIDCs from other cysts. Histopathologically, CIDCs display stratified squamous epithelium with appendages like hair follicles and sebaceous glands, confirming the diagnosis. Neuroimaging reveals cystic lesions with no evidence of intracranial involvement. Surgical excision is the treatment of choice and usually results in favorable outcomes with minimal complications. A case of a 14-year-old female with a progressively enlarging CIDC at the anterior fontanel is presented. Imaging and histopathological analysis confirmed the diagnosis, and surgical resection was performed successfully, leading to excellent cosmetic and functional results. CIDCs are benign and, with proper diagnosis and timely surgical intervention, patients experience positive long-term outcomes without recurrence or neurological deficits. Early diagnosis is essential to prevent complications such as infection or skull deformities.

Keywords: *Dermoid cyst; Cranial sutures; Bregmatic fontanel; Anterior fontanel*

RESUMO

Os cistos dermoides de inclusão congênita (CDICs) são lesões raras e benignas, comumente encontradas sobre a fontanela anterior. Esses cistos são tipicamente suaves, móveis, indolores e podem crescer progressivamente, sendo a maioria dos casos diagnosticada na primeira infância. Uma revisão de 24 estudos destacou os principais achados clínicos, laboratoriais, histopatológicos e neurorradiológicos dos CDICs. A idade média no diagnóstico é de 5,3 anos. A análise laboratorial frequentemente revela fluido claro ou turvo contendo queratina e material sebáceo, às vezes assemelhando-se ao líquido cefalorraquidiano (LCR), o que ajuda a diferenciar os CIDCs de outros cistos. Histopatologicamente, os CDICs apresentam epitélio estratificado pavimentoso com apêndices como folículos pilosos e glândulas sebáceas, confirmando o diagnóstico. A neuroimagem revela lesões císticas sem evidências de envolvimento intracraniano. A excisão cirúrgica é o tratamento de escolha e geralmente resulta em desfechos favoráveis com complicações mínimas. É apresentado o caso de uma paciente de 14 anos com CDIC progressivamente crescente na fontanela anterior. A análise de imagem e histopatológica confirmou o diagnóstico, e a ressecção cirúrgica foi realizada com sucesso, resultando em excelentes resultados estéticos e funcionais. Os CDICs são benignos, e com diagnóstico adequado e intervenção cirúrgica oportuna, os pacientes experimentam resultados positivos a longo prazo, sem recorrência ou déficits neurológicos. O diagnóstico precoce é essencial para prevenir complicações, como infecção ou deformidades no crânio.

Palavras-Chave: *Cisto dermoide; Suturas cranianas; Fontanela bregmática; Fontanela anterior*

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INTRODUCTION

The congenital inclusion dermoid cyst (CIDC) over the anterior fontanel is a rare, benign cystic lesion most commonly seen in childhood. These cysts are lined with stratified squamous epithelium and contain developmentally mature ectodermal tissues, such as skin, hair follicles, sebaceous glands, and sweat glands[1]. CIDCs arise from a defect in the separation of neuroectoderm during neural tube formation between the third and fifth weeks of embryogenesis, leading to the inclusion of dermal elements along the embryonic fusion line[2].

CIDCs most commonly present in the head and neck region, particularly on the scalp, where they develop from areas of embryonic fusion along the midline, around the anterior fontanel. These cysts may extend intracranially or intradurally due to their proximity to the sagittal suture. The incidence of CIDCs ranges from 15% to 22%, with cranial extension being rare[1].

Clinically, CIDCs typically present as small, non-tender, well-circumscribed masses that grow slowly in the subcutaneous tissue and are covered by intact skin. These masses may also present focal alopecia and a ring of hypertrophic hair. In rare instances, CIDCs can erode through the bony skull and extend intracranially or intradurally, forming a "dumbbell dermoid," a mass connected to the skull by a sinus stalk. The midline location of these cysts makes them more likely to extend intracranially. Notably, the hypertrophic hair ring around the lesion may serve as a marker for potential intracranial extension[1].

The differential diagnosis for CIDCs includes conditions such as meningocele, encephalocele, lipoma, sebaceous cyst, subgaleal hematoma, cephalhematoma, sinus pericranii, cystic hygroma, cavernous angioma, lymphangioma, hemangioma, bone tumors, eosinophilic granuloma, growing fractures, heterotopic brain tissue, meningioma, myxopapillary ependymoma, and melanotic progonoma[3]. Although most cases do not cause neurological complications or recurrence, surgical removal is recommended to prevent infections, obtain a definitive histopathological diagnosis, and improve cosmetic outcomes. Imaging techniques like computed tomography (CT) and magnetic resonance imaging (MRI) are effective in confirming the extracranial location of the cyst[2].

Various surgical approaches are adopted: performing a skin incision over the vertex of the cyst, either sagittally or coronally; a semicircular incision at the base of the cyst, with the cyst separation starting subgaleally and then at the base of the cyst. Therefore, lesions located over the anterior fontanel should be treated by neurosurgeons due to their proximity to the superior sagittal sinus[3].

The objective of this work is to provide a comprehensive understanding of congenital inclusion dermoid cyst (CIDC), demonstrating its benign nature and the effectiveness of treatment based on the analysis of treated cases.

METHODS

The present research is an exploratory-descriptive study with a qualitative approach, based on the Integrative Literature Review (ILR) methodology (Ganong, 1987), focusing on the characteristics and neurosurgical treatment of CIDCs located in the anterior fontanelle region. In this context, the initial stage involved formulating the guiding research question based on the PICo strategy: "What are the main characteristics and the most commonly adopted neurosurgical approaches for treating patients with dermoid cysts in the anterior fontanelle?".

The article search was conducted in the following databases: Medical Literature Analysis and Retrieval System Online (MedLINE) via the PubMED portal, and the Latin American and Caribbean Literature in Health Sciences (LILACS) via the Regional Portal of the Virtual Health Library (VHL). Using the Medical Subject Headings (MeSH) database, the following descriptor was applied: "Dermoid Cyst," along with alternative terms for Cranial Fontanelles: "Bregmatic Fontanel" and "Anterior Fontanel." The descriptors were combined for searches in both databases as follows: ((Dermoid Cyst) AND ((Bregmatic Fontanel) OR (Anterior Fontanel))).

The inclusion criteria established were primary studies and original articles that answered the research question, with no restrictions on language or publication date. The exclusion criteria included dissertations, theses, reviews, editorials, books, documents, opinion articles, theoretical reflections, and conference proceedings.

Data collection from the selected articles was conducted after duplicate removal, resulting in a total of 34 articles. The authors performed a joint and simultaneous reading of the distributed titles, progressing to an abstract review of the previously selected titles. This process led to a full-text review of the selected abstracts, ultimately identifying studies that met the inclusion criteria for the review. The selection process for the included studies is illustrated in Figure 1, adapted from the PRISMA Flowchart[4]. A total of 24 articles were selected.

For data analysis, a structured framework was developed, including the following elements: Authors, Publication Year, Method, Age at Diagnosis, Main Clinical Features of Congenital Inclusion Dermoid Cysts (CIDCs) in the Anterior Fontanelle, Histopathology Findings (HP), and Neurosurgical Treatment. Considering the levels of evidence, all the selected articles were classified as Level 4 – qualitative case series studies[5].

The descriptive presentation of the results and discussion was structured based on the organization of analytical categories derived from the data obtained in the selected studies, through the identification of common variables and key concepts, as recommended for ILR[6,7].

RESULTS

The analysis of 24 articles revealed consistent clinical, laboratory, and histopathological characteristics associated with congenital inclusion dermoid cysts (CIDCs), which are detailed below. The studies originated from various countries: Japan (7), Brazil (4), United States (2), Nigeria (2), South Africa (2), India (2), Dominican Republic (1), China (1), Czechoslovakia (1), Rhodesia

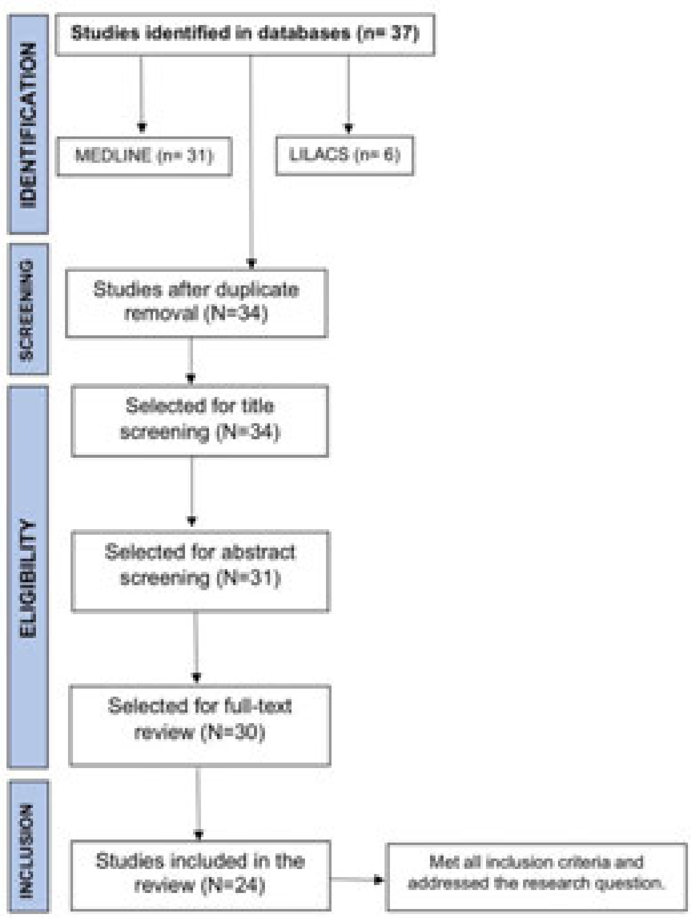

Figure 1. Flowchart of the selection process for articles included in the Integrative Literature Review, Marília, São Paulo, Brazil, 2025. **Source**: Adapted from Page et al.[4].

(1), and Honduras (1). The mean age at diagnosis ranged from 3 weeks to 32 years, with an approximate mean of 5.3 years (Table 1). The predominant location was the anterior fontanel, though cysts were also observed in other scalp regions[2,3,8-11,14,16,19,21].

Main clinical features

CIDCs were described as soft, mobile, painless, and non-pulsatile cysts typically located over the anterior fontanel. The cysts ranged in size from 1 to 4 cm, with some patients experiencing progressive enlargement over time. They did not show changes with posture or crying, suggesting they were unrelated to intracranial pressure. Most cysts were non-adherent to the skin, with no signs of inflammation or rupture. Pain or discomfort was rarely reported, although one case noted local pain, headache, and progressive enlargement after the age of 28, and no abnormalities on neurological examination.

Laboratory findings

The laboratory findings varied, but the most common feature was clear or turbid fluid, often with keratin particles and occasionally hair. In some cases, the fluid collected from the cysts had characteristics similar to cerebrospinal fluid (CSF), with low levels of protein and glucose, helping differentiate CIDCs from other cysts such as epidermoid cysts[12,15,16,18,24]. Protein and glucose concentrations in the fluid varied, but typically low levels were a key distinguishing feature. The presence of caseous or sebaceous material was noted in some cases, supporting the glandular nature of the cysts[11,21].

Table 1. Articles Included in the Integrative Literature Review According to: Authors, Publication Year, Method, Age at Diagnosis, Main Clinical Features of Congenital Inclusion Dermoid Cysts (CIDCs) in the Anterior Fontanelle, Histopathology Findings (HP), and Neurosurgical Treatment, Marília, São Paulo, Brazil, 2025.

Authors	Methods Number of patients (n)	Age at Diagnosis	Main Clinical Features Histopathology Findings (HP)	Neurosurgical Treatment
Cao et al.[8]	RE n = 9	6 months to 8 years of age	Soft, cystic, immobile, painless, non-pulsatile cysts. HP: Stratified squamous epithelium (SSE) and adnexal structures.	TCR without complications
Aquino et al.[2]	CR n = 3	5 months to 3 years	Soft, mobile, and painless. No communication with the intracranial cavity HP: SSE and adnexal structures	TCR without complications
Fermín et al.[9]	RE n = 27	2 months to 6 years	Painless mass over the anterior fontanel HP: Dermoid cyst confirmed	TCR without damage to the sagittal sinus
Tateshima et al.[10]	CR n = 1	2 months	Small, painless, sessile, slightly mobile, covered by intact skin, without translucency HP: Dermoid cyst confirmed	Curvilinear incision along the mass, with careful dissection, avoiding total resection due to the cyst's adhesion to the dura mater
Parízek et al.[3]	CR n = 13	2 months to 19 months	Firm, smooth, non-pulsatile, round, painless, and exhibited slow growth. Not adherent to the skin, with slight mobility over the periosteum HP: Typical of dermoid cysts	A semicircular incision was made on the skin and galea at the base of the dermoid cyst. A circumferential incision was performed on the periosteum. The cyst was carefully dissected from the anterior fontanel and the galea aponeurosis. All cysts were dissected without aspiration and without perforation, except for one case. Only the skin was sutured
Glasauer et al.[11]	CR n = 10	3 weeks to 12 months	Soft, mobile cystic mass with translucency HP: Stratified squamous epithelium (SSE) and adnexal structures	TCR, easily dissected and excised without recurrence

Retrospective Study (RS); Case Report (CR); Total Cyst Resection (TCR).

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Table 1. Continued...

Authors	Methods Number of patients (n)	Age at Diagnosis	Main Clinical Features Histopathology Findings (HP)	Neurosurgical Treatment
Dadlani et al.[12]	CR n = 1	20 years	Soft, fluctuating swelling, negative for translucency HP: Keratinized squamous epithelium and underlying cutaneous appendages	TCR. No connection to the superior sagittal sinus was observed, and there was no intradural extension
O'Shea et al.[13]	CR n = 1	2 months	Fluid collection in the deep scalp, overlying a calvarial defect with possible intracranial extension HP: Consistent with a dermoid cyst	Excision via supratentorial craniectomy with neuronavigation, followed by cranioplasty. The mass was removed in fragments until all visible portions were extracted. The craniotomy dimensions were 12 × 17.5 × 20 mm after removal. Cranioplasty was performed using autologous bone chips and moldable demineralized bone mass
Adachi et al.[14]	CR n = 1	2 months	Spherical solid mass, covered by normal scalp skin, soft, mobile, and non-collapsing upon compression HP: Yellow adipose tissue, with a histological diagnosis of a dermoid cyst	TCR. Located subgaleally, with no adhesion to adjacent structures and was easily removed
Kanamaru and Waga[15]	CR n = 1	6 months	Rounded cystic mass. HP: Dermoid cyst confirmed	TCR without complications
Saito et al.[16]	CR n = 2	5 and 6 months	Patient 1 (5 months): clear, watery fluid, caseous material, and a small amount of hair HP: Stratified squamous epithelium (SSE) and adnexal structures Patient 2 (6 months): Rounded, soft, non-tender, fluctuating, non-compressive, and immobile, covered by normal skin HP: Fragments of keratin, small amounts of hair, hair follicles, and sebaceous glands	TCR without complications
Ojikutu and Mordi[17]	CR n = 2	28 and 32 years	Large, soft, non-tender, non-pulsatile cystic mass over a closed anterior fontanel, covered by intact skin. Not translucent. No other anomalies or neurological deficits were observed. In one patient, local pain, headache, and progressive enlargement of the cyst were noted after the age of 28 HP: Dermoid cyst confirmed	TCR without complications
Peter et al.[18]	CR n = 35	30 patients under 1 year of age, 4 between 1 and 4 years, 1 adolescent aged 16 years	Mobile and occasionally painful, with no evidence of infection. Transillumination present in neonates HP: not described	TCR without complications

Retrospective Study (RS); Case Report (CR); Total Cyst Resection (TCR).

Table 1. Continued...

Authors	Methods Number of patients (n)	Age at Diagnosis	Main Clinical Features Histopathology Findings (HP)	Neurosurgical Treatment
Peter et al.[19]	CR n = 33	All patients were under 1 year of age	Most with dermal appendages. None connected to the dura mater or the brain HP: not described	TCR without complications
Sonntag and Waggener[20]	CR n = 1	2 years	No intracranial extension; other characteristics not described HP: not described	TCR without complications
Yuasa et al.[21]	CR n = 1	8 months	Soft, non-tender, non-pulsatile cystic, covered by intact and transilluminated skin HP: not described	The root and lateral walls of the cyst were removed together with the overlying pericranium, leaving the base, which was then removed in fragments from the surface of the dura mater at the anterior fontanel. No intracranial connection was demonstrated
Chaudhari et al.[22]	CR n = 21	2.5 weeks to 2.5 years.	Mobile, non-tender, and contained clear fluid in smaller cysts, and fluid in larger ones HP: Stratified squamous epithelium (SSE) and adnexal structures	TCR without complications
Borkar et al.[23]	CR n = 1	4 years	Swelling in the lumbosacral region since birth and a progressively enlarging swelling at the anterior fontanelle since birth. No abnormalities were observed on neurological examination (motor, sensory, or autonomic). The swelling was soft, globular. The overlying skin was normal, with no visible drainage point HP: Stratified squamous epithelium (SSE) and adnexal structures Lumbosacral Region: Open spina bifida with a 3×4 cm meningocele	Surgical intervention involved repair of the lumbosacral meningocele and TCR without complications
Sekimoto et al.[24]	CR n = 1	10 months	Normal surface, translucent, elastic, non-tender, and non-compressible HP: Stratified squamous epithelium (SSE), adnexal structures and absence of melanocytes	TCR without complications
Macedo et al.[25]	CR n = 1	6 months	Soft, non-tender, non-pulsatile, non-compressible, covered by intact skin, without transillumination HP: Stratified squamous epithelium (SSE) and adnexal structures	TCR without complications
Oliveira[26]	CR n = 1	24 years	Soft, non-tender, without visible signs of inflammation or pulsations, covered by intact skin, without transillumination HP: not described	TCR without complications. The mass was adherent to the aponeurotic galea, but no intracranial connection was observed
Tan and Takagi[27]	CR n = 5	5 months to 10 years (median age: 7 months)	Non-pulsatile. The mass did not change size with postural alterations or crying HP: conducted on all patients, revealing dermoid cysts in four cases and an epidermoid cyst in one case	TCR without complications

Retrospective Study (RS); Case Report (CR); Total Cyst Resection (TCR).

Table 1. Continued...

Authors	Methods Number of patients (n)	Age at Diagnosis	Main Clinical Features Histopathology Findings (HP)	Neurosurgical Treatment
Barahona et al.[28]	CR n = 1	6 years	Soft, non-tender, mobile, with no adhesion to deeper planes HP: not described	TCR without complications.
Pereira et al.[29]	CR n = 2	7 months and 7 years	Soft consistency, painless, immobile, and without pulsation or inflammatory signs HP: HP: Dermoid cyst confirmed	TCR without complications

Retrospective Study (RS); Case Report (CR); Total Cyst Resection (TCR).

Histopathological findings

CIDCs exhibited stratified squamous epithelium with associated cutaneous appendages such as hair follicles, sebaceous glands, and sweat glands. Histologically, the cysts were characteristic of dermoid cysts, with keratinized squamous epithelium and the presence of sebaceous glands and hair follicles confirming the diagnosis. In some cases, yellow adipose tissue and sebaceous-like or keratin material were also identified[3,8,9,14,17,18,20,21].

Neuroradiological investigations

The analysis of neuroradiological investigations showed consistent findings regarding the nature and location of CIDCs. Computed tomography (CT) and magnetic resonance imaging (MRI) revealed that the cysts were hypodense, typically located over the anterior fontanel, with no communication with intracranial structures. CT scans often showed bone erosion or depression in the surrounding skull, with a few cases showing bone deficiency in the cyst region. MRI showed low signal intensity on T1-weighted images and high signal intensity on T2-weighted images, confirming the cyst's liquid nature and absence of intracranial extension[2,8,9,11-15,17]. X-ray findings demonstrated soft tissue shadow or swelling over the anterior fontanel, with some cases showing flattening or depression of the external bony table, but no intracranial involvement. Ultrasound revealed a well-defined mass with clear fluid and irregular hypoechoic masses, suggesting the presence of keratin or other cystic components, and confirmed the absence of intracranial extension[3,10,27].Specialized imaging, such as 3D CT and cystography, was used in some cases and confirmed no communication with intracranial structures[11,14,27]. A brachial arteriography was performed to rule out vascular abnormalities and showed no significant findings[21].

Neurosurgical treatment

The majority of studies involved complete excision of CIDCs, with largely favorable surgical outcomes. Various surgical techniques were employed, including semicircular, elliptical, or curvilinear skin incisions followed by careful dissection of the cyst from surrounding structures like the galea, periosteum, and scalp. Some cysts were closely adherent to the galea aponeurosis but were removed without damaging the underlying dura mater or other intracranial structures. Several studies confirmed no intracranial connections, with cysts, easily separated from the dura mater and cranial bone[2,3,8,12,15,16,19,20,22,24-26]. Postoperative outcomes were positive, with excellent aesthetic results and no recurrence in most cases. In some instances, cranioplasty was performed following excision, especially for larger cysts or those with significant bone remodeling. The procedure was generally safe, with no complications such as infection or damage to adjacent tissues[2,3,8,12,15,16,19,20,22,24-26].

Special cases

One case involved supratentorial craniectomy with neuronavigation due to the cyst's size and location. Another study combined the excision of a lumbosacral meningocele and CIDC in a single surgical intervention[13,23].

CASE PRESENTATION

A 14-year-old female patient presented with a bulging lesion in the anterior fontanelle (AF) since birth, with progressive enlargement over time. At the age of 12, the frontal bulging experienced exponential growth, prompting her to seek neurosurgical evaluation. The patient was asymptomatic, with no neurological or cognitive deficits, but was concerned about the lesion's growth and cosmetic implications.

On physical examination, a painless, mobile, fibroelastic frontal bulging lesion was noted, non-adherent to deep planes. Neuroimaging studies, including magnetic resonance imaging (MRI), revealed a large, expansive subgalea cystic lesion in the midline frontal region at the anterior fontanelle (bregmatic) site, with regular surfaces, measuring 60 × 60 × 32 mm, and no contrast enhancement following paramagnetic contrast infusion (Figures 2-4).

The patient underwent surgical resection of the abnormality via a bicoronal approach. Intraoperatively, an external cranial table depression was observed, along with a cyst containing brownish, sebaceous material with hair-like structures. Complete evacuation of the cyst's contents and removal of the lesion capsule were performed without complications. The surgical specimen was sent for histopathological analysis, confirming the diagnosis of a CIDC.

DISCUSSION

The CIDC is a rare lesion, accounting for 0.1-0.5% of intracranial tumors, with its presentation more commonly observed along the midline of the craniospinal axis, and with an incidence of only 0.2% in FA[30].

Imaging tools such as MRI, cranial tomography, and histopathological analysis are essential for optimizing surgical management and distinguishing CIDC from other conditions like epidermoid cysts, encephalocele, lipomas, and hemangiomas. Cranial tomography can show hypodense, cystic, and extracranial characteristics of the dermoid cyst. Clinically, children with CIDC typically exhibit normal neuropsychomotor development without neurological abnormalities, and malignant degeneration of the cyst is rare. Surgical excision is

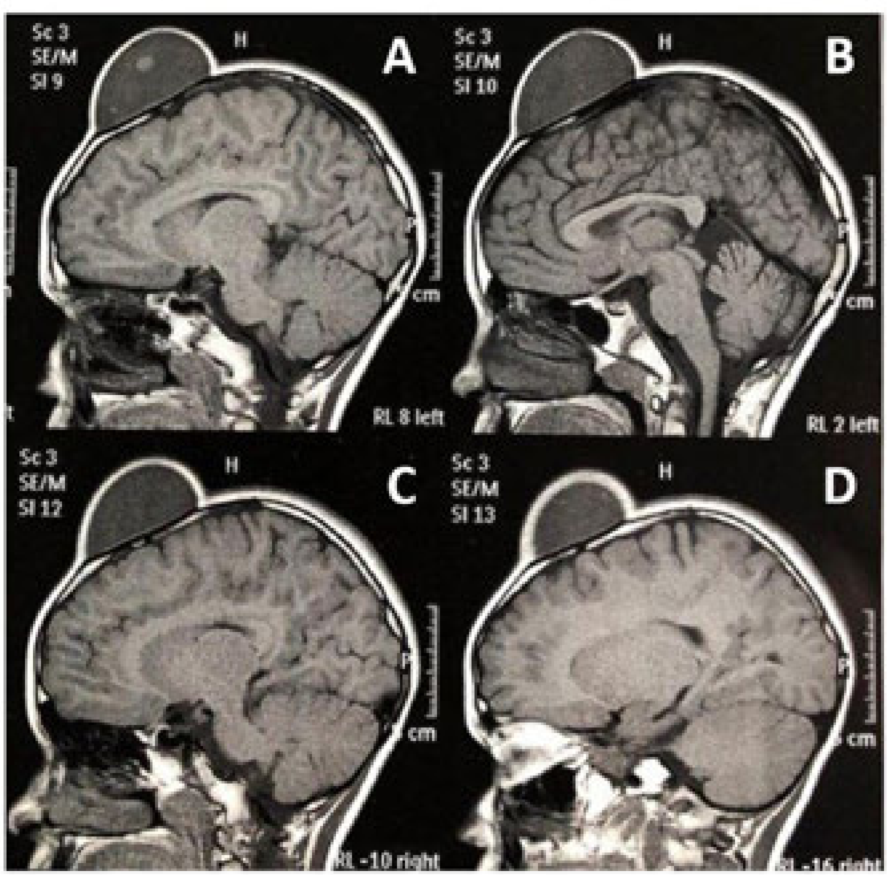

Figure 2. A-D. Cranial Magnetic Resonance Imaging (MRI) revealing a well-defined, midline frontal subgalea cystic expansive lesion, hypointense on T1-weighted imaging, measuring 60 × 60 × 32 mm, located at the anterior fontanelle (Bregma).

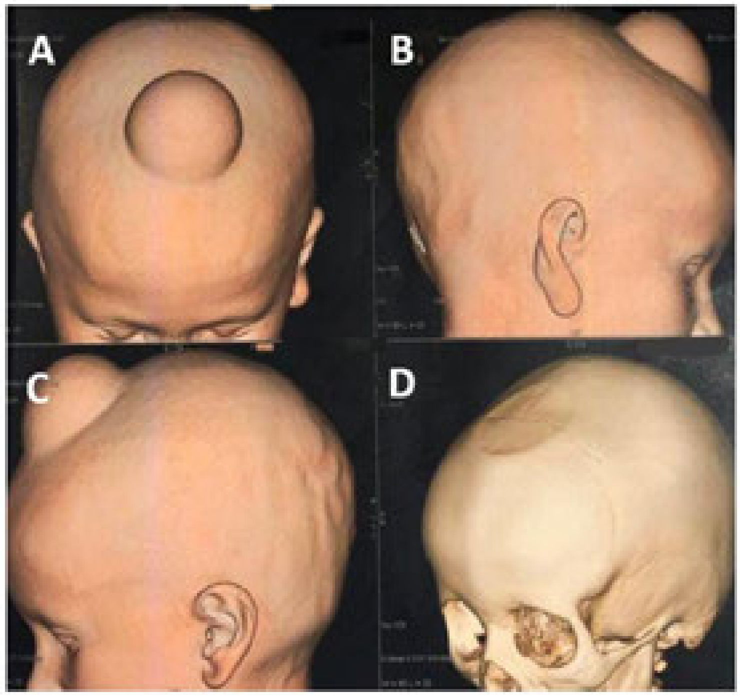

Figure 3. A-D. Cranial Computed Tomography (CT) with 3D reconstruction reveals a tumor in the anterior fontanelle region with a slight depression of the outer table of the skull bones underlying the cyst.

Figure 4. Focus on the external bone table after resection of the CIDC.

the preferred treatment, based on the need for histopathological diagnosis, infection prevention, and aesthetic concerns[31].

CIDCs present with soft, mobile, and painless cysts, often located on the scalp, particularly near the anterior fontanel[2,8,9]. These cysts can vary in size, from small (1 cm) to larger masses (up to 5 cm or more), and generally exhibit slow, progressive growth[10,14]. The cysts are typically non-pulsatile, non-tender, and immobile, distinguishing them from other cystic lesions like encephaloceles[12,22]. In rare cases, patients have reported local pain, headaches, and progressive enlargement, especially after 28 years of age[19]. There is generally no evidence of inflammation or rupture, and changes are not observed with posture or crying[2,3,8]. These consistent clinical signs support CIDC diagnosis.

Laboratory findings provide further diagnostic support. Fluid within these cysts is typically clear, watery, and occasionally turbid, sometimes containing keratin or sebaceous-like material[3,11,.18,19] Some cysts contain white or yellowish fluid with cheesy particles or hair. The fluid often resembles cerebrospinal fluid (CSF), with low protein and glucose levels, helping differentiate dermoid cysts from epidermoid cysts[15,16,18]. This biochemical analysis plays a role in diagnosing potential complications, such as infections or intracranial extension.

Histopathological analysis shows a consistent pattern of stratified squamous epithelium and dermal appendages like hair follicles, sebaceous glands, and sweat glands[8,9,11]. These features are crucial for confirming the diagnosis of CIDC and distinguishing it from other cysts, such as epidermoid or teratoid cysts[21,25]. The cyst's fluid composition varies depending on the size, age, and glandular content of the cyst, with smaller cysts containing clear fluid and larger cysts showing yellow or brownish fluid[2,23]. The analysis of sodium, cholesterol, and chloride levels varies across cysts[21]. These variations reflect the glandular composition and help differentiate CIDCs from other cystic lesions.

Histopathological findings also show a capsule made of connective tissue lined with stratified squamous epithelium, and the cyst walls contain sweat glands, sebaceous glands, hair follicles, and keratin debris[21]. Bacteriological analysis typically shows sterile fluid, with rare instances of contamination, such as Escherichia coli[23]. These findings underscore the importance of histopathological analysis for confirming CIDC diagnosis. However, some reports highlight CIDC complications, such as infections or unusual contents like hair or yellow, purulent material, which may suggest inflammation or secondary infection[12,13]. In rare cases, CIDC has been found to extend into the underlying bone without communication with the intracranial cavity[13-15]. These instances highlight the need for comprehensive clinical and histopathological evaluations.

Neuroradiological investigations, including CT, MRI, and ultrasound, are critical for diagnosing CIDCs and guiding preoperative planning. Ultrasound is particularly useful in infants with open fontanelles, clearly demonstrating the cyst's contents and its relation to intracranial structures[10].

Several studies have noted potential complications of CIDC. In some cases, cysts delayed the closure of the anterior fontanelle due to pressure, causing an osseous defect. One patient experienced this delay between 1 and 1.5 years of age[8]. Other potential complications include adherence to the dura mater or intracranial extension, which can complicate treatment and management[2]. In rare instances, cyst wall perforation during surgery led to drainage of clear fluid and caseous material, highlighting the challenges of surgical removal[9]. Additionally, partial adhesion to the dura mater made complete resection difficult in some cases, particularly when the cyst adhered to the superior sagittal sinus[10].

Despite these challenges, postoperative outcomes are generally favorable. Most children recover without significant complications, with only a few patients experiencing mild side effects such as ataxia or intranuclear ophthalmoplegia[18]. These results suggest that CIDCs can be treated effectively with minimal long-term complications when managed appropriately.

While CIDCs are generally not associated with syndromes, a case was documented where a patient had a concurrent lumbosacral meningocele, indicating that CIDC may occasionally be linked to other congenital malformations[8]. Recurrence after surgical removal is rare, with no instances of relapse reported in the reviewed studies. Most patients show satisfactory postoperative progress, with normal development and no neurological deficits. Follow-up MRIs have shown residual tumor capsules in some cases, but they did not lead to complications[2].

The prognosis for CIDC is generally positive after complete excision, typically performed for cosmetic reasons or to prevent infection. Early removal is recommended to avoid complications such as injury to the superior sagittal sinus or delayed skull fusion, as seen in some cases[10].

This case report, part of an integrative literature review, aligns with prior studies on CIDCs. While CIDCs are typically benign with low complication rates, their aesthetic impact is a key reason for seeking medical help. The focus on aesthetics may contribute to underreporting and delayed diagnoses, negatively affecting patients' mental health. In the presented case, the lesion caused bone deformity despite being asymptomatic, which could lead to more severe complications requiring complex surgery. Early diagnosis and intervention are crucial for optimizing prognosis and minimizing biopsychosocial consequences.

CONCLUSION

CIDCs are rare, benign lesions that grow slowly, which may contribute to their size. Surgical excision is the preferred treatment for accurate diagnosis, prevention of growth, and to avoid complications like infections. Advanced imaging techniques, such as CT and MRI, are vital for diagnosis and management, ensuring favorable outcomes. CIDCs typically appear as painless, mobile cysts over the anterior fontanel, with histopathological analysis showing stratified squamous epithelium and cutaneous appendages like hair follicles and sebaceous glands. Neuroradiological findings confirm their extracranial nature, distinguishing them from other cysts. CIDCs are characterized by consistent clinical, radiological, and histopathological features, which aid in differentiating them from other cystic lesions and guiding appropriate treatment. While most cases are benign, surgical treatment significantly impacts aesthetics and mental health, underscoring the importance of early intervention.

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Polytrauma Patient with Thoracic Spondyloptosis and Neurological Preservation: a case report

Paciente Politraumatizado Com Espondiloptose Torácica e Preservação Neurológica: relato de caso

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ABSTRACT
Traumatic thoracic spondyloptosis is a rare condition, typically resulting from high-energy trauma, with catastrophic neurological deficits in most of the cases. This case report describes a 27-year-old man who sustained a T5-T6 spondyloptosis following a motorcycle accident. The patient presented with severe spinal instability, spinal cord compression, and partial neurological deficits (AIS D). Emergency surgical intervention, including a posterior thoracic corpectomy (shortening the thoracic spine for reduction) and posterior instrumented fusion, was performed to stabilize the spine and preserve neurological function. The patient's postoperative course was complicated by ICU delirium, but early rehabilitation led to partial neurological improvement restoring walking ability without assistance. This case highlights the challenges and effective management strategies for thoracic spondyloptosis, emphasizing the importance of prompt surgical intervention and multidisciplinary care.

Keywords: *Spinal trauma; Thoracic vertebrae; Spondyloptosis*

RESUMO
A espondiloptose torácica traumática é uma condição rara, geralmente resultante de um trauma de alta energia, com déficits neurológicos catastróficos na maioria dos casos. Este relato de caso descreve um homem de 27 anos que sofreu espondiloptose em T5-T6 após um acidente de motocicleta. O paciente apresentou instabilidade vertebral grave, compressão da medula espinhal e déficits neurológicos parciais (AIS D). Uma intervenção cirúrgica de emergência, incluindo corpectomia torácica posterior (encurtando a coluna torácica para redução) e fusão instrumentada posterior, foi realizada para estabilizar a coluna e preservar a função neurológica. O pós-operatório do paciente foi complicado por delirium na UTI, mas a reabilitação precoce levou a uma melhora neurológica parcial, restaurando a capacidade de caminhar sem assistência. Este caso destaca os desafios e as estratégias eficazes de manejo da espondiloptose torácica, enfatizando a importância da intervenção cirúrgica imediata e do cuidado multidisciplinar.

Palavras-Chave: *Trauma espinhal; Vértebras torácicas; Espondiloptose*

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INTRODUCTION

Spondyloptosis is the complete slippage of a vertebral body from its anatomical position, a rare spinal condition typically associated with high-energy trauma, such as motor vehicle accidents or falls from significant heights[1-4]. While most documented cases occur at the lumbosacral junction, thoracic spondyloptosis is relatively rare, requiring significant forces to overcome the spine's anatomical stability[3,5]. Even rarer is neurological preservation, once the vast majority of patients are neurologically compromised due to vertebral translation.

Surgical management of thoracic spondyloptosis typically involves a combination of techniques to restore anatomical alignment and stabilize the affected segment, with the choice of approach depending on the severity of the injury, the patient's neurological status, and the surgeon's expertise[4,6]. Despite advances in surgical techniques, thoracic spondyloptosis remains a challenging condition to manage, often resulting in significant mortality due to the high risk of spinal cord injury and associated complications[4].

We present a case of traumatic thoracic spondyloptosis following a motorcycle accident in a healthy adult, who exhibited motor incomplete neurological deficit, rated American Spine Injury Classification Impairment Scale D (AIS D). The surgical technique used was discussed to achieve a successful outcome.

CASE PRESENTATION

A 27-year-old man was brought to the emergency department following a high-energy motorcycle collision with a fixed barrier. The patient was found approximately 200 meters from the motorcycle, without a helmet, and with a Glasgow Coma Scale (GCS) score of 6 at the scene.

Prehospital care included orotracheal intubation and fluid administration during transport. Upon arrival, the patient was hemodynamically unstable, with desaturation and signs of polytrauma. A red alert protocol was activated and the patient was classified as a polytrauma case. The initial evaluation identified bilateral hemopneumothorax, requiring immediate bilateral chest tube placement. The patient was treated to stabilize hemodynamic parameters.

The neurosurgery team was consulted and trauma computed tomography (CT) revealed multiple injuries, including a grade 2 splenic laceration, thoracic vertebrae, and rib fractures, severe bilateral pulmonary contusion, and pneumomediastinum (Figure 1). Spinal imaging showed a T5-T6 fracture with anterolisthesis, ptosis, and foci of pneumorrhachis, but no unstable cervical fractures. Cranial CT demonstrated spontaneously hyperdense foci in the brain parenchyma. After withdrawal of sedation one week after admission, neurological assessment classified the patient as AIS D, indicating partial debility of motor function below the level of injury.

Surgical fixation of the T5-T6 fracture was planned after the patient's clinical condition improved, with improvements in respiratory parameters and hemodynamic status, aiming to reduce perioperative risks and optimize neurological recovery conditions. A cervical collar was applied and in-block mobilization was maintained to prevent further spinal injury. Once hemodynamically stable, a magnetic resonance imaging (MRI) scan was requested for detailed surgical planning (Figure 1).

The patient underwent surgery, which was described in detail: after posterior spinal exposure, pedicle screws were inserted at T2-3-left T4 and T7 and T8. Then, a wide laminectomy, as well as concomitant posterior facet joint removal, was performed (T4-5, T5-6). The nerve roots of T5-6 were resected bilaterally to avoid spinal cord traction and increase the surgical field, followed by a posterolateral transpedicular corpectomy of T6 with a unilateral temporary rod. Then, a definitive rod was inserted at T7 and T8, and the spinal translation was reduced progressively, while the temporary rod was removed and the upper portion of the rod was fixed at T2-3-4, reducing the spinal dislocation to its normal position. Intraoperative neuromonitoring was used during the procedure; however, the evoked potentials were poor, fluctuating between absent signals and low amplitude responses. The procedure presented without incidents and postoperative imaging (Figure 2) showed satisfactory results with no complications.

Patient remained hemodynamically stable. Early rehabilitation was initiated, resulting in partial neurological improvement,

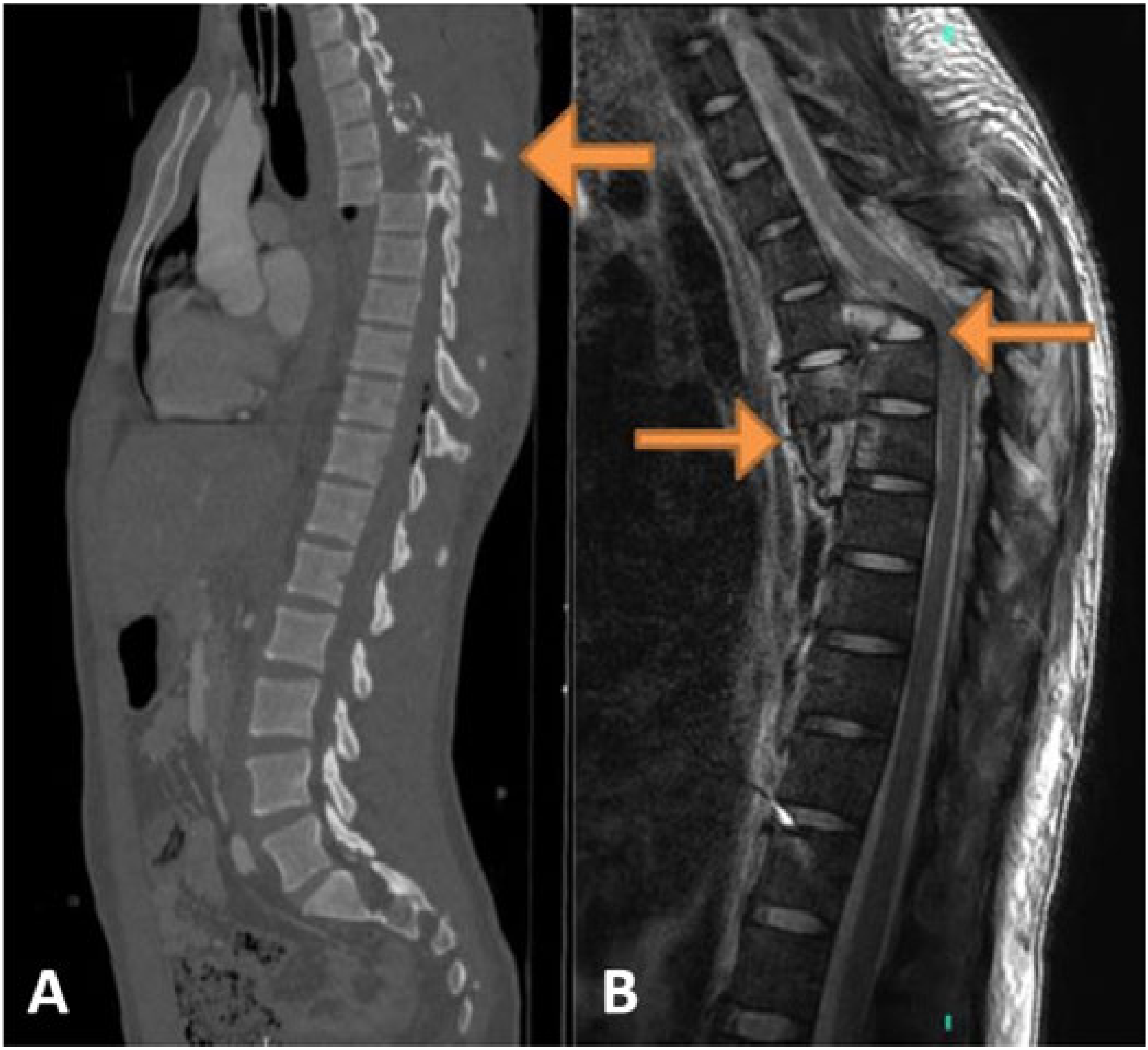

Figure 1 Preoperative imaging: Computed Tomography (CT) and sagittal T2-weighted MRI demonstrating T5-T6 spondyloptosis.

with increased lower limb strength and mobility, maintaining his neurological status. He had no surgical complications, his situation improved and he was discharged after 15 days. He was able to walk after three months of follow-up. At the one-year medical follow-up, the patient exhibited improvements in both sensory and motor functions. Hyperreflexia persisted, albeit with improvement compared to the previous evaluation. The overall clinical picture suggests a sustained and progressive neurological recovery over the course of one year.

DISCUSSION

Spondyloptosis is more commonly documented in the lumbosacral region. Its occurrence in the thoracic spine is rare due to its protective anatomical features, including the ribs and the frontal plane orientation of facet joints which allows more flexibility[3,7]; as such, it is often linked to high-energy traumas,

Figure 2. A and B. Postoperative imaging demonstrating thoracic arthrodesis from T2 to T8 in sagittal plane. C and D. Medical follow-up at 1 year showing stabilization of the thoracic vertebrae in coronal and sagittal planes.

such as vehicle accidents[8]. In the present case, the patient sustained a spondyloptosis following a motorcycle collision. The mechanism of injury likely involved a combination of axial compression, flexion, and rotational forces, leading to complete displacement of the T5 vertebral body, classified as type C according to the AOSPINE classification. The associated findings of pneumorrhachis and bilateral pulmonary contusions further underscore the severity of the trauma.

Its surgical management typically requires reduction and vertebral fusion, using pedicle screws and techniques to restore stability[3,4]. In our case, the approach involved a posterior corpectomy to decompress the spinal cord and remove the damaged vertebral body, followed by posterior arthrodesis for stabilization after shortening the spine. The patient exhibited neurological deficits classified as AIS scale D (motor incomplete), indicating preserved movement below the fracture level functionally useful. This is contrary to expectation once thoracic spondyloptosis frequently results in significant neurological injuries due to trauma severity[3,4,8].

This case is significant not only due to its rarity but also for describing the surgical technique used to reestablish spinal alignment, spinal stability, and preservation of neurological function. Due to its rigidity, the thoracic region is less prone to complete dislocations, requiring tailored surgical approaches that consider unique injury mechanisms, which differ from those in the lumbosacral region. In this context, the successful use of corpectomy and posterior arthrodesis demonstrates an effective strategy for spinal stabilization and functional recovery[2,3,5,6], rated as AIS D (post-operative) and AIS E (follow-up).

This report benefits from documented follow-up evaluations at 3 months and 1 year postoperatively, allowing for a more comprehensive assessment of outcomes. The patient's recovery may still vary based on individual factors and the severity of the trauma, which could influence the reproducibility of surgical results in similar cases[3,8].

CONCLUSION

This case highlights a rare clinical presentation and a detailed surgical technique description to treat such a challenging situation. Our experience demonstrates that a corpectomy shortening the spine with a posterior arthrodesis allows for restoring spinal stability and maintaining neurological function, resulting in a favorable patient outcome. These findings emphasize the importance of real-time surgical intervention in managing such complex cases.

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Case Report

Synchronous Glioblastoma and Grade 1 Angiomatoid Meningioma: case report and literature review

Glioblastoma e Meningioma Angiomatoide Grau 1 Sincrônicos: relato de caso e revisão da literatura

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ABSTRACT

The coexistence of glioblastoma (GBM) and meningioma is a rare finding. The glioblastoma is the most aggressive primary brain tumor in adults, while meningioma, which is usually benign, is slow growing. This study presents the case of a 69-year-old patient diagnosed with both neoplasms, confirmed by histopathological and immunohistochemical analysis after surgical resection. The literature suggests several hypotheses for this occurrence, including genetic predisposition, microenvironmental influences and possible shared cellular signaling mechanisms. Despite the different origins and prognoses, the simultaneous presence of these tumors represents a diagnostic and therapeutic challenge.

Keywords: *Glioblastoma; Meningioma; Brain tumors*

RESUMO

A coexistência de glioblastoma (GBM) e meningioma é um achado raro. O glioblastoma é o tumor cerebral primário mais agressivo em adultos, enquanto o meningioma, geralmente benigno, apresenta crescimento lento. Este estudo apresenta o caso de uma paciente de 69 anos diagnosticada com ambas as neoplasias, confirmadas por análise histopatológica e imuno-histoquímica após ressecção cirúrgica. A literatura sugere diversas hipóteses para essa ocorrência, incluindo predisposição genética, influências microambientais e possíveis mecanismos compartilhados de sinalização celular. Apesar das diferentes origens e prognósticos, a presença simultânea desses tumores representa um desafio diagnóstico e terapêutico.

Palavras-Chave: *Glioblastoma, meningioma, tumor cerebral:*

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INTRODUCTION

The coexistence of glioblastoma and meningioma is a rare condition, in which the etiology is not fully understood. The glioblastoma is the most aggressive and common primary malignant brain tumor in adults, characterized by rapid growth, diffuse invasion and poor prognosis. The meningioma, on the other hand, is the most common primary brain tumor, is usually benign, originates from the meninges and is usually slow growing. The objective of this study is to report a rare case of coexistence of glioblastoma and meningioma, analyzing the diagnostic, therapeutic and prognostic challenges of this association. In addition, it aims to review the existing literature to discuss possible etiological mechanisms, influence of the tumor microenvironment and possible molecular connections between these neoplasms.

CASE REPORT

Female patient, 69 years-old, previously dyslipidemic and taking rosuvastatin. No other comorbidities. Referred to neurosurgery due to mental confusion for about 4 days, headache and altered gait. On physical examination, she was alert, confused, with moderate motor aphasia, no cranial nerve alterations, no motor or sensory deficits. A non-contrast computed tomography (CT) scan of the skull was conducted, which showed: left frontal extra-axial lesion with calcifications, suggestive of meningioma, measuring 3.9 cm, associated with diffuse vasogenic edema. An isodense area to the parenchyma was also noted, expanding the left frontal cortex in a parafalcine situation, which may correspond to an intra-axial tumor lesion, resulting in a deviation of the midline to the right of 0.9 cm at the level of the septum pellucidum and compression of the left lateral ventricle (Figure 1).

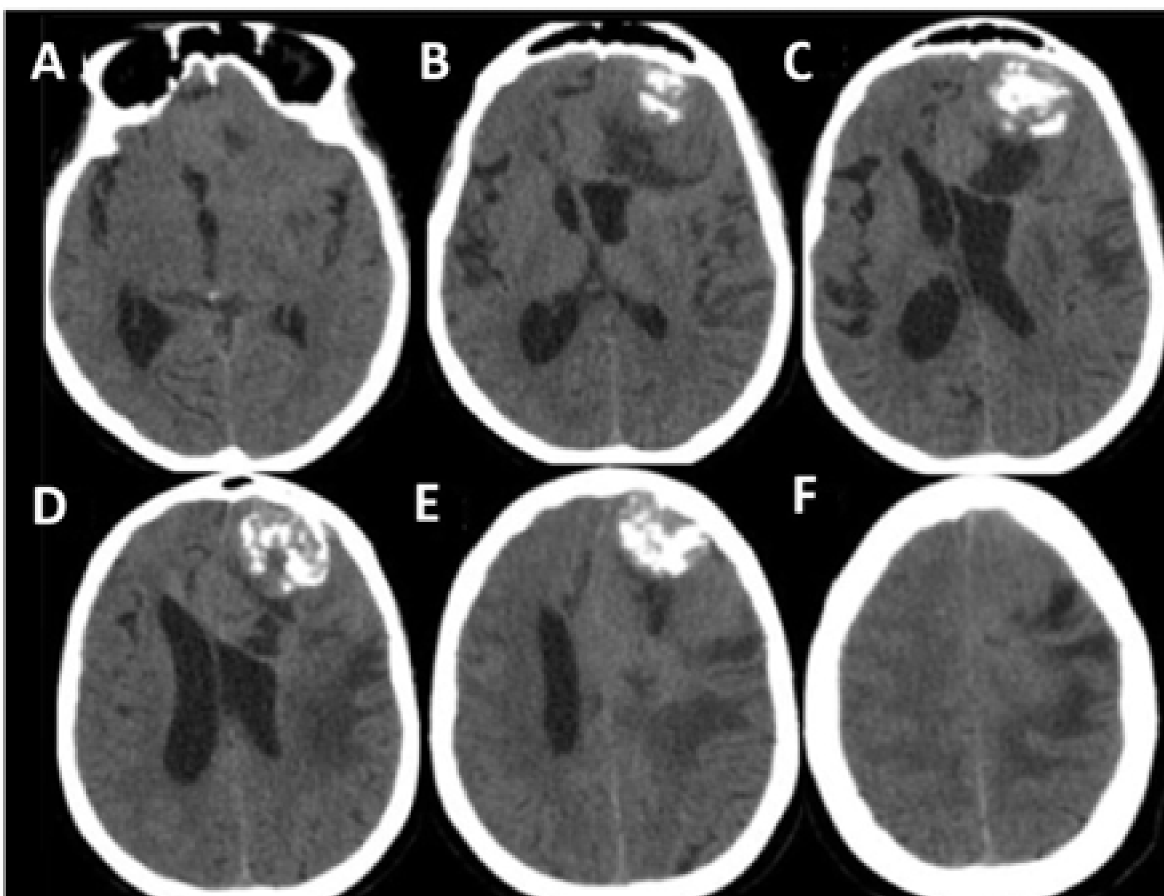

Figure 1. A-F. CT scan of the skull in axial sections, showing an extra-axial lesion on the left front with calcifications, possibly corresponding to a meningioma, measuring approximately 3.9 cm and with perilesional vasogenic edema.

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The investigation was complemented by a contrast-enhanced magnetic resonance imaging (MRI) of the skull, which showed an extra-axial lesion on the left frontal plane with a dural tail, suggestive of meningioma, and an adjacent intra-axial lesion, infiltrative, on the left frontal plane, with significant mass effect on the ipsilateral ventricle and midline structures, with probable invasion of the corpus callosum, extending to the contralateral parenchyma. Heterogeneous uptake of paramagnetic contrast, suggesting high-grade glioma (Figures 2 and 3).

Total macroscopic resection of the left frontal extra-axial lesion and wide, partial resection of the infiltrative intra-axial lesion were performed without complications. Control cranial CT showed no evidence of neurosurgical complications (Figure 4).

he anatomopathological examination revealed a high-grade infiltrating astrocytoma, adult type (WHO Grade 4), with hypercellularity, marked cellular atypia, focuses of glomeruli vascular proliferation and small areas of necrosis with a peripheral palisade border. The neoplasm invades a small area of angiomatoid meningioma with Psammoma bodies (WHO Grade 1) (Figure 5). Immunohistochemistry was compatible with glioblastoma (WHO Grade 4), wild-type IDH with Ki-67 of 60%. The patient was led for oncological and radiotherapy follow-up. She did not present

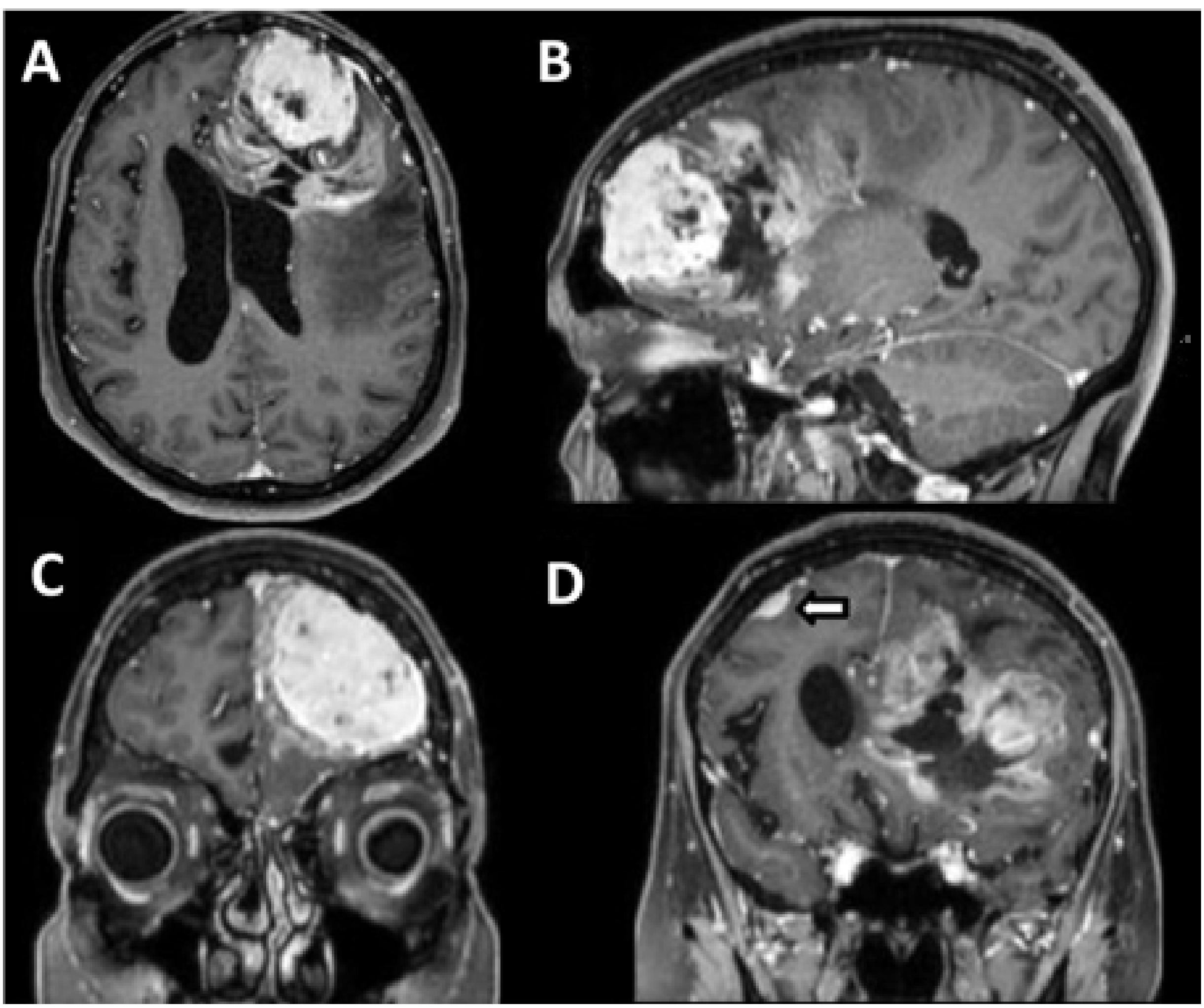

Figure 2. T1-weighted MRI of the skull with gadolinium. **A.** axial section, **B.** sagittal section, showing an expansive lesion on the left front with an extra-axial component with a dural tail and homogeneous contrast enhancement, and around it, showing an intra-axial, infiltrative lesion with heterogeneous contrast enhancement. **C.** coronal section showing an expansive lesion with homogeneous contrast enhancement. **D.** coronal section showing an expansive, heterogeneous and infiltrative lesion on the left and a small contralateral extra-axial lesion with homogeneous contrast enhancement, compatible with a convexity meningioma (arrow).

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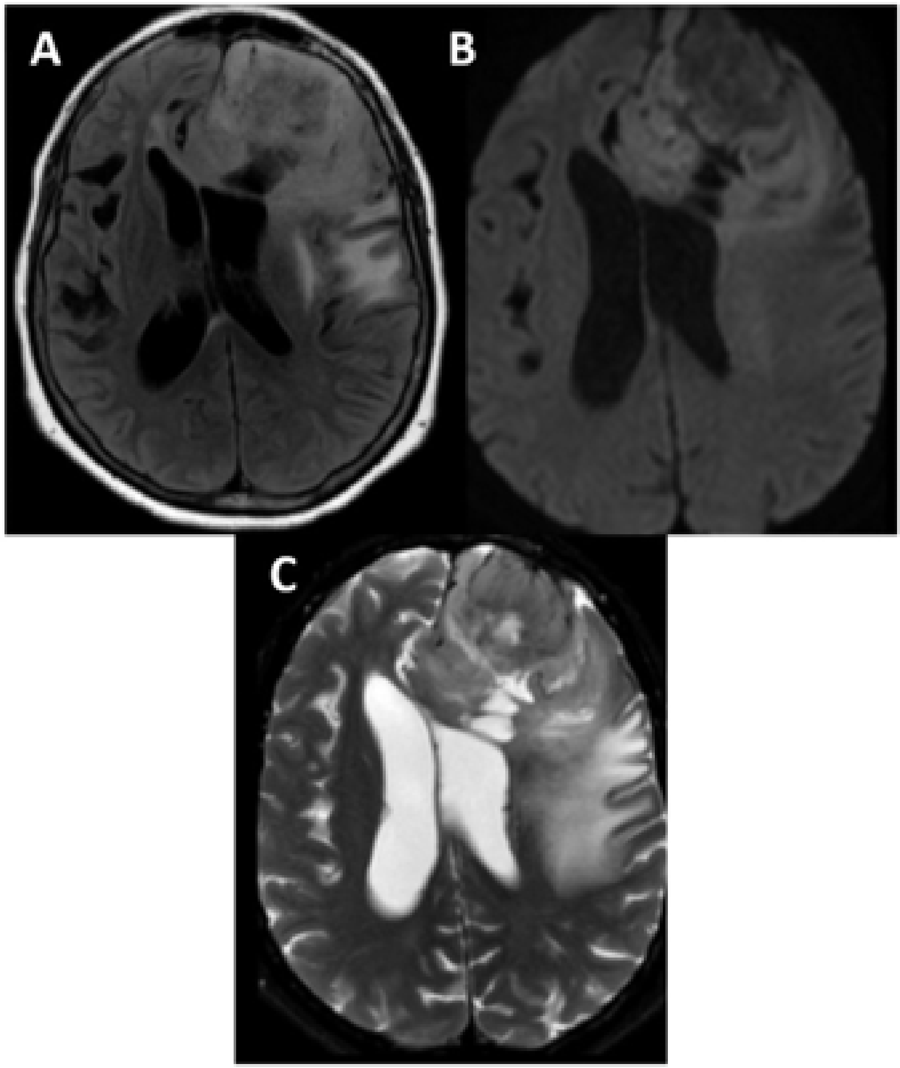

Figure 3. Skull MRI in axial sections, in FLAIR sequence (A), showing frontal infiltrative lesion on the left side with invasion of the corpus callosum and contralateral parenchyma; B100 diffusion (B), showing restricted diffusion in the infiltrative lesion; and T2 (C), showing dilation of the lateral ventricles and perilesional vasogenic edema.

focal deficits in the postoperative period. The patient's moderate motor aphasia remained.

DISCUSSION

In 2021, the World Health Organization (WHO) published a new classification for central nervous system tumors, incorporating genetic, oncogenic, and histological criteria to improve diagnostic accuracy. Within this approach, IDH-wild-type diffuse astrocytic tumors that present certain molecular alterations — such as mutation in the TERT promoter, amplification of the EGFR, or the combination of gain of chromosome 7 and loss of chromosome 10 (+7/-10) — demonstrate a biological behavior comparable to the glioblastoma. Consequently, these tumors are directly classified as IDH-wild-type glioblastoma (WHO grade 4), regardless of their histological features[1-3].

The Angiomatoid meningioma is a subtype of meningioma (WHO grade 1) with typically benign behavior. The presence of Psammoma bodies — concentric calcified deposits — is a histological feature observed in several subtypes of meningiomas, including angiomatoid meningioma. Detection of these bodies

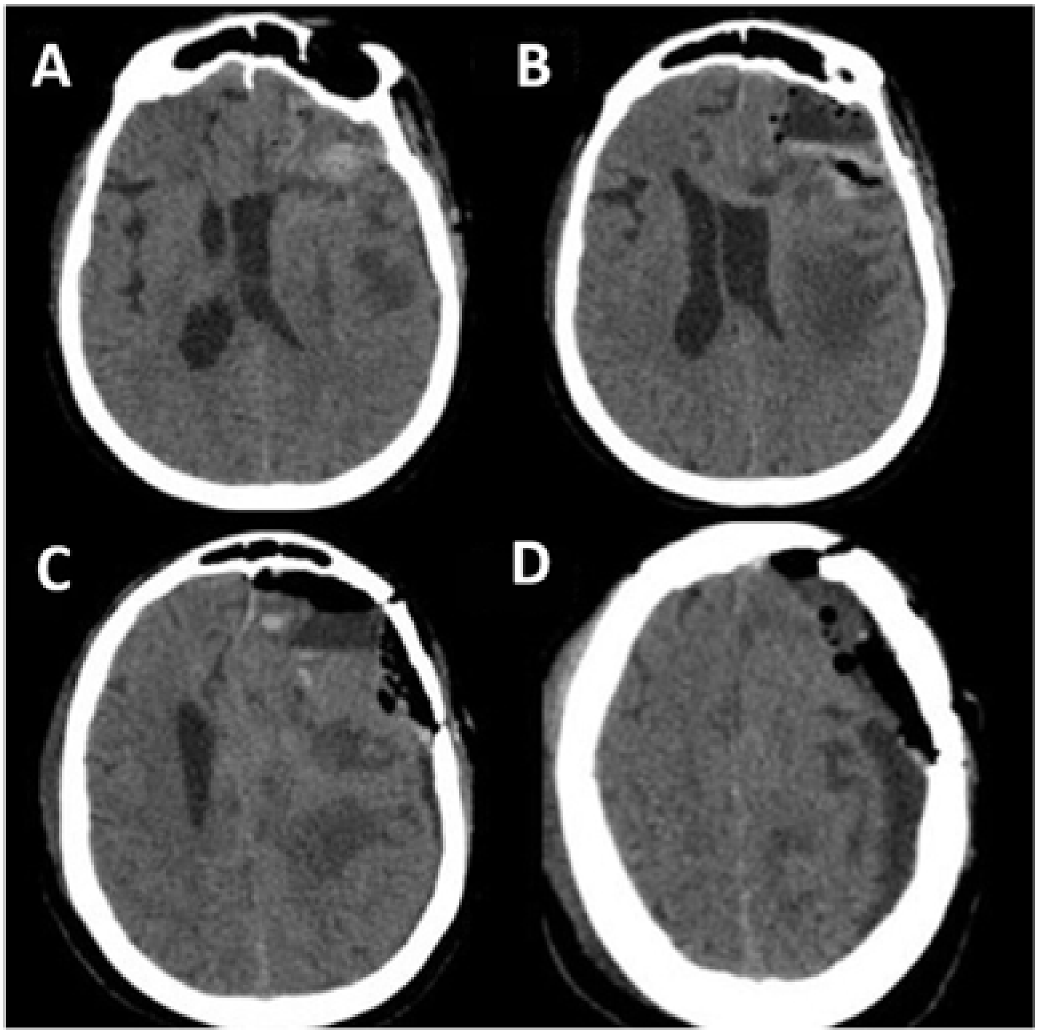

Figure 4. A-D. CT in axial sections showing the area of surgical resection, with no evidence of postoperative complications.

does not alter the tumor classification, but serves as an additional marker in the histopathological evaluation[4,5].

Atallah et al. carried out a systematic review, analyzing 21 studies that described 23 patients with concomitant diagnosis of these neoplasms, revealing a higher incidence in females (61.9%) and an average age of 61 years at diagnosis. In 80.9% of cases, both tumors were located in the same cerebral hemisphere, suggesting a possible regional predisposing factor[6].

The simultaneous presence of distinct intracranial tumors originating from different cell lines raises questions about the underlying mechanisms involved. Although the coexistence may be coincidental, factors such as genetic predisposition, environmental influences or changes in the tumor microenvironment may play a role in this context. Current literature does not yet fully clarify whether there is a direct connection between the simultaneous presence of Meningioma and Glioblastoma or whether their joint occurrence is merely random[6,7]. Despite the uncertainty about the relationship between the two tumors, further investigations into their molecular mechanisms and underlying genetic factors are essential for the development of more effective and individualized therapeutic strategies.

The simultaneous association of Meningioma and Glioblastoma is rare, especially in patients without a history of radiation therapy or systemic diseases such as neurofibromatosis or Von Hippel-Lindau disease. Radiation therapy is a known risk factor for gliomas, but there have been reports of Glioblastoma arising in areas adjacent to Meningiomas without prior radiation exposure.

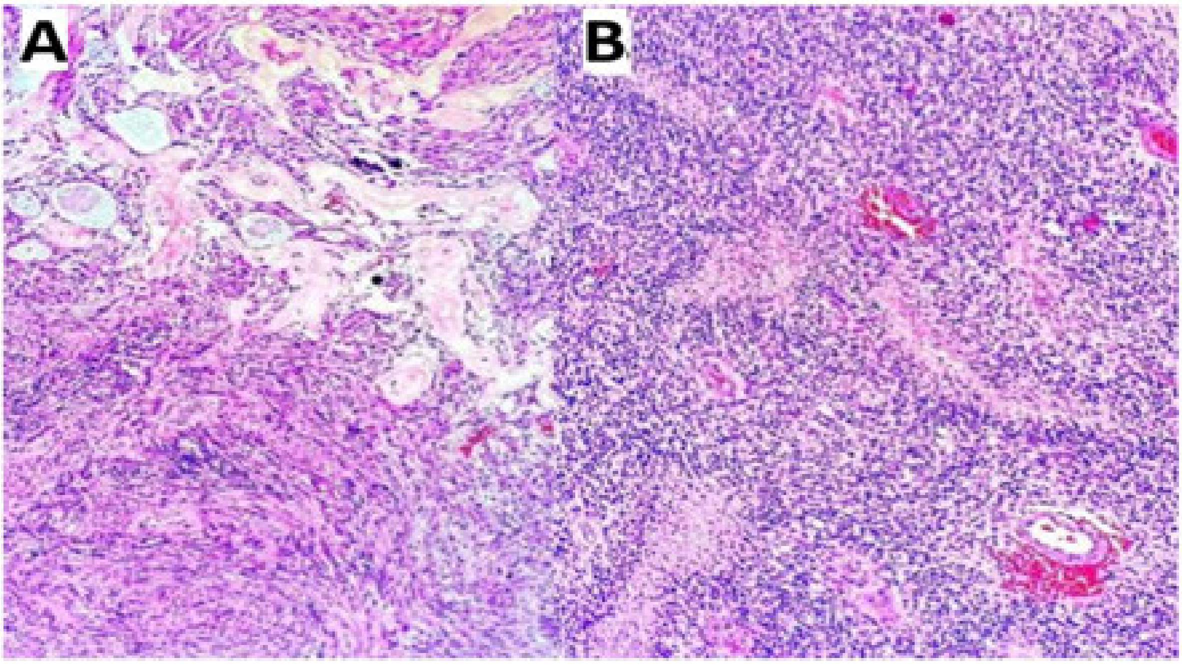

Figure 5. A. Primary poorly differentiated malignant neoplasm of the brain with astrocytic differentiation and high mitotic index, with area of invasion of meningothelial meningioma (WHO Grade 1), hematoxylin-eosin, 40x. **B.** High-grade astrocytoma showing hypercellularity, marked atypia and palisade necrosis, hematoxylin-eosin, 40x.

One hypothesis suggests that the meningioma may alter the brain microenvironment, favoring the malignant transformation of adjacent glial cells. Another theory proposes that the meningioma surgery triggers local inflammation, similar to brain trauma, which may contribute to the development of gliomas. However, this correlation is still controversial, since gliomas are rare in patients with a history of trauma or surgery[8,9].

Besides, some researchers suggest that meningiomas and gliomas may share alterations in cellular signaling pathways, but the exact molecular mechanisms remain unclear. Wang et al., reported on a case in which the glioblastoma arose in the hemisphere contralateral to the operated meningioma, without association with radiotherapy or systemic diseases. The pathogenesis of this phenomenon is still unknown, highlighting the need for further studies to clarify the underlying mechanisms and improve the understanding of this unusual tumor coexistence[8].

Furthermore, Spallone et al., reviewed 54 cases of simultaneous occurrence of meningioma and glioma. Diagnosis can be challenging due to discrepancies between clinical and imaging findings, which can lead to unexpected worsening of the condition after resection of one of the tumors or to a pattern that mimics tumor recurrence. Simultaneous resection of both tumors showed the best outcomes, while isolated surgery for glioma was associated with a high mortality rate. Despite the various hypotheses suggested to explain this association, it is most likely that meningiomas and gliomas are distinct primary tumors that occur randomly in the same patient[10].

Differential diagnosis between Glioblastoma and Meningioma is essential, especially when the radiological characteristics suggest an extra-axial lesion. There are reports of cases in which primary Glioblastoma mimics, both in imaging exams and intraoperatively, a Meningioma, which can generate diagnostic uncertainties and impact the therapeutic strategy[11,12].

CONCLUSION

The occurrence of glioblastoma and meningioma at the same time is a rare phenomenon and is not yet fully understood. Differential diagnosis can be challenging due to overlapping clinical and radiological features, making histopathological analysis essential for a definitive diagnosis. The combined surgical approach has proven to be the most appropriate therapeutic option, but the prognosis remains reserved due to the aggressiveness of the glioblastoma. Current literature suggests that this coexistence may be a random event or the result of genetic and microenvironmental factors that have not yet been fully elucidated. Further investigations are needed to clarify the molecular mechanisms involved and optimize therapeutic strategies for patients affected by these neoplasms.

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Case Report

UBE TLIF, Inverted Learning Curve. Our Experience in an Iberic Hospital

UBE TLIF, Curva de Aprendizagem Invertida. A Nossa Experiência num Hospital Ibérico

Marcel Sincari[1]
Eduardo Mendes[2]
Luciano Guerra[2]
Mark-Daniel Sincari[3]

ABSTRACT

The surgical technique has developed continuously from open surgery to minimally invasive methods, the spine surgeons always are looking for better solutions, trying to improve patient's satisfaction. The concept and goal of minimally invasive surgery is to diminish the destruction of muscles and bony structures, thus reducing the pain and shortening the recuperation of the operated patients. We report our first experience with UBE TLIF with normal used cages and with large cages used for OLIF. All colleagues and the literature recommend to gain some initial experience by doing decompressions by UBE technique and after gaining confidence to start doing UBE TLIF, the learning curve being described as steep. We broke this concept and started to do TLIF without any experience in performing UBE decompression. Our team is composed by a neurosurgeon and orthopedic surgeons and the facilitating factor was some anterior experience with uniportal endoscopy and the orthopedic surgeons were skilled in triangulation because was preforming arthroscopic knee surgeries. We do not advise this type of learning curve; we just want to count our experience.

Keywords: *Biportal; Endoscopy; Decompression*

RESUMO

A técnica cirúrgica evoluiu continuamente, desde a cirurgia aberta até métodos minimamente invasivos. Os cirurgiões de coluna estão sempre buscando as melhores soluções, buscando aumentar a satisfação do paciente. O conceito e o objetivo da cirurgia minimamente invasiva são diminuir a destruição de músculos e estruturas ósseas, reduzindo assim a dor e encurtando o tempo de recuperação dos pacientes operados. Relatamos nossa primeira experiência com TLIF por UBE com cages comuns e com cages grandes para OLIF. Todos os colegas e a literatura recomendam adquirir alguma experiência inicial realizando descompressões pela técnica UBE e, após ganhar confiança, começar a realizar TLIF por UBE, sendo a curva de aprendizado descrita como íngreme. Quebramos esse conceito e começamos a realizar TLIF sem qualquer experiência na realização de descompressão por UBE. Nossa equipe é composta por um neurocirurgião e cirurgiões ortopédicos, e o fator facilitador foi a experiência prévia com endoscopia uniportal, e os cirurgiões ortopédicos eram habilidosos em triangulação, pois realizavam cirurgias artroscópicas do joelho. Não recomendamos esse tipo de curva de aprendizado; apenas queremos compartilhar nossa experiência.

Palavras-Chave: *Biportal; Endoscopia; Decscompressão*

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INTRODUCTION

Since its beginning, spine surgery has had a continuous and dynamic evolution, the most important being cited below. In 1944, Briggs and Milligan published their novel technique, the posterior lumbar interbody fusion (PLIF), involving continuous removal of vertebral bone chips and replacement of the disc with a round bone peg[1]. In 1952, posterior lumbar interbody fusion (PLIF) was proposed by Cloward using banked bone[2]. In 1973, Philadelphia orthopedic surgeon Parviz Kambin, Professor of Orthopedic Surgery and Endowed Chair of Spinal Surgery Research at Drexel University College of Medicine, introduced a transforaminal route to the disc space, exploiting an access corridor free of significant vascular and neural structures. Kambin initially explored this pathway in the percutaneous posterolateral resection of herniated L3–4 and L4–5 discs using fluoroscopic guidance and an incision 8–9 cm from the midline[3]. "Kambin's triangle", recently described three-dimensionally as "Kambin's prism", is enclosed anteriorly by the exiting nerve root, inferiorly by the proximal endplate of the lower vertebral body, posteriorly by the superior articular process of the lower vertebra, and medially by the traversing nerve root and thecal sac[4]. Without necessitating bone removal, this anatomical prism enabled Kambin to perform endoscopic discectomy procedures while avoiding neural retraction[5].

In 1982, Harms and Rolinger redefined the posterior corridor by approaching the disc space through the intervertebral foramen, establishing the transforaminal lumbar interbody fusion (TLIF)[6].

In 1996, Daniel Julio de Antonio, from Argentina, described the unilateral biportal endoscopic (UBE) technique decompression[7]. 6 years after UBE decompression was described, Foley and Lefkowitz published the novel MIS-TLIF technique in 2002. The UBE technique caught the attention of spine surgeons and has evolved significantly during the past years[8].

METHODS

Our first experience with UBE TLIF consists of 12 operated patients, the cages used were bullet, banana titanium and large OLIF PEEK cages. The main indication for surgery was central, foraminal stenosis and low grade listhesis. Our purpose is not statistical or clinical; we aim at sharing our experience, as stated, performing UBE TLIF without any experience in UBE decompression.

The first case was a bullet cage (Figures 1-2) and as seen in the postoperative pictures it was a small IAP resection

In the next case we became more confident and the decompression was larger (Figures 3-4) and the implant was a banana shape cage.

The following cases were L5-S1 left side UBE TLIF (Figures 5-6) and L4-L5 right side UBE TLIF (Figures 7-8).

Our seventh case was UBE TLIF with large OLIF cage (Figure 9) for severe L4-L5 stenosis and degenerative listhesis with good evolution and good disc height restoration, adequate decompression (Figure 10).

Our series of large-cage TLIF were followed by three more OLIF cages, in total four cases, and in the last case we had a major complication. Until this moment, we had one case with postoperative partial neural deficit, in progressive recovery.

It was a case of cage mispositioning into retroperitoneal space (Figures 10-11), diagnosed intraoperatively. The cage was removed 1 week later through retroperitoneal approach, together with vascular surgeon with suturing of cava vein. As seem on Figure 11 the posterior opposite quarter of the intervertebral disc was not enough prepared and at the moment of rotation of the cage, it penetrated the anterior longitudinal ligament and went to retroperitoneal space. The patient had no neurological deficits, it was decided not to put another cage (Figures 12-13).

RESULTS

In our series of 12 cases of UBE TLIF, four were with large-sized cages (OLIF cage 45x18mm, the height depending on the intervertebral space). We had two complications and both

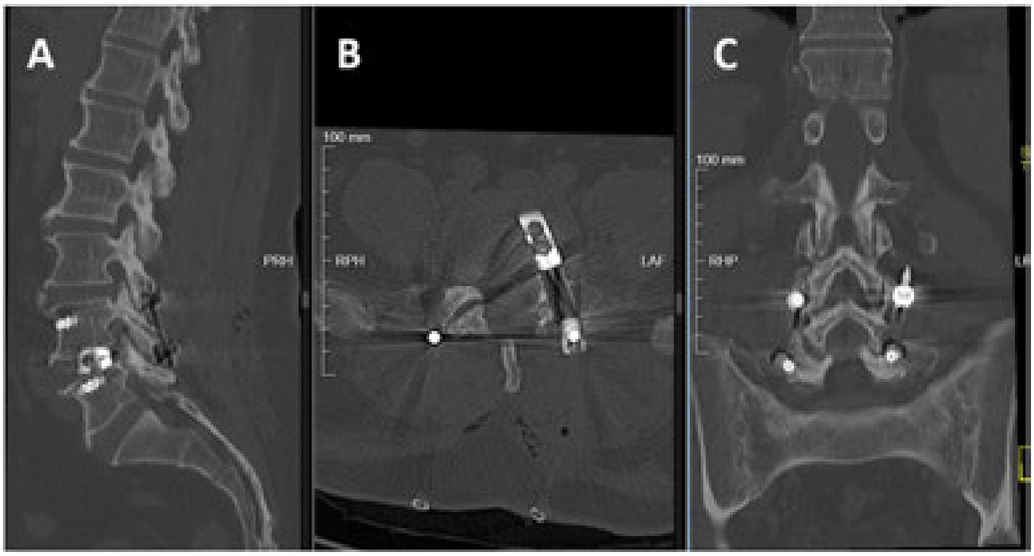

Figure 1. A-C. UBE TLIF with bullet cage.

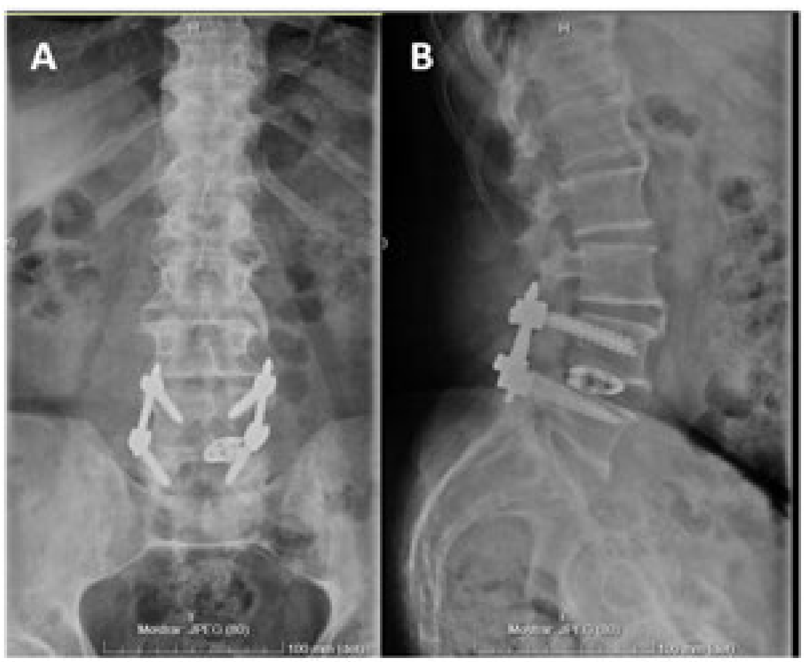

Figure 2. A and **B**. UBE TLIF with bullet cage.

were with large-sized cages. One complication was partial neurological deficit in progressive recuperation, and one cage migration resolved surgically. In the rest of the group with normal-sized cages, we had no complications. The last case of UBE TLIF died three months after surgery due to a severe pulmonary infection.

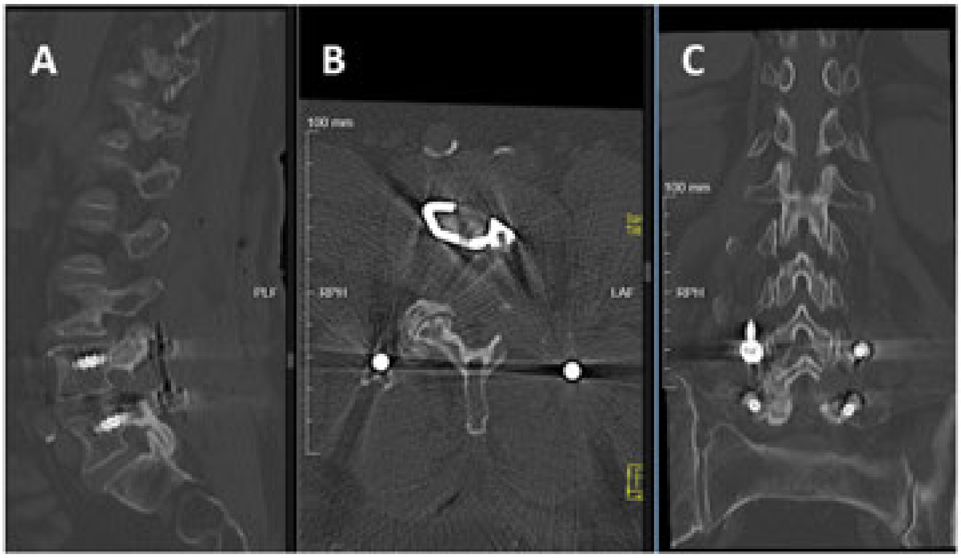

Figure 3. UBE TLIF with banana shape cage.

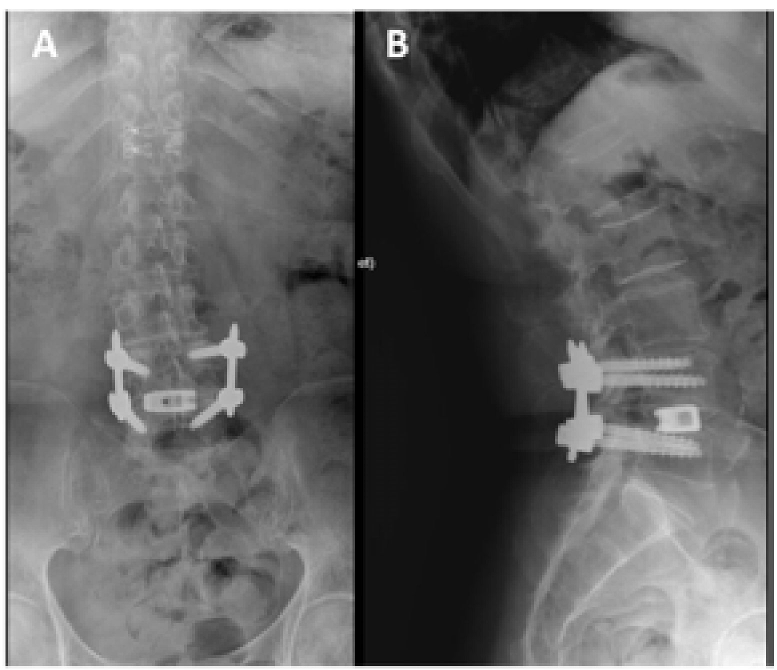

Figure 4. UBE TLIF with banana shape cage.

DISCUSSION

Our results do not seem unsatisfactory, excluding the two cases with large-sized cages that were perfectly avoidable. This outlines the importance of avoiding cage positioning and neurologic complications by 1) Continuous increase of team experience; 2) Preoperative planning by measuring the extended Kambin triangle; 3) Adequate disc preparation, especially the opposite posterior quarter; 4) Complete intraoperative integrity check by palpating; 5) Preservation of yellow ligament as protection of dura and nerves during cage insertion; and 6) Postoperative CT scan to check decompression and device placement, at least at the beginning of the learning curve.

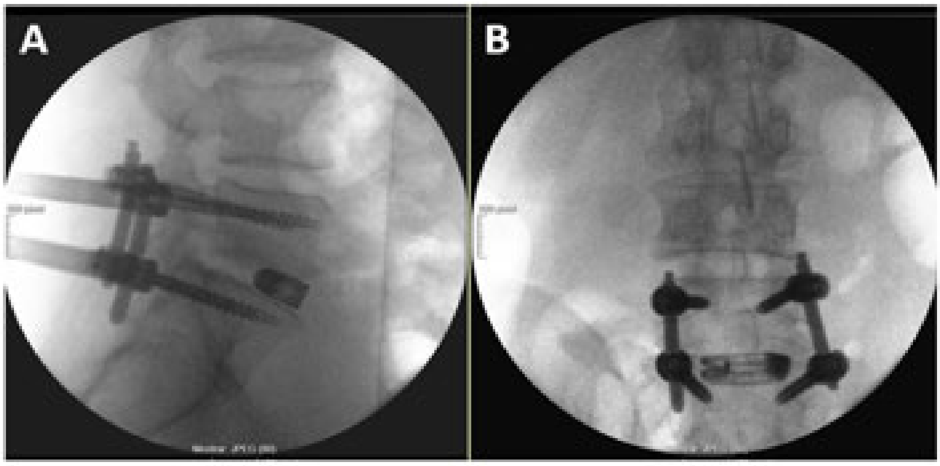

Figure 5. L5-S1 UBE TLIF.

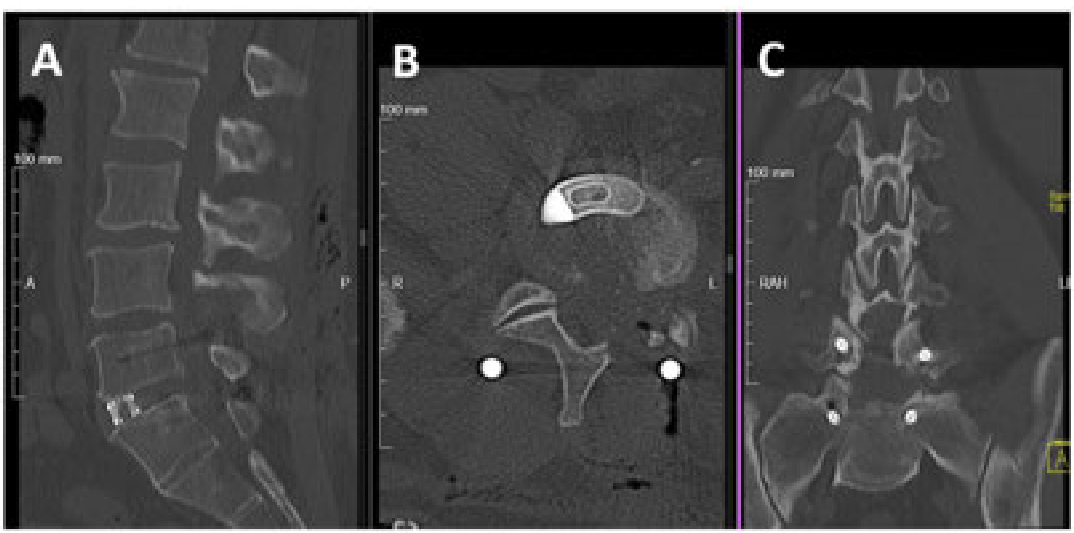

Figure 6. L5-S1 UBE TLIF.

Some publications enhance the importance of measuring the distance between the exiting and traversing nerve roots preoperatively on axial MRI slices. According to Heo, if this distance is larger than 16 mm, a large-sized cage could be safely inserted without neural injury. This distance is relatively wide in the lower lumbar area, including the L4–L5 and L5-S1 levels. If the distance between the exiting and traversing nerve roots is narrow (less than 15 mm), TLIF cages or two PLIF cages are recommended instead of a large-sized cage[9].

No data are available on the adequacy of disc space preparation in vivo; however, a cadaveric study with 40 lumbar levels compared the process in minimally invasive vs open approach and demonstrated that the percentage of disc material removed was

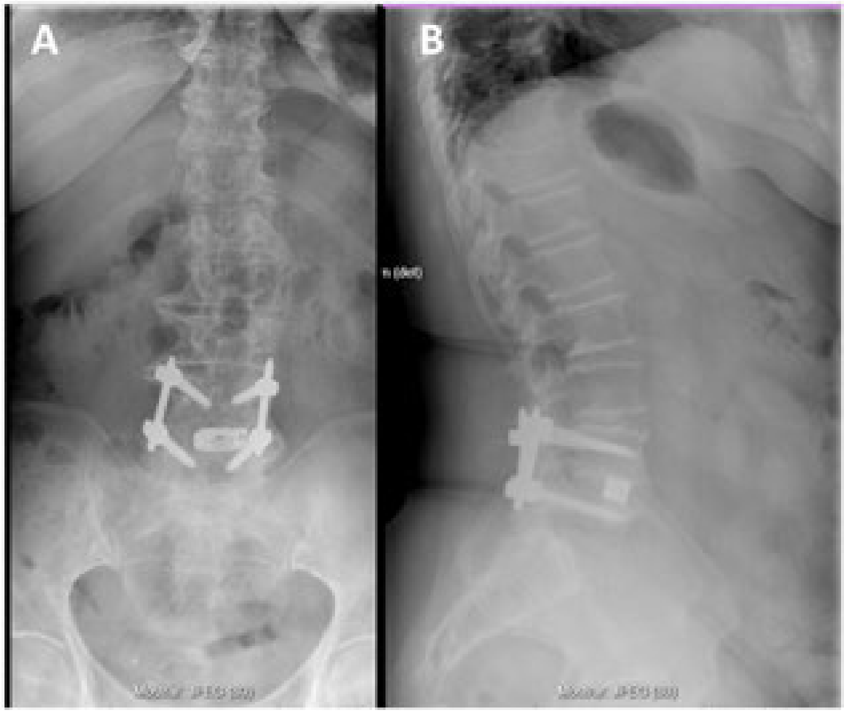

Figure 7. Right side L4-L5 UBE TIF.

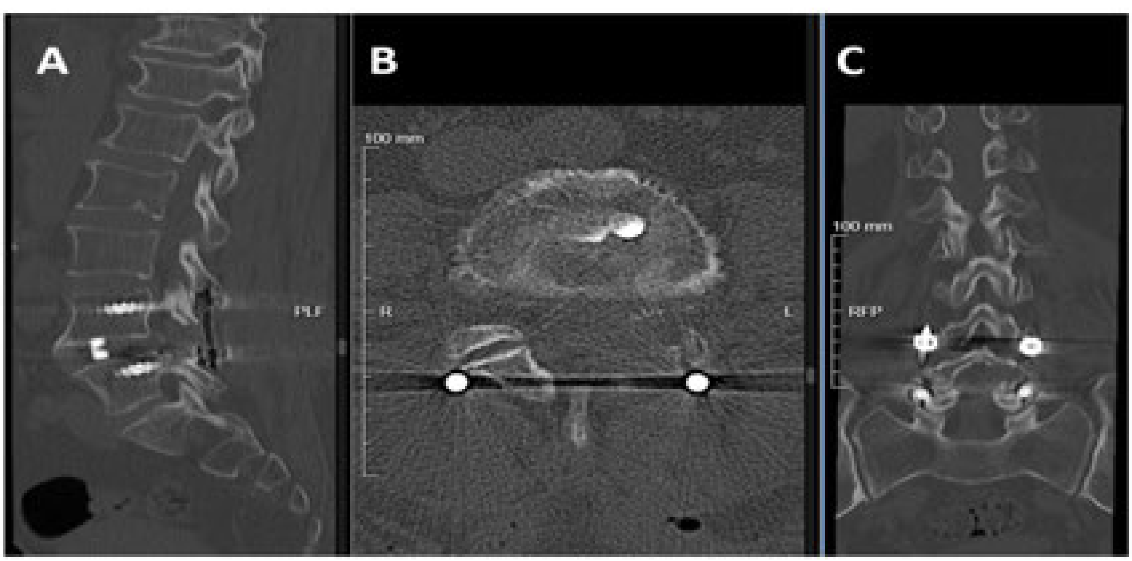

Figure 8. Right side L4-L5 UBE TIF.

approximately 75% for either approach. The posterior contralateral quadrant of the disc space was the area with the lowest percentage of disc removed[10]. This data is applicable also to UBE TLIF and it is more important in cases of large cage placement, since the

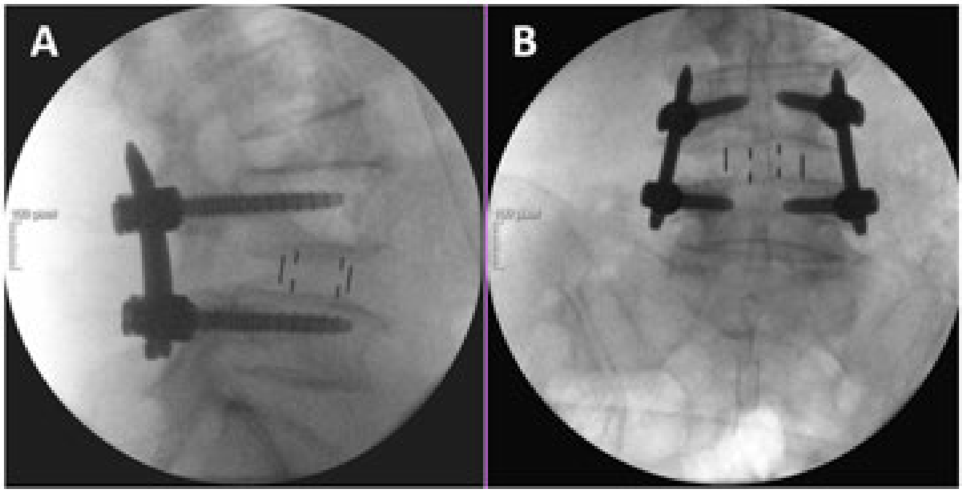

Figure 9. UBE TLIF L4-L5 with large cage.

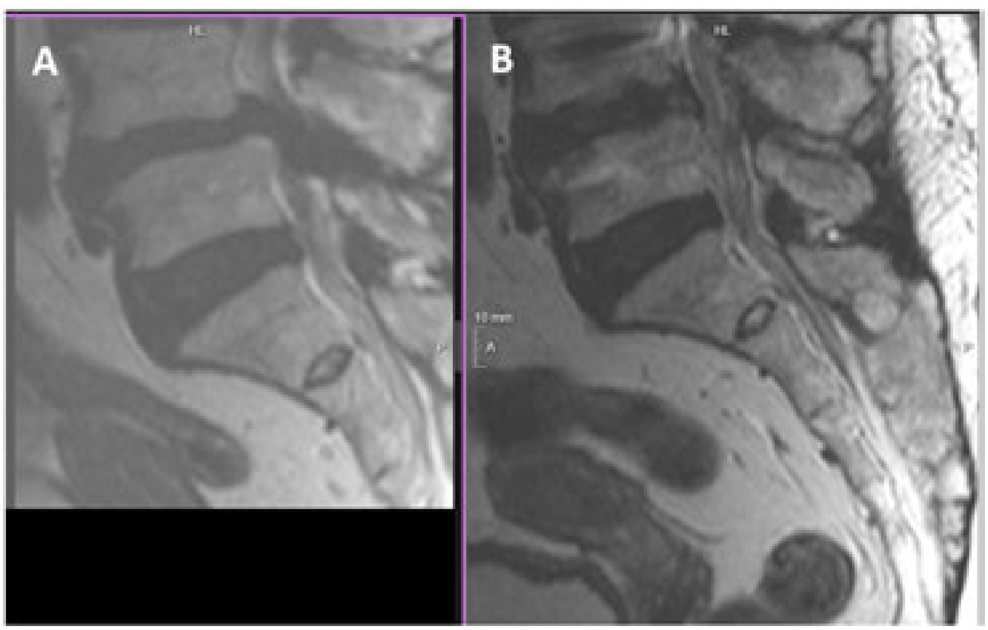

Figure 10. Preoperative and postoperative MRI.

lack of preparation of the posterior contralateral quadrant of the disc does not allow for a good rotation of the cage and leads to different kinds of complications.

Injury of the anterior longitudinal ligament was reported in one case out of 7[11]. In spite of this small incidence, it is not difficult to check its integrity during the surgery by palpating.

The yellow ligament and its foraminal extension is a protection for neural elements during cage insertion and, after X-Ray confirmation of the adequate positioning of the implant, it is safe to remove the ligament and proceed to decompression.

We believe that it is important to perform a CT scan postoperatively. First, it detects any potential complication and

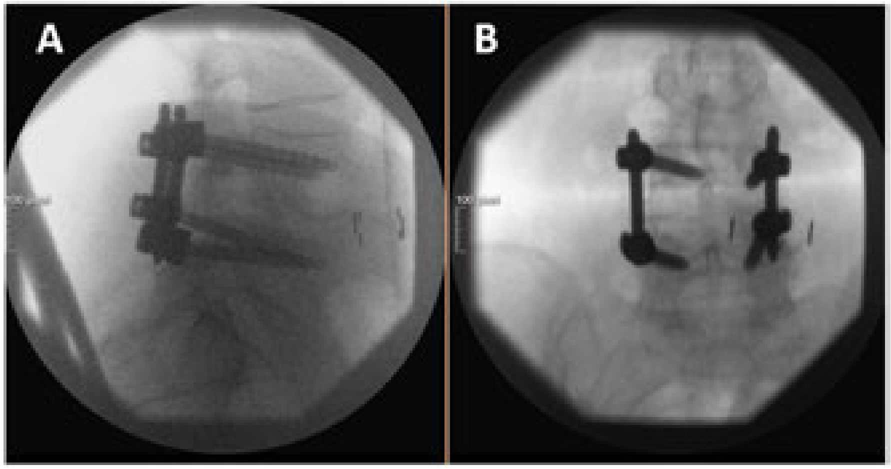

Figure 11. A and **B**. Large cage positioned into the retroperitoneal space.

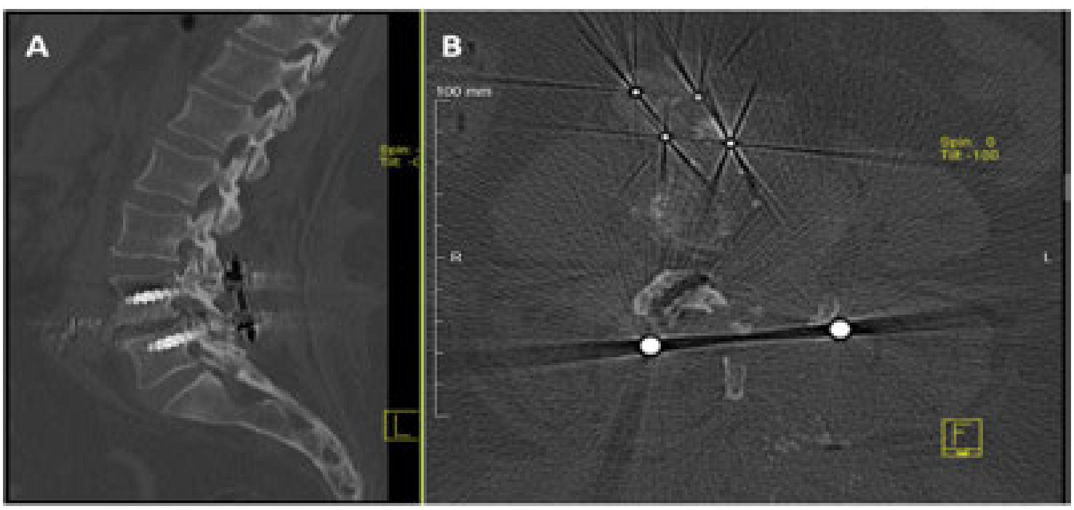

Figure 12. A and **B**. CT scan showing the OLIF cage situated into retroperitoneal space.

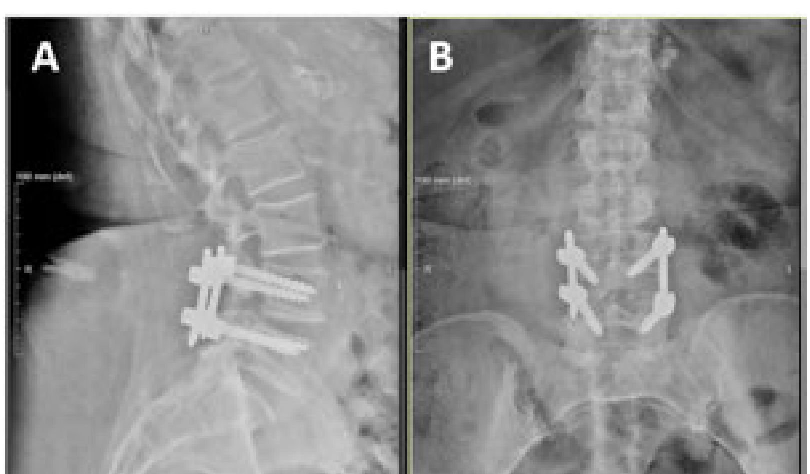

Figure 13. A and **B**. Postoperative X-Ray.

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arthrodesis material mispositioning early on and, second, it has an academic purpose, allowing the visualization of decompression adequacy and improving the technique in the future.

CONCLUSION

The incidence of complications of the UBE technique is comparable or less than those with MISS TLIF. The results of a single-arm rate meta-analysis showed 6.27%, while the incidence of dural tear was 2.49%. In UBE treatment of lumbar spine stenosis the incidence of transient paresthesia was 0.14%; the incidence of postoperative spinal epidural hematoma was 0.27% and the incidence of postoperative headache, inadequate decompression, root injury and infection was 0.00%[12].

The incidence of postoperative spinal epidural hematoma in biportal endoscopic surgery observed on postoperative MRI (24.7%) is higher than expected, although the number of those requiring revision (1.9%) is significantly lower. Revision surgery is necessary when canal encroachment is >50% as a result of postoperative spinal epidural hematoma[13]. The postoperative hematoma has always been a topic for debate; in our small series, we did not put in drains and had no hematoma, although we admit that one series is small.

UBE TLIF is a safe and effective minimally invasive surgical method for treating patients with lumbar spinal stenosis and intervertebral disc herniation, with low grade listhesis. UBE TLIF combined with endoscopic unilateral pedicle screw fixation can achieve excellent clinical results and may become a new minimally invasive endoscopic fusion method for lumbar degenerative diseases. The use of large cages is technically more demanding but reduces the risk of subsidence and promotes better fusion.

As stated by some authors, cages with large footprints would enhance the segmental stability and more evenly distribute the loading between the adjacent vertebrae at the endplate, resulting in less likelihood of endplate point-loading and resultant subsidence. Moreover, larger cages generally have a bigger hollow space within the cage to accommodate larger graft volume[14].

UBE TLIF with a large cage permits better restoration of disc height, providing better condition for fusion, and less probability of subsidence, but it is technically more demanding with more probability of neurological complications. Hence, it should be done when the surgeon feels prepared, always accompanied by good preoperative planning.

UBE TLIF with a large cage is not a criterion of professionalism; its purpose is the patient's well-being. In case there is the smallest doubt, it is better to bet on the safest method, such as UBE TLIF with TLIF, PLIF cage, double cage, etc. Sometimes, less is more.

In any case, we consider our learning curve favorable. It highlighted that it is not mandatory to start gaining experience by doing UBE decompressions, and some experienced surgeons could start with UBE TLIF. We do not outline this as a recommendation but as a possibility.

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Brief Note

Persistent Type 1 Proatlantal Artery Associated with Internal Carotid Artery Stenosis Treated by Percutaneous Angioplasty

Artéria Proatlantal Tipo 1 Persistente Associada à Estenose da Artéria Carótida Interna Tratada por Angioplastia Percutânea

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Gabriel Mossmann[3]

ABSTRACT

The proatlantal artery (PA) is a rare anatomical variation resulting from the persistence of this vessel from the embryological period and connects the internal carotid artery (ICA) with the vertebrobasilar system. A 67-year-old male presented with cerebral ischemic symptoms was investigated with arteriography, which demonstrated a PA as the source of blood supply to structures of the posterior fossa. A 70% stenosis of the ICA was identified associated with the PA and treated with stent angioplasty. PA is a rare anatomical anomaly and, when associated with carotid atheromatosis, can cause ischemic events in the anterior and posterior circulation. Treatment can be challenging due to the complex anatomy related to this anatomical alteration.

Keywords: *Carotid artery diseases; Carotid stenosis; Cerebrovascular disorders; Stroke*

RESUMO

A artéria proatlantal (AP) é uma variação anatômica rara resultante da persistência deste vaso desde o período embriológico e conecta a artéria carótida interna (ACI) com o sistema vertebrobasilar. Paciente masculino de 67 anos com sintomas isquêmicos cerebrais foi investigado com arteriografia, que demonstrou AP como fonte de suprimento sanguíneo para estruturas da fossa posterior. Foi identificada uma estenose de 70% da ACI associada à AP e tratada com angioplastia com stent. A AP é uma anomalia anatômica rara e, quando associada à ateromatose carotídea, pode causar eventos isquêmicos na circulação anterior e posterior. O tratamento pode ser desafiador devido à complexa anatomia relacionada a essa alteração anatômica.

Palavras-Chave: *Doenças das artérias carótidas; Estenose carótida; Doenças cerebrovasculares; Acidente vascular cerebral*

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INTRODUCTION

The proatlantal artery (PA) is a rare anatomical variation resulting from the persistence of this vessel from the embryological period. This embryological vessel connects the internal carotid artery (ICA) with the vertebrobasilar system[1].

Other embryologic arteries include the trigeminal, otic, and hypoglossal arteries, and may also be found as remnants in adult life. The incidence of persistent embryologic anastomoses has been estimated at between 0.1 and 1%, with the trigeminal artery being the most common, followed by the hypoglossal, proatlantal, and otic arteries being the rarest[2-5].

Its association with carotid stenosis, especially when symptomatic, can be of great risk to the patient, since generally all vascular supply to the posterior circulation comes from the PA, its presence usually being associated with agenesis or hypoplasia of the vertebral arteries[6,7].

The present study aims to describe a case of symptomatic carotid atheromatosis in a patient with anatomical variation of the pro-atlantal type 1, describing the treatment with stent angioplasty. A review of the subject was also performed based on the previously published literature.

CASE PRESENTATION

A 67-year-old male, previously a smoker and a type 2 diabetic, was admitted for investigation of visual impairment, mental confusion and paresis in the right upper limb. The symptoms were transient, improving completely after 7 days. On physical examination, the patient appeared confused and disoriented, with no other changes in the neurological examination after this period.

The investigation started with a head computed tomography (CT) that showed multiple foci of periventricular hypodensity, lacunar infarcts in the basal ganglia, and hypodensity in the frontal and occipital region on the left side. The investigation continued with a brain magnetic resonance imaging (MRI) that showed foci of diffusion restriction in the occipital regions, pons and cerebellar hemispheres, related to recent ischemia. Ultrasonography of cervical vessels showed a 70% stenosis of the left internal carotid artery.

Since this was symptomatic carotid stenosis, endovascular treatment with stent angioplasty was indicated. Angiography revealed the presence of an extensive, ulcerated plaque in the bulb region of the left internal carotid artery, with 70% stenosis of its lumen. It was also identified that the origin of the left vertebral artery is in the proximal left internal carotid artery, characterizing a type I pro-atlantal anatomical variation, also affected by an atheromatous plaque in its ostium (Figure 1).

Angioplasty from common carotid artery and ICA before the origin of PA on the left side was then performed. The carotid and posterior circulation were protected using two filters. The first filter was placed in the PA and then the stent was placed in the stenosis region, distal to the origin of the PA. After the stent was placed, another protective filter was placed in the ICA through the stent and the balloon angioplasty was performed. The two filters were not placed simultaneously to prevent the PA filter from getting stuck in the stent (Figure 2). The procedure was uneventful and the control image demonstrated the opening of the affected vessel and maintenance of cerebral circulation (Figure 3). The patient progressed well clinically and neurologically. He was reevaluated as an outpatient 2 months after the procedure and there was no recurrence of symptoms.

DISCUSSION

The PA is an anatomical variation of the cerebral circulation resulting from the persistence of this vessel from the embryological period, originating in the dorsal portion of the cervical ICA at the level of C2-C3, and entering the skull through the foramen magnum to join the vertebrobasilar system. Embryonic anastomoses are usually an incidental finding in vascular examinations, and their bilateral persistence is even rarer[8]. The entry point of the PA is the main form of differentiation of the hypoglossal artery, which has a higher origin in the ICA, and enters the skull through the hypoglossal canal, causing its dilation. There are two types of PA described. Type 1 is the most common and refers to the previously described pattern. Type 2 is rarer

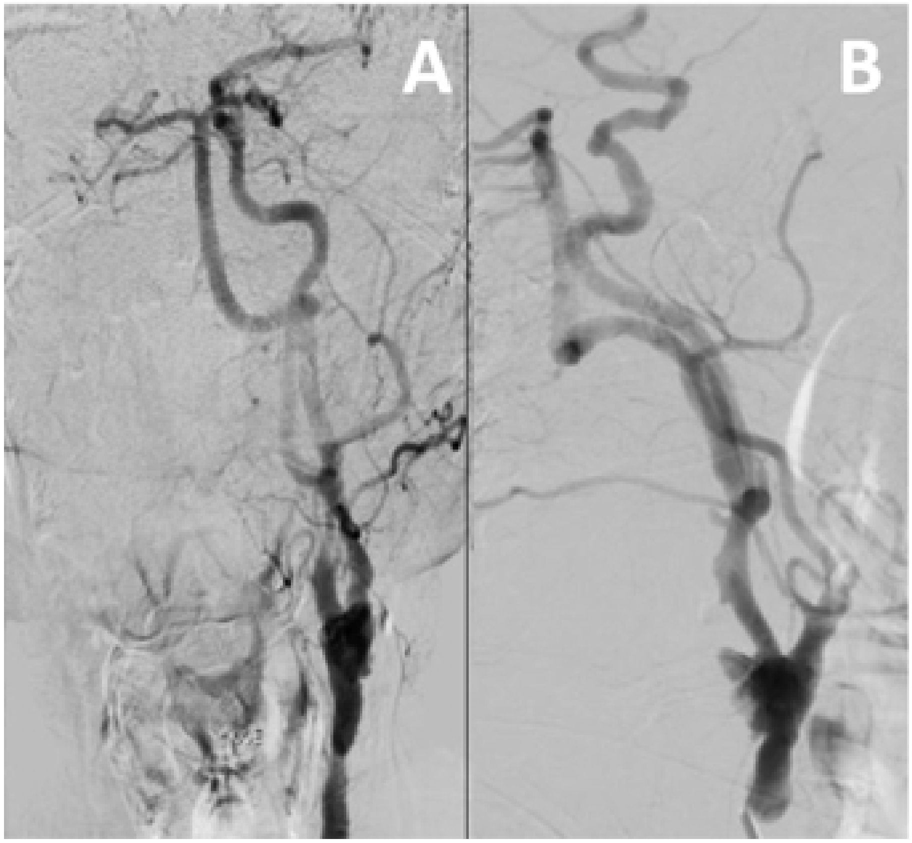

Figure 1. A-B. Contrast injection through the left common carotid artery demonstrating atheromatous plaque in the region of the left ICA bulb, and origin of the left vertebral artery in the proximal ICA, characterizing a type I proatlantal anatomical variation, also affected by atheromatous plaque in its ostium.

and occurs when the PA originates from the external carotid artery and joins the vertebral artery below C1[9,10]. The presence of PA is commonly associated with other vascular alterations, both intra- and extra-cranial, especially agenesis/hypoplasia of the vertebral arteries[11].

Symptomatic carotid stenosis is a common cause of cerebral ischemic events, especially in patients with comorbidities that increase the risk of cerebrovascular events, such as smoking and type 2 diabetes mellitus, and presents different therapeutic approaches and outcomes, depending on factors such as the severity of the stenosis, comorbidities and anatomical variations, as observed in the case of this patient[12].

Previous studies indicate that carotid stenosis greater than 70% is associated with a significant increase in the risk of ischemic stroke. Patients with significant carotid stenosis treated with angioplasty and stenting showed clinical improvements, with a low rate of complications[13,14].

The literature reports cases of embryological anatomical variations, with pro-atlantal type I variation being a rare occurrence. The case reported here combines this anatomical variation with agenesis and hypoplasia of the vertebral arteries, resulting in unilateral dependence on the posterior fossa through the carotid circulation. Cases of anatomical variations are described as relevant in determining cerebral blood flow and associated with a higher risk of ischemia in situations of carotid stenosis[15].

CT and MRI are essential to identify ischemic changes and areas of infarction. In the aforementioned case, CT revealed multiple areas of hypodensity and MRI highlighted foci of diffusion restriction in both anterior and posterior circulation regions. The imaging patterns of recent ischemia in patients with carotid

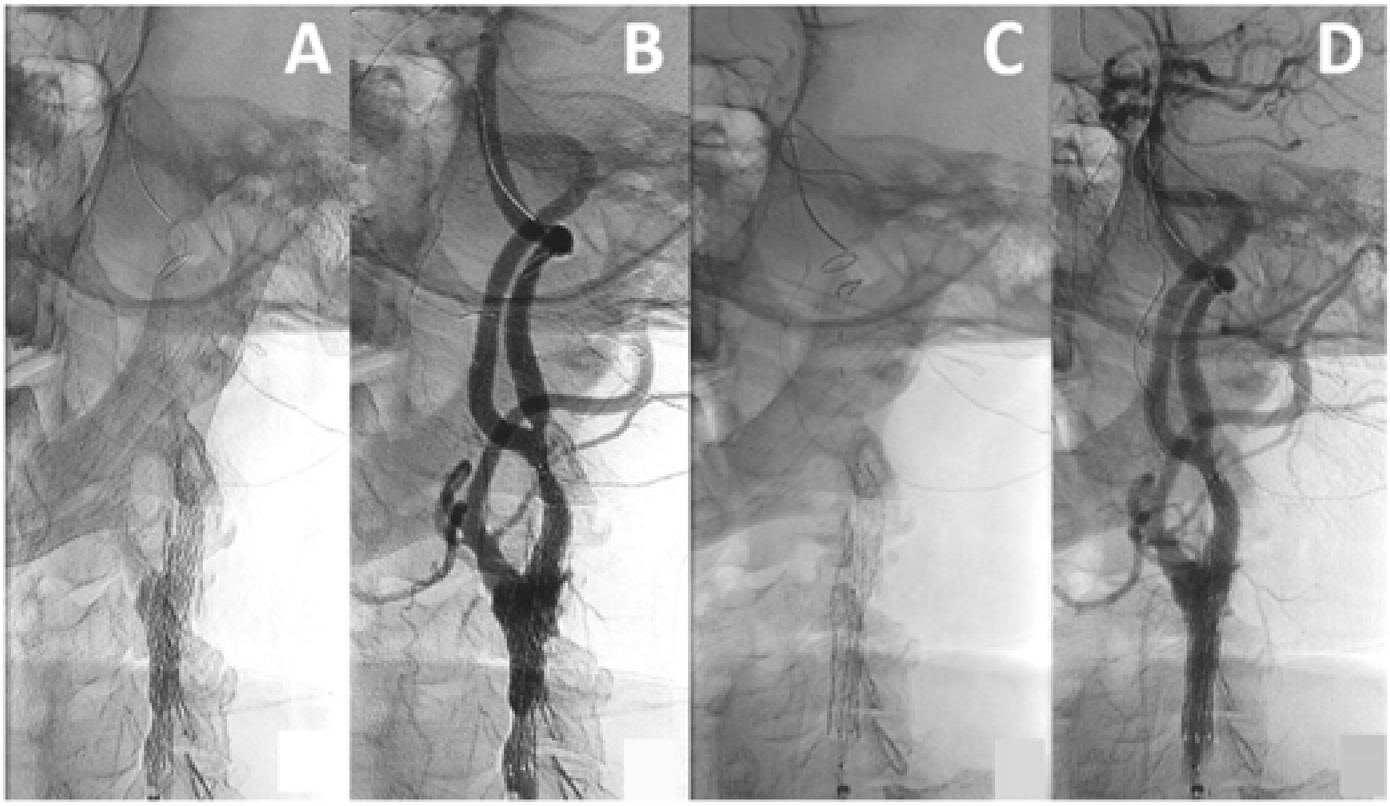

Figure 2. A-B. First filter was placed in the PA, followed by the stent. **C-D.** Second protective filter placed in the ICA through the stent.

stenosis reinforce the importance of early diagnosis to define the therapeutic approach[16].

The presence of embryologic anastomoses associated with carotid stenosis has been previously described, and when present, it may be responsible for symptoms of both anterior and posterior circulation[17]. Both open surgical approaches, with endarterectomy, and endovascular approaches have been described as treatment options. Temporary occlusion of the carotid artery, used during open surgical procedures, may have an associated risk of posterior fossa ischemia, due to hypoplasia of the vertebral arteries that are commonly associated. Early intervention, especially in patients with complex anatomy, reduces the risk of future ischemic events[18].

A review of 9 previously published cases of PA associated with carotid stenosis is described in Table 1. The mean age of the patients was 63 years (57-78), with the majority of cases being in men (6). The majority (6) presented with both anterior and posterior circulation symptoms.

Ouriel et al.[23] described the first case of PA associated with surgically treated carotid stenosis. Berger et al.[7] report a case of type 2 PA with associated carotid stenosis of 80%, treated surgically with endarterectomy, with bypass between the common carotid artery and the PA, treatment that was also used by Kolbinger et al.[20]. Bour et al.[19] describe a similar case to that presented by the authors, treated with balloon angioplasty.

Another case similar to the one we described was reported by Morales et al.[21], also treated with stent angioplasty. The authors report that during the procedure, a protection filter was used only in the carotid artery, and the patient developed transient deficits in the right hemibody during the procedure. Therefore, they believe that, in cases of carotid stenosis with PA, cerebral protection filters should be used in both the carotid and PA, to avoid distal embolism resulting from manipulation of the plaque, a measure

Figure 3. A-B. Control after endovascular angioplasty of the stenosed segment, with preservation of distal circulation.

Table 1. Published cases of PA associated with carotid stenosis.

Author	Year	Age (years)	Gender	Side	Symptoms	Treatment
Berger et al.[7]	2011	60	Female	Left	Ataxia, homonymous hemianopsia, aphasia	Endarterectomy
Bour et al.[19]	1991	58	Male	Right	Asymptomatic	Endovascular
Ferrone et al.[2]	2016	65	Male	Right	Vertigo, balance disorders	No treatment
Grego et al.[17]	2004	78	Female	Left	Paresis, syncope and vertigo	Endarterectomy
Kolbinger et al.[20]	1993	66	Male	Right	Vertigo, blurred vision and diplopia	Endarterectomy
Lode[8]	2000	57	Male	Bilateral	Hemiparesis	Not reported
Morales et al.[21]	2006	65	Male	Left	Dizziness and Hemiparesis	Endovascular
Teraa et al.[11]	2014	63	Female	Right	Visual impairment	Not reported
Yu et al.[22]	2017	56	Male	Right	Vertigo	Drug therapy

that was taken in the case presented. Pharmacological treatment is also a possibility in these cases, as reported by Yu et al.[22].

CONCLUSION

Embryological anastomoses are rare and, when associated with carotid stenosis, increase the morbidity of ischemic events by evolving with ischemia in both the posterior and anterior circulation. Their treatment is challenging since agenesis of the vertebral arteries is common in these cases, making the PA the only source of blood supply to vital structures of the posterior fossa. The endovascular approach with stent proved to be effective and safe, with favorable outcomes. This report adds the experience of managing a patient with unusual vascular anatomy to the literature, providing additional support for future interventions in similar conditions.

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Teleproctoring with Virtual Reality: the next leap in endoscopic spine surgery

Teleproctoring com Realidade Virtual: o próximo salto na cirurgia endoscópica da coluna

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ABSTRACT

This study presents the feasibility of using virtual reality (VR) for teleproctoring in endoscopic spine surgery. Advances in digital technologies have enhanced surgical techniques through teleproctoring, allowing specialists to remotely guide procedures in real-time using interactive platforms and wearable devices such as smartglasses and headsets. Endoscopic spine surgery represents a minimally invasive alternative to traditional techniques but faces significant challenges related to reduced visual fields and decreased depth perception. Virtual reality emerges as a promising tool, optimizing intraoperative visualization and enabling detailed remote supervision. In this case report, a 74-year-old patient with an L3-L4 disc herniation underwent endoscopic discectomy assisted by teleproctoring using Meta Quest 3. Specialists located in São Paulo remotely supervised the procedure performed in Goiânia, interacting in real-time without interruptions. Postoperative evolution was excellent, with complete pain relief and significant functional restoration. Although the study highlights clear benefits, technical limitations such as connection instability and transmission quality were identified, suggesting the need for redundant systems. This technology may accelerate the adoption of minimally invasive techniques and significantly enhance training and execution of neurosurgical procedures.

Keywords: *Educational technology; Endoscopy; Neurosurgery; Spine; Technological development*

RESUMO

Este estudo apresenta a viabilidade da utilização da realidade virtual (VR) para teleproctoring em cirurgia endoscópica da coluna vertebral. A evolução das tecnologias digitais permitiu aprimorar técnicas cirúrgicas por meio do teleproctoring, possibilitando que especialistas orientem procedimentos em tempo real, utilizando plataformas interativas e dispositivos vestíveis como smartglasses e headsets. A cirurgia endoscópica da coluna representa uma alternativa minimamente invasiva às técnicas tradicionais, mas possui desafios significativos relacionados ao campo de visão reduzido e menor percepção de profundidade. Nesse contexto, a realidade virtual surge como ferramenta promissora, otimizando a visualização intraoperatória e permitindo supervisão remota detalhada. Neste relato de caso, um paciente de 74 anos com hérnia discal L3-L4 submeteu-se à discectomia endoscópica assistida por teleproctoring usando o Meta Quest 3. Especialistas em São Paulo supervisionaram remotamente o procedimento realizado em Goiânia, interagindo em tempo real sem interrupções. A evolução pós-operatória foi excelente, com alívio total da dor e restauração funcional expressiva. Embora o estudo destaque benefícios claros, limitações técnicas, como instabilidade de conexão e qualidade de transmissão, foram identificadas, sugerindo a necessidade de sistemas redundantes. Essa tecnologia pode acelerar a adoção de técnicas minimamente invasivas e melhorar significativamente o treinamento e a execução de procedimentos neurocirúrgicos.

Palavras-Chave: *Tecnologia da educação; Endoscopia; Neurocirurgia; Coluna; Desenvolvimento tecnológico*

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INTRODUCTION

Advancements in digital technologies have revolutionized surgical practices, allowing improvements in training and supervision through teleproctoring. This approach enables specialists to remotely guide surgeons in real-time using interactive platforms, virtual reality (VR), and wearable devices such as smartglasses and mixed reality headsets, providing live transmission from the operator's perspective[1,2].

Endoscopic spine surgery, a highly technologically driven modality, has established itself as a minimally invasive alternative to conventional techniques, offering reduced tissue trauma, shorter recovery times, and shorter hospital stays[3-5]. However, this technique presents inherent challenges, including a limited visual field and reduced depth perception compared to conventional microscopic surgery[5,6]. Integrating immersive technologies such as virtual reality offers a promising strategy for optimizing intraoperative visualization, combining the benefits of minimal invasiveness with enhanced anatomical perception. Moreover, VR facilitates teleproctoring—a digitally mediated remote supervision model—which has shown potential in improving both surgical training and procedural execution across various specialties[7-9].

Using optical devices to magnify surgical visualization has been essential in evolving surgical techniques[10]. From initial surgical loupes enhancing precision to recent VR applications, the surgeon's interaction with the surgical field has transformed significantly. This technological advancement has facilitated the introduction of VR-assisted teleproctoring, providing more detailed and interactive remote support. Smartglasses and VR headsets have been successfully applied in various surgical specialties, demonstrating benefits in medical training and remote supervision of complex procedures[11]. Studies in endovascular, cardiac, and neurointerventional fields have also highlighted the efficacy of teleproctoring in high-stakes procedures, reinforcing its role in the surgical and learning field[7,8,12].

Despite growing interest, the application of virtual reality technologies as tools for intraoperative decision-making and surgical execution remains in its early stages within the current medical literature. The use of VR headsets to enable real-time connection with remote proctors represents an innovative surgical paradigm. Assessing the effectiveness of remote assistance, the quality of intraoperative visualization, and the practical integration of this technology into minimally invasive spine surgery constitutes a meaningful step forward in expanding the boundaries of telemedicine and surgical education.

This article aims to demonstrate the feasibility of using virtual reality devices for teleproctoring in endoscopic spine surgery through a clinical case report, identifying any technical challenges in remote transmission and intraoperative interaction.

CASE PRESENTATION

Male patient, 74-year-old, presented with severe lower back pain radiating to the anterior thigh and left knee.. The pain, rated 9 on the Visual Analog Scale (VAS), had persisted for several months without associated sphincter impairment. Pain worsened when sitting, significantly impacting his quality of life. The Oswestry Disability Index (ODI) revealed an 82% score, indicating severe impact on daily activities and justifying assertive therapeutic intervention.

Physical examination revealed no motor or sensory deficits in the lower limbs. Lasègue's maneuver was bilaterally negative, but the femoral stretch test was positive, reproducing pain in the L3 and L4 dermatomes on the left, reinforcing the hypothesis of lumbar radiculopathy.

Lumbar spine MRI demonstrated an L3-L4 disc herniation with a left-sided paracentral and foraminal component causing radicular conflict with the ipsilateral L3 and L4 roots (Figures 1 and 2). Surgical treatment was chosen, and the patient underwent unilateral biportal transforaminal endoscopic discectomy on the left.

The procedure was performed in Goiânia (GO) with remote support from a neurosurgical team in São Paulo (SP) via teleproctoring using Meta Quest 3® VR technology (Meta Platforms, Inc., Menlo Park, CA, USA), as demonstrated in the Figure 3. This approach allowed remote specialists to follow the surgery in real-time, providing precise guidance and interacting with the local team as if physically present in

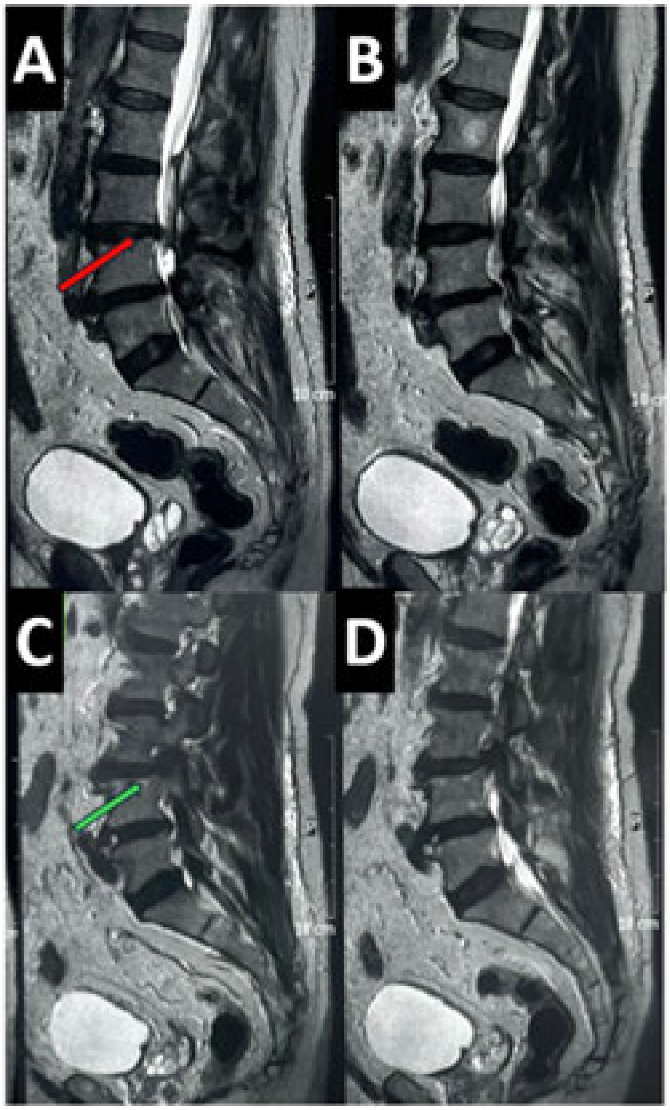

Figure 1. T2-weighted magnetic resonance imaging of the lumbosacral spine, showing median sagittal (A and B) and left paramedian (C and D) sections. The red arrow points to herniation of the L3-L4 disc (A) and the green arrow highlights foraminal stenosis in L3 and L4 on the left (C).

the operating room (Figure 3). All media stored on the local device were remotely accessible, enabling the proctor to access imaging exams, clinical records, and intraoperative videos in real-time without interrupting the procedure or diverting focus from the operative field[13].

Postoperative evolution was satisfactory, without neurological deficits and significant pain improvement. Immediately postoperatively, the patient reported pain reduction to 0 on the VAS and ODI reduced to 4%, reflecting significant recovery and restoration of functional independence.

DISCUSSION

Optical innovations in spine surgery have advanced significantly, enhancing surgical precision and reducing complication risks[10]. VR teleproctoring provides immersive three-dimensional visualization, overcoming the limitations of simple optical magnification. Recent studies in neurosurgery and endovascular fields confirm that immersive visualization tools—when combined with real-time interaction—improve decision-making and precision, especially in procedures with high anatomical complexity[14,15].

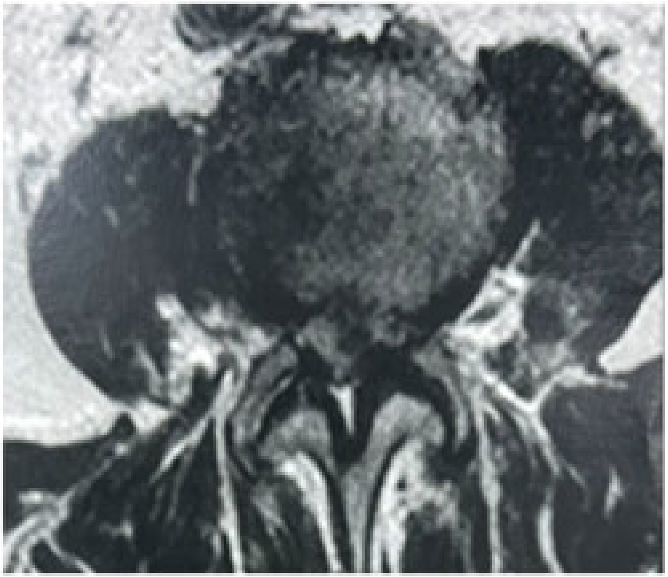

Figure 2. T2-weighted magnetic resonance imaging of the lumbosacral spine, axial section at the level of the L3-L4 foramen, demonstrating left median and paramedian herniation, with stenosis of the corresponding neuroforamen.

Endoscopic spine surgery has rapidly advanced by incorporating VR, assisted navigation, and robotics, enabling safer and more effective minimally invasive procedures[3]. Combining endoscopic approaches with teleproctoring can optimize the learning curve for surgeons in training, allowing remote specialists to provide detailed intraoperative guidance. VR in teleproctoring integrates real-time three-dimensional visualization, enhancing precision and reducing operative errors. Technologies such as telestration and augmented reality have further amplified this capability, offering annotation-based interaction during procedures[6].

This study explored the feasibility of teleproctoring mediated by a VR device in endoscopic spine surgery. Continuous image transmission allowed remote procedure monitoring and enabled real-time interaction between proctor and surgeon. This model reinforced the potential integration of this technology into surgical practice, especially where on-site support is limited, although uncertainties remain regarding broader systematic implementation. Immersive technologies also show promise in

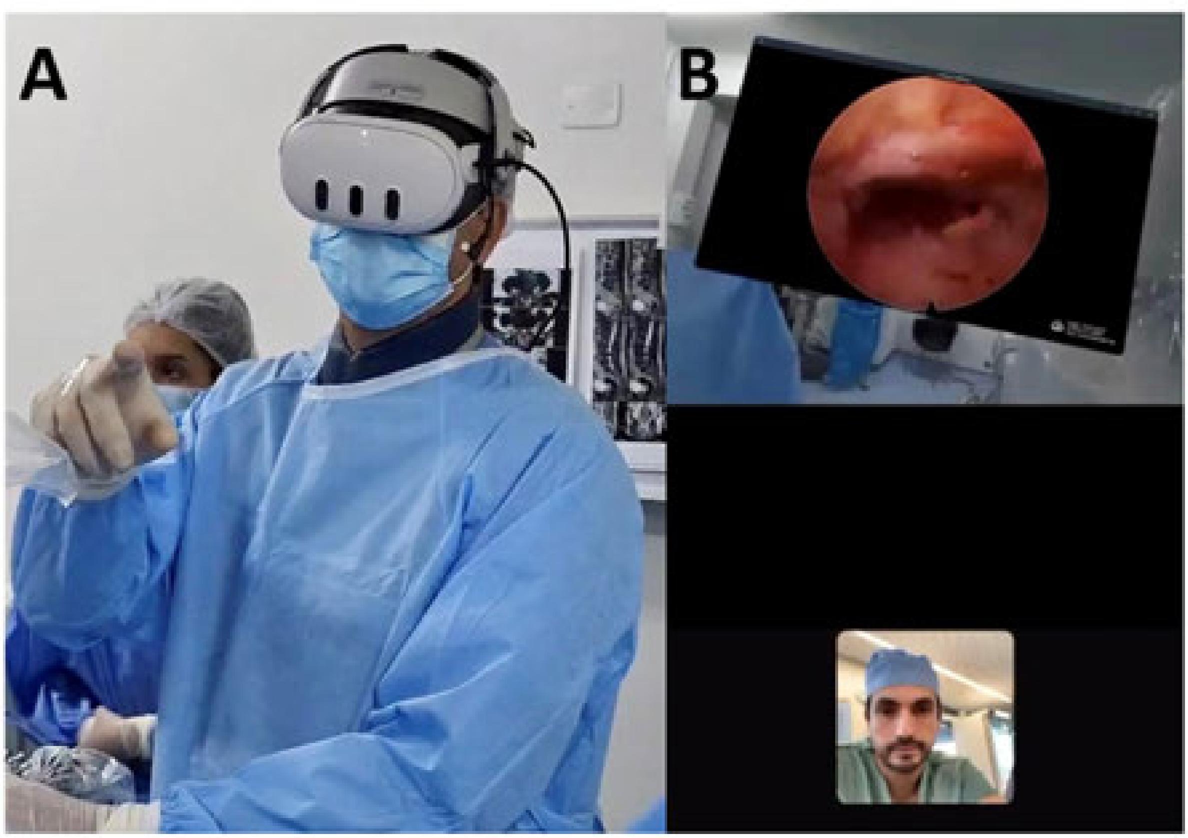

Figure 3. A. Neurosurgeon in the city of Goiânia performing the procedure with the aid of Meta Quest 3 ® virtual reality glasses. **B.** Screenshot of the mobile device on which the neurosurgeon from São Paulo monitored and guided the surgery in real time.

medical education, having demonstrated improved engagement and anatomical understanding in both pre-clinical and procedural training environments[16,17].

Despite promising findings, additional studies are necessary to assess reproducibility in different clinical scenarios and specialties.

CONCLUSION

This study demonstrates the feasibility of teleproctoring in endoscopic spine surgery using virtual reality glasses, enabling real-time remote supervision and increased procedural safety. Incorporating this technology represents significant progress in disseminating new techniques, expanding access to specialized training, and accelerating adoption of minimally invasive approaches. Although challenges like connectivity and transmission latency remain limitations, dedicated cabling and redundant transmission systems can mitigate these issues, ensuring robust technology use. Furthermore, randomized clinical trials and multicentric studies will be key to validating this model's efficacy and long-term impact in various neurosurgical domains[4,5,9].

Future studies are essential to optimize this approach and expand its applications in neurosurgery and other specialties.

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