Microsurgical Anatomy of the Central Retinal Artery

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■ BACKGROUND: **The central retinal artery (CRA) has been described as one of the first branches of the ophthalmic artery.It arises medial to the ciliary ganglion and after a sinuous path within the orbital cavity it penetrates the lower surface of the dura mater that covers the optic nerve, approximately 1 cm behind the eyeball. However, the numerous anatomic descriptions that were made of the CRA have been insufficient or unclear in relation to certain characteristics that are analyzed in the present study.**

■ METHODS: **An electronic literature search was made in the PubMed database and a cadaver dissection was performed on 11 orbits fixed in formaldehyde.**

■ RESULTS: **Results were obtained regarding the source, collateral branches, curves, direction, length of the optic nerve, dural perforation site, distance, path and relations, diameter, and area of the central artery of the retina.**

■ CONCLUSIONS: **Our anatomic study innovates in 2 aspects of the CRA: area and curves. Not only was there a simple count of the number of curves, but it also analyzed the angle presented by each of the curves based on photos obtained in high definition, with a digital program to reduce the margin of error. These curvatures of the CRA were classified according to their spatial disposition within the orbital cavity based on a pattern that was easy to understand. Data were obtained from the area of the CRA on the penetration of the CRA into the dural sheath of the optic nerve.**

INTRODUCTION

The central retinal artery (CRA) is described as one of the first branches of the ophthalmic artery. It arises medial to the ciliary ganglion, and after a sinuous path inside the orbital cavity, penetrates the lower surface of the dura mater that covers the optic nerve, approximately 1 cm behind the eyeball. After a short journey inside this meninge, it crosses the cranial nerve to be located in its center and travels until it reaches the optical papilla where it divides into several branches. During this entire journey, the CRA does not present any anastomoses, considering it as a terminal branch.[1-4]

However, the descriptions that many investigators make about some of thesecharacteristics of the CRA differ with the classic disposition] (Tables 1—12).[5-40] The numerous anatomic descriptions that have been made of the CRA[1-40] have been insufficient or unclear regarding the diameter and area at the point of perforation of the dural sheath of the optic nerve and also, about its distance from the point of dural perforation to the optic disc. There are also no complete descriptions about the number and spatial distribution of their curves or anatomic repairs of their origin, intradural trajectory, point of entry into the dural sheath of the optic nerve, and the most probable direction of dural penetration (Tables 1—12).

it is important to remember that the CRA has 2 narrowings, 1 at the level of the dural sheath and another at the level of the cribriform plate of the eyeball. This is important in the occlusion of the CRA due to embolisms of atheromatous origin in the internal carotid artery.[5]

Therefore, the objective of this study is to clarify the topics mentioned with respect to CRA by reviewing the existing literature and through cadaveric dissection.

METHODS

An electronic literature search was performed in the PubMed database using the termscentral retinal artery; central artery of the

Key words
- Central retinal artery
- Central retinal artery area
- Microsurgical retina anatomy
- Retina

Abbreviations and Acronyms
CRA: Central retinal artery
CRAO: Central retinal artery occlusion

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Table 1. Most Frequent Origin of the CRA According to Each Article Analyzed

Origin of the CRA	Article Reference Number
Double CRA	-
Collateral branch of the ophthalmic artery	1—5,7,9*, 10—14,16—18,20,23—25,28,30,32—37,39,40
Common trunk with posteromedial ciliary artery	9*,15,22
Common trunk with posterolateral ciliary artery	6,9*
Common trunk with muscle artery	-
Do not study the origin	8,19,21,26,27,29,31,38

CRA, central retinal artery.
*This article mentions that the CRA arises from the ophthalmic artery, either solitarily or from a common trunk with a posterior ciliary artery (without distinguishing between posteromedial and posterolateral), but does not specify which of the origins predominates.

retina; morphometric of central artery of the retina; central artery of the retina anatomy; anatomy of the central retinal artery; vascularization of the optic nerve; arterial anatomy of the orbit; and orbital vascular anatomy.

The results were searched manually using also the option "similar articles" and filtered using the "human species" option. Only articles in English and Spanish were included in this analysis.

Table 2. The Second Most Frequent Origin of the CRA According to Each Article Analyzed

Origin of the CRA	Article Reference Number
Double CRA	-
Collateral branch of the ophthalmic artery	6,22
Common trunk with posteromedial ciliary artery	7,10*,12*,13,14†,16†,17*,32*,35*,37†
Common trunk with posterolateral ciliary artery	10*,12*,14†,16,†,17*,32*,35*,37†,40
Common trunk with muscle artery	14†,16†,37†
Do not study the origin	1—5,8,9,11,15,18—21,23—31,33,34,36,38,39

CRA, central retinal artery.
*These articles mention that the second predominant type of origin is through a common trunk with a posteromedial ciliary artery or posterolateral ciliary artery, but does not clarify which predominates.
†These articles mention that the second predominant type of origin is through a common trunk with a posterior ciliary artery (without specifying if it was posterolateral or posteromedial) or a common trunk with a muscular artery. But does not specify which of the origins predominates.

Table 3. Presence of Collateral Branches of the CRA and its Most Frequent Location According to Each Article Analyzed

Collateral Branches (location)	Article Reference Number
Yes (intradural)	8*,10,21
Yes (intraneural)	3,8*,38‡
Yes (intraorbital)	12†,40†
Yes (intraorbital-intradural-intraneural)	1,6,9,27,28,30
No	1,2,4,11,26,35,37
Yes (does not specify)	16,17,29
Do not study them	5,7,13—15,18—20,22—25,32—34,36,39

CRA, central retinal artery.
*This article mentions the presence of collateral branches in the intraneural and intradural path of the CRA. But it does not mention collateral branches in the intraorbital tract.
†This article mention that only 1 CRA of the casuistry gave off a branch and that branch followed a recurrent course along the optic sheath. The article number 40 adds that this branch appears to supply blood to the proximal portions of the orbital optic nerve.
‡This article mentions that during the intraneural course, the central retinal artery gave off several small branches in the retrolaminar region. These intraneural branches made anastomotic communications with the pial arterial supply.

Eleven human orbits ($n = 11$) were analyzed in the present study (6 right and 5 left from 4 male and 4 female adult subjects). The orbits were fixed with aqueous solution of formaldehyde diluted at 10% for 30 days. Five of them were injected with red latex.

To perform the research work, blunt instruments and umlaut elements were used (Figure 1A): curved and straight microsurgery scissors (16 cm × 10 cm × 15 cm), straight microtweezers (8 mm, 15 cm), and Penfield Model 7 decorator or elevator. In addition, the dissections were performed with 2 NEWTON microscopes (Buenos Aires, Argentina) (Figure 1B) with 5 magnification options. The attached photographs were made with a tripod and were taken with a Nikon (Nikon corporation, Tokyo, Japan) D7200 camera with a Micro Nikon 40mm F2.8 lens and an annular flash. The camera was configured in the same way for all shots, using a diaphragm of 20, a shutter speed of 100, ISO 250, and a ring flash 1/128.

Table 4. Presence of Collateral Branches of the CRA and its Second Most Frequent Location According to Each Article Analyzed

Collateral Branches (location)	Article Reference Number
Yes (intradural predominantly)	8
Yes (intraneural predominantly)	8,10,21
Yes (intraorbital predominantly)	-
No	1,2,4,11,26,35,37
Yes (but does not specify)	-
Do not study them	3,5—7,9,12—20,22—25,27—34,36,38,39,40

CRA, central retinal artery.

Table 5. Anatomic Repair Point of the Origin of the CRA According to Each Article Analyzed

Anatomic Repair Point	Article Reference Number
Do not study	1,3,5,6,8—11,13—15,17,21,23—30,31,33,36,38,39
First part of the ophthalmic artery*	2,7,12†,16,18,20,22,32,37‡,40§
Angle of the ophthalmic artery*	7,35
Second part of the ophthalmic artery*	37‡,40§
Third part of the ophthalmic artery	
Medial to the ciliary ganglion	4,12†,37‡
Close to the vertex of orbit	12†,19,34

CRA, central retinal artery.
*The first part of the ophthalmic artery is one that extends along the inferolateral aspect of the optic nerve. The second part corresponds to the part that passes above or below the optic nerve to be located medial to said cranial nerve, and the third part is the portion of the ophthalmic artery that lies medial to the optic nerve. The curvature of the artery that is formed between the first and the second part is called angle.
†Specify these 3 repairs (first part of the ophthalmic artery, medial to the ciliary ganglion and close to the vertex of the orbit) as belonging to the origin of the CRA.
‡It is mentioned that the CRA can arise from the first or second part of the ophthalmic artery without defining prevalence between any of them, and also that this origin is medial to the ciliary ganglion.
§It is mentioned that it is usually arise from the first or second part of the ophthalmic artery but it does not clarify which predominates.

The medial and lateral walls of the orbits and associated structures were removed to access the optic nerve on its medial and lateral sides (Figures 2 and 3A,B). A dissection was also performed from the roof of the orbit until the CRA (Figure 3C,D). The origin, trajectory, relationships, presence of anastomoses and collateral branches, and also diameters and areas at the level of the dural penetration of the CRA were examined. In addition, the distance from the point where the CRA perforates the dural sheath of the optic nerve to the optic disc of the retina, using a digital caliber, was measured. The direction of the penetration of the CRA into the dural sheath of the optic nerve was recorded. Finally, the length of the optic nerve was measured in its intraorbital path in each separate orbit, and then divided into 3 equal parts (anterior, middle, and posterior) to obtain the relationship between the perforation point of the CRA in the dural sheath with respect to the 3 parts (Figure 4).

The eyeball was removed from the casuistry, exposing the optic nerve and the structures related to it. The arrangement of the artery curves was examined, using a pattern based on the hours of a clock projected onto the orbital rim. For this purpose, the orbital cavity was observed from an anterior view and the optic nerve was taken as the central point of reference and the orbital rim as a peripheral point. With these 2 points of reference a clock is described where the hands are located in the central point and the numbers in the periphery. Then 2 perpendicular lines were drawn, a vertical line passing between the numbers 12 and 6, and a horizontal line between the numbers 3 and 9, dividing this previous view into 4 quadrants (upper nasal, lower nasal, upper temporal, and lower temporal) (Figure 5). Based on these 2 divisions of the anterior opening of the orbit (base of the orbit), the arrangement of the different curves was recorded. When a curve was between 2 quadrants they were noted as follows: between lower nasal and lower temporal quadrants (lower temporal nasal quadrant [this position corresponds to the clock point 6]); bBetween the lower nasal and upper nasal quadrants (upper lower nasal quadrant [this position corresponds to the clock point 9 or 3, in the left and right orbit, respectively]); between the upper nasal and upper temporal quadrants (upper temporal nasal quadrant [this position corresponds to the clock point 12]); between the upper temporal and lower temporal

Table 6. Presence of Anastomoses of the CRA According to Each Article Analyzed

Anastomoses	Article Reference Number
Yes	5,6,8,9,16,21,27,36*,38,40†
Do not	1—4,10—13,30
Do not study them	14,15,17‡,18—26,28,29,31—35,37,39

CRA, central retinal artery.
*This article mention the presence of anastomoses between the CRA and the "collateral arteries of the optic nerve" (arteries that form a ring around the optic nerve).
†During the embryologic review carried out in this article it is mentioned that there is an anastomose ring around the optic nerve to which the CRA contributes.
‡This article does not include among its objectives the search for anastomoses between the central artery of the retina and any blood vessel. But it mentions on the basis of the bibliographic search that performs that if anastomoses exist through the subpial plexus of the optic nerve.

Table 7. Presence of Curves in the Path of the CRA According to Each Article Analyzed

Curves	Article Reference Number
Yes	4,6,7*,12,16,18,35,40
Do not	1—3,5,8—11,13—15,17,19—34,36—39

CRA, central retinal artery.
*Mentions curves—all open angles.

Table 8. Part of the Path of the CRA Where it Presents Curves According to Each Article Analyzed

Part	Article Reference Number
Intraorbital	4,7,12,16,18,35,40
Intradural	6,7,24
Intraneural	7,24

CRA, central retinal artery.

Table 9. Distance in Millimeters Between the Dural Perforation Point of the CRA and the Optic Disc According to Each Article Analyzed

Distance (mm)	Article Reference Number
5—9	16,19
8	12
10	1—3,6,7,17,18,20,34,37,38,39
9—13	13
10—15	30,32
15	9
7—17	10,40
10—20	11
Do not study it	4,5,8,14,15,21—29,31,33,35,36

CRA, central retinal artery.

quadrants (upper lower temporal quadrant [this position corresponds to the clock point 3 or 9, in the left and right orbit, respectively]).

The presence or absence of curves of the CRA was analyzed. A record of the number of curves was taken and a classification was established based on the angle that they formed. If it was >90°, it would be an open curve, whereas if it was <90°, it would be registered as a closed curve. To calculate the angles, the free Surgimap (Nemaris, Inc., New York, USA) digital software was used by applying its "angle" tool (**Figure 6A**). When the angle of a curve of the central artery of the retina was very wide, the 2 rays that it forms were very far apart. Then the program extends them to the point where they both touch (**Figure 6A**, angle in *green*).

The measurements of the diameter and area were made digitally using the Surgimap program. The photographs of each piece were taken with a millimeter guide. Then, using the Surgimap program, each image was calibrated using the photographic guide as reference. Once calibrated, the different measurements proposed in the work were taken: diameters of the free edge of the CRA and the opening surface (**Figure 6B—D**). It should be noted that the orbits injected with red latex were excluded from this

Table 10. The Most Frequent Site of Perforation of the CRA in the Dural Sheath of the Optic Nerve According to Each Article Analyzed

Site of Penetration	Article Reference Number
Lower face	1—5,8,17,18,20,28,34
Inferomedial	6,7,10,13,16,32,35,37
Inferolateral	40
Bottom (middle line)	12
Does not specify	9,11,14,15,19,21—27,29—31,33,36,38,39

CRA, central retinal artery.

Table 11. Direction of Perforation of the CRA in the Dural Sheath of the Optic Nerve According to Each Article Analyzed

Direction of Perforation	Article Reference Number
Perpendicularly	7*,9*,12*
Does not mention it	1—6,8,10,11,13—40

CRA, central retinal artery.
*This articles mentions that the CRA perforates the dural sheath of the optic nerve perpendicularly.

measurement due to the possibility that the injection technique caused a modification of the area and diameters of the CRA. Only 6 orbits of the casuistry were analyzed with this parameter. The anatomic terms used in the present work were updated according to international anatomic terminology.[41,42]

RESULTS

These results were taken from cadaver dissections.

Origin

In 45.45% (5 cases) of the cases analyzed, the origin of the CRA was from a common trunk with a ciliary artery, either posterolateral or posterior posteromedial (**Table 13** and **Figure 7**). In 45.45% (5 cases) of the cases registered, the CRA was arising as a collateral branch of the ophthalmic artery (**Figure 8A,B**). In 9.09% (1 case) of the cases, the CRA was arising from a common trunk with a muscular artery (**Figure 8C,D**).

The most frequent clock point of the CRA for the left orbits was 5, and for the right orbits it was 8. Therefore, the most frequent point of origin is in the lower temporal quadrant for the right and left orbits of the casuistry.

Table 12A. Presence of Diameter Study According to Each Article Analyzed

Diameter Study	Article Reference Number
Yes	12§,13‖,14‖,16‖,17‖,18‖,19‖,35‖,36‖,37§,40‖
Do not	1—5*,6—9†,10,11‡,15,20—34,38,39

CRA, central retinal artery.
*This article does not analyze the caliber of its casuistry but mentions that the part of the CRA where it has the smallest caliber corresponds to the point of perforation in the dural sheath of the optic nerve.
†This article does not analyze the caliber of its casuistry but mentions that the caliber of the CRA decreases when perforating the optic nerve.
‡This article raises the question that the caliber of the CRA would not remain constant if collateral branches were arising from this vessel. But then it is mentioned that it is practically unsuccessful to have collateral branch of the CRA because if it exists it would not adequately nourish the optic nerve.
§These articles mention the diameter of the CRA at its origin in the ophthalmic artery.
‖These articles does not specify which part of the journey of the CRA corresponds to the value of the diameter that is mentioned.

Table 12B. Diameter of the CRA According to Each Article Analyzed

Article Number	Diameter (mm)	Diameter Mean (mm)	Diameter Median (mm)	Diameter Mode (mm)
12	0.4	0.41	0.4	0.5
13	(left) 0.46 ± 0.04 (right) 0.47 ± 0.05	-	-	-
14	(left) 0.58 ± 0.2 (right) 0.64 ± 0.12	-	-	-
16	(left) 0.6 ± 0.2 (right) 0.6 ± 0.1	-	-	-
17	0.5	-	-	-
18	0.5	-	-	-
19	0.3	-	-	-
35	0.1–0.6	-	-	-
36	0.3	-	-	-
37	0.2	-	-	-
40	0.1–0.4	-	-	-

CRA, central retinal artery.

Collaterals

In only 1 case, the CRA presented a muscular artery as a collateral branch in its intraorbital tract (Table 14 and Figure 8A [*blue arrow*], B [structure number 3]). In the rest of the specimens (90%), the CRA did not present any collateral branch.

Curves

The highest number of curves observed was 7 in 2 cases. The least number of curves observed was 1 in 1 case (Table 15A–C).

Two types of curves were found: open whose angle >90° and closed whose angle was <90°. The largest number of open curves found was 6 in 1 case. The absence of open curves was found in 2 cases. The largest number of closed curves found was 3 in 3 cases. The absence of closed curves was found in 1 case.

The anatomic location of the curves according to the 2 patterns established (quadrants and clock points) was the site where more curves were found, the lower temporal nasal quadrant (middle line between the inferior's temporal and nasal quadrants). The second most abundant was the lower temporal quadrant. The clock point where the greatest number of curves was found was at hour 6.

Curves were found throughout the casuistry, regardless of the type of curve.

Direction

The direction of penetration of the CRA into the dural sheath of the optic nerve was not perpendicular (oblique) in 8 cases (Table 16). In 3 cases the direction of dural penetration was perpendicular.

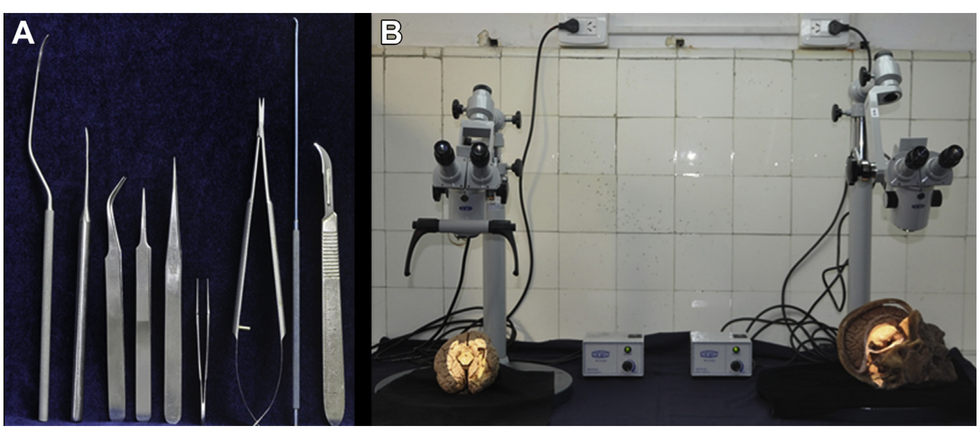


Figure 1. (**A**) Microdissection tools. (**B**) Neurosurgery microscopes.

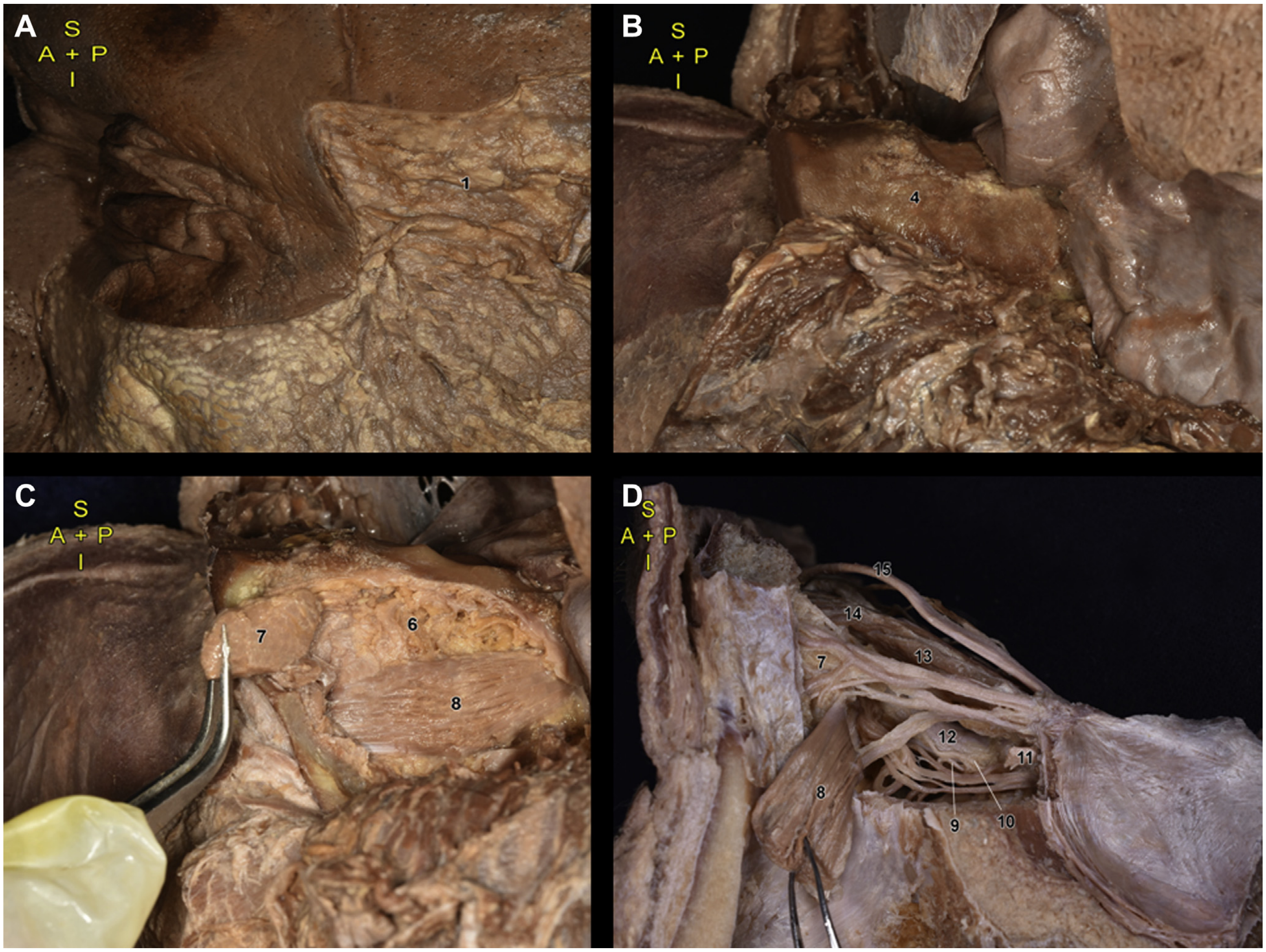


Figure 2. (**A**) Left view of a head. The part of the skin was removed to observe the subcutaneous tissue (*1*). (**B**) Left view of an orbit. The skin, subcutaneous tissue, fascia, and temporal muscle were removed until they reached the lateral wall of the orbit (*4*). (**C**) Left view of an orbit. Part of the adipose tissue (*6*) was removed to observe the lacrimal gland (*7*) reclined forward with a clamp. In the lower part, muscle fascicles in the anterior-posterior direction represent the lateral rectus muscle of the eye (*8*). (**D**) Left view of an orbit. Adipose tissue was removed from the orbital cavity to observe the structures contained in them: lacrimal gland (*7*); right lateral muscle (*8*); central retinal artery (*9*); ciliary ganglion (*10*); abducens nerve (*11*); optic nerve (*12*); upper rectus muscle of the eye (*13*); elevating muscle of the upper eyelid (*14*); frontal nerve (*15*). S, superior; A, anterior; P, posterior; I, inferior.

Optic Nerve Length

The greatest length found was in a case in which the optic nerve measured 29.08 mm (**Table 17**). The shortest length found was in a case in which the optic nerve measured 18.01 mm.

Dural Drilling Site

In 54.54% (6 cases) the CRA penetrated the dura mater in the anterior third (**Table 18**). In 45.45% (5 cases) the CRA penetrated the dura mater in the middle third.

In 45.45% (5 cases) the CRA penetrated the dura mater of the optic nerve in the midpoint of its inferior aspect (lower temporal nasal) (**Figure 9**). In 27.27% of the dissections (3 cases) the CRA penetrated the dura mater of the optic nerve on its inferomedial aspect (**Figure 9**).

In 18.18% of the dissections (2 cases) the CRA penetrated the dura mater of the optic nerve on its inferolateral aspect (**Figure 9**). In 9.1% of cases (1 case) the CRA penetrated the dural sheath of the optic nerve on its upper lower nasal side (midpoint between the upper nasal and lower nasal quadrants), that is, on its medial side (**Figure 9**).

Distance

The greatest distance found from the point of perforation of the CRA in the dural sheath of the optic nerve to the optic disc was 12.52 mm (**Table 19**). The shortest distance found from the point

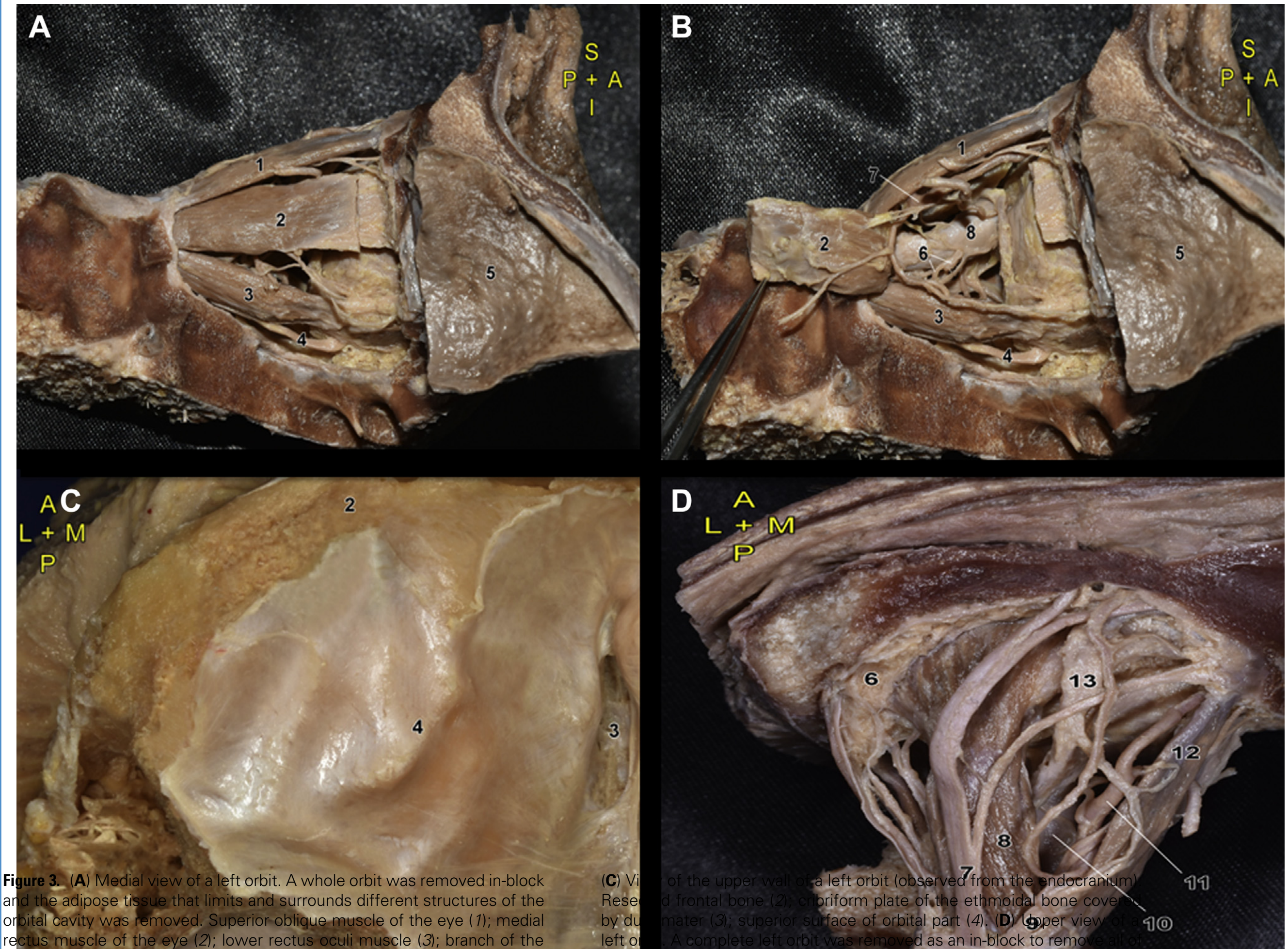


Figure 3. (**A**) Medial view of a left orbit. A whole orbit was removed in-block and the adipose tissue that limits and surrounds different structures of the orbital cavity was removed. Superior oblique muscle of the eye (*1*); medial rectus muscle of the eye (*2*); lower rectus oculi muscle (*3*); branch of the oculomotor nerve for the lower rectus oculi muscle (*4*); nasal septum (*5*). (**B**) Medial view of a left orbit. The medial rectus muscle was sectioned and reclined (*2*) to observe the structures contained in the orbital cavity: superior oblique muscle of the eye (*1*); lower rectus oculi muscle (*3*); branch of the oculomotor nerve for the lower rectus oculi muscle (*4*); nasal septum (*5*); central retinal artery (*6*); ophthalmic artery (*7*); optic nerve (*8*). (**C**) View of the upper wall of a left orbit (observed from the endocranium). Resected frontal bone (*2*); cribriform plate of the ethmoidal bone covered by dura mater (*3*); superior surface of orbital part (*4*). (**D**) Upper view of a left orbit. A complete left orbit was removed as an in-block to remove all of the adipose tissue and observe the structures contained in it. Lacrimal gland (*6*); frontal nerve (*7*); elevating muscle of the upper eyelid (*8*); trochlear nerve (*9*); optic nerve (*10*); ophthalmic artery (*11*); upper oblique muscle of the eye (*12*); superior ophthalmic vein (*13*). L, lateral; A, anterior; P, posterior; M, medial; S, superior; I, inferior.

of perforation of the CRA in the dural sheath of the optic nerve to the optic disc was 3.21 mm. The average distance from the point of perforation of the CRA in the dural sheath of the optic nerve to the optic disc was 8.36 mm.

Intradural Journey

In 6 cases curves were in the intradural trajectory and in 4 cases were not found (Table 20).

Diameter and Area

The largest area was 0.2 mm^2 in 2 orbits (Table 21). The smallest area was 0.09 mm^2 in an orbit. The largest diameter was 0.5 mm in an orbit. The smallest diameter was 0.2 mm in an orbit. The average of the area was 0.132 mm^2. The average diameter was 0.36 mm.

DISCUSSION

The reference articles[1-40] were analyzed comparatively using the anatomic study of the CRA as a common inclusion criterion in cadaveric dissections and imaging studies. The population differences were not taken into account, as in most of the analyzed works this information was not detailed.

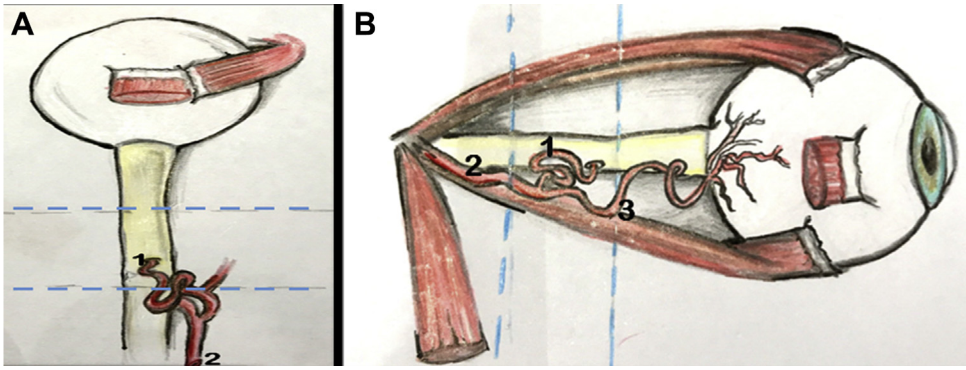
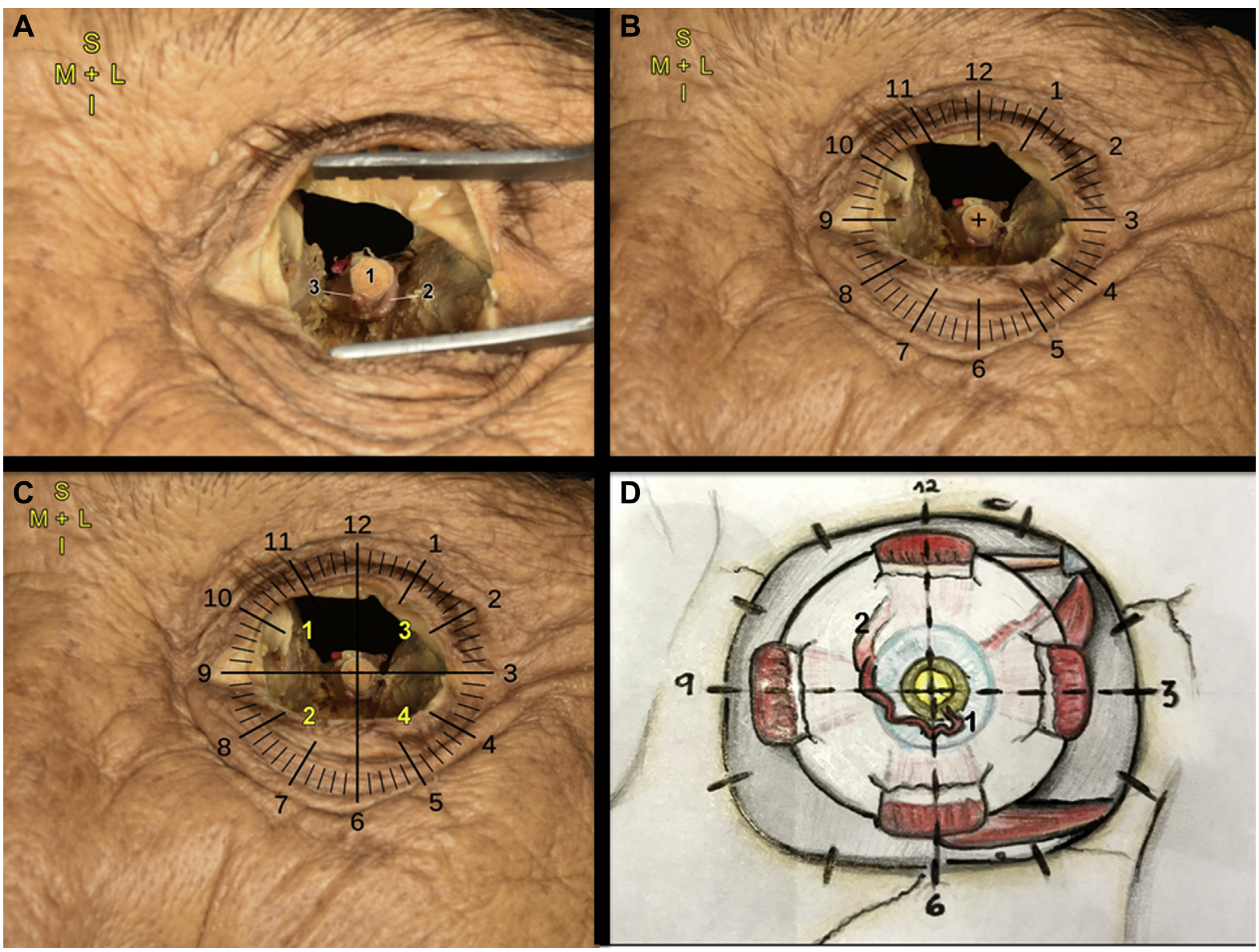


Figure 4. (**A**) Optic nerve cut in thirds to show which of them can reach the central retinal artery. Inferior view. Central retinal artery (*1*); ophthalmic artery (*2*). (**B**) Optic nerve cut in thirds to show which of them can reach the central retinal artery. Lateral view. Central retinal artery (*1*); ophthalmic artery (*2*); posterior ciliary artery (*3*).



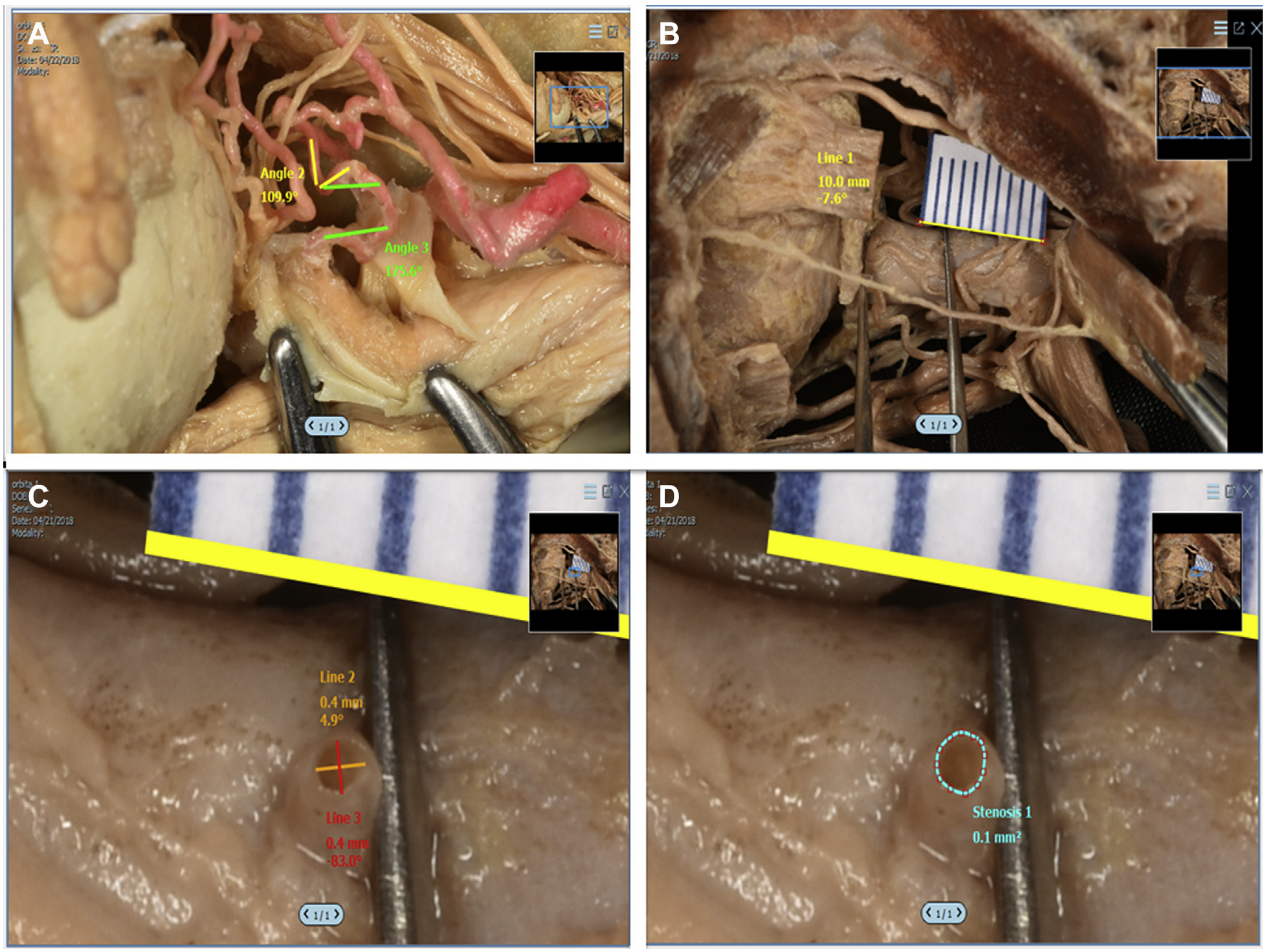


Figure 6. (**A**) Use of the Surgimap program by applying its "angle" tool to calculate the angle of the curvatures of the central retinal artery. One of the angles whose value is 109.9 degrees (open angle) is observed (*yellow*). (**B**) Surgimap program. First step: calibrate the photo with the 10-mm guide. (**C**) Surgimap program. Second step: obtaining the diameter (*red and orange lines*). (**D**) Surgimap program. Third step: obtaining the area (*blue dotted line*).

Type of Origin

In 70% (28 articles) of the articles reviewed, it is mentioned that CRA is predominantly arise as a collateral branch of the ophthalmic artery (Tables 1 and 2). Whereas 5% (2 articles) of the articles claim that CRA arises, in most cases, from a common trunk with a posteromedial ciliary artery. One article (2.5%) mentions that the CRA arises from the ophthalmic artery, either solitary or from a common trunk with a posterior ciliary artery (without distinguishing between posteromedial and posterolateral), without specifying which of the two origin predominates. One article (2.5%) mentions that the CRA arises, in most cases, from a common trunk with a posterolateral ciliary artery (Table 1).Eight articles (20%) do not study the origin of the CRA (Table 1).

The second most predominant origin of the CRA, according to 20% (8 articles) of the articles is through 2 possible origins (Table 2). Twenty-seven articles (67.5%) did not analyze which was the second most predominant type of origin (Table 2).

Figure 5. (**A**) Anterior opening of the left orbital cavity lifted up and down by a retractor. Optic nerve (*1*); ophthalmic artery (*2*); central retinal artery (*3*). (**B**) Clock points of the anterior opening of the left orbital cavity. (**C**) Clock points of the anterior opening of the left orbital cavity and the corresponding quadrants. Upper nasal quadrant (*1*); lower nasal quadrant (*2*); upper temporal quadrant (*3*); lower temporal quadrant (*4*) (*yellow*). (**D**) Clock points of the anterior opening of the right orbital cavity and corresponding quadrants. The optic nerve with its dural sheath is seen by transparency. Central retinal artery penetrating the optic nerve at the level of the lower nasal orbitary quadrant (*1*); ophthalmic artery (*2*). S, superior; I, inferior; M, medial; L, lateral.

Table 13. Origin of the CRA According to Clock Point in the Right and Left Orbits of the Casuistry

Orbit Number (side)	Origin (clock point)	Type of Origin	Mode (left orbits)	Mode (right orbits)
1 (left)	5	Simple collateral branch of the ophthalmic artery	5	8
2 (right)	6	Common trunk with posteromedial long ciliary artery		
3 (left)	5	Common trunk with posteromedial long ciliary artery and a muscular branch		
4 (right)	8	Common trunk with posterolateral long ciliary artery		
5 (left)	6	Simple collateral branch of the ophthalmic artery		
6 (left)	3	Simple collateral branch of the ophthalmic artery		
7 (right)	8	Common trunk with posterolateral long ciliary artery		
8 (right)	7	Simple collateral branch of the ophthalmic artery		
9 (left)	5	Simple collateral branch of the ophthalmic artery		
10 (right)	7	Common trunk with posterolateral long ciliary artery		
11 (right)	4	Common trunk with a muscular branch		

CRA, central retinal artery.

Collateral Branches

Twenty-four articles (60%) take into account this topic (Tables 3 and 4). Of these, 29.16% (7 articles) deny its existence (Table 3) and 32.5% (13 articles) mention the existence of collateral branches of the CRA during the intraorbital, intradural, or intraneural path (Table 3). Three articles (7.5%) do not specify in which part of the CRA path the collateral branches appear (Table 3) and 42.5% (17 articles) did not take this objective into account (Table 3).

Anatomic Repair Point of Origin

Twenty-six articles (65%) did not study this topic (Table 5). Of those who did take it into account, 64.28% (9 articles) mentioned the first part of the ophthalmic artery as a point of anatomic repair of the origin. The remaining 35.72% (5 articles), however, mentioned the proximity to the vertex of the orbit and the ciliary ganglion (Table 5).

Anastomoses

Nineteen articles (47.5%) studied anastomoses (Table 6). Of these, 47.37% (9 articles) deny their existence (Table 6).

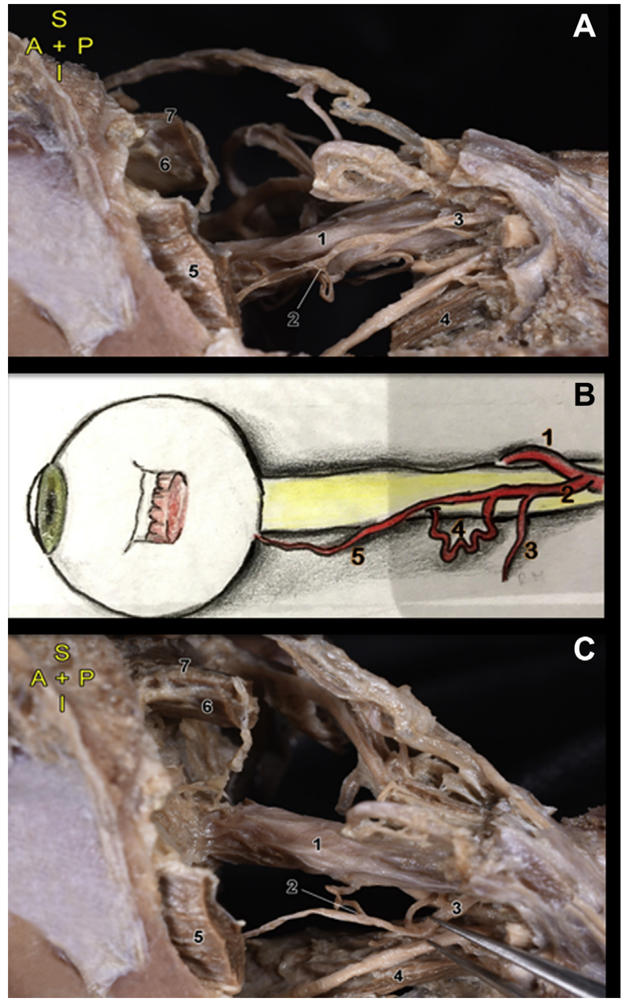


Figure 7. (**A**) Lateral view of a left orbit. The lateral rectus muscle of the eye was sectioned (*5*) and all adipose tissue was removed to observe the structures contained in the orbital cavity. Optic nerve (*1*); central retinal artery (*2*); common trunk (*3*) between the central artery, the retina (*2*) and a posterior ciliary artery; lower rectus muscle of the eye (*4*); upper rectus muscle of the eye (*6*); elevating the muscle of the upper eyelid (*7*). (**B**) Scheme of **A**. Lateral view of an eyeball and an optic nerve. Origin of the central retinal artery (CRA) through a common trunk with a posterior ciliary artery. Ophthalmic artery (*1*); common trunk (*2*); muscular artery (collateral branch of the common trunk) (*3*); CRA (*4*); posterior ciliary artery (*5*). (**C**), Lateral view of a left orbit (same as A). The common trunk that originates from a muscular collateral branch and then divides into 2 arteries: central retinal artery and posterior ciliary artery. Optic nerve (*1*); central retinal artery (*2*); common trunk (*3*) between the CRA and the retina (*2*) and a posterior ciliary artery; lower rectus muscle of the eye (*4*); upper rectus muscle of the eye (*6*); elevating the muscle of the upper eyelid (*7*). S, superior; I, inferior; A, anterior; P, posterior.

Curves

Eight articles (20%) have had as one of the objectives of their studies the presence or absence of curves and their description (Tables 7 and 8). Of this minority, 75% (6 articles) affirms the predominance of curves, especially in the intraorbital part of the CRA (Tables 7 and 8).

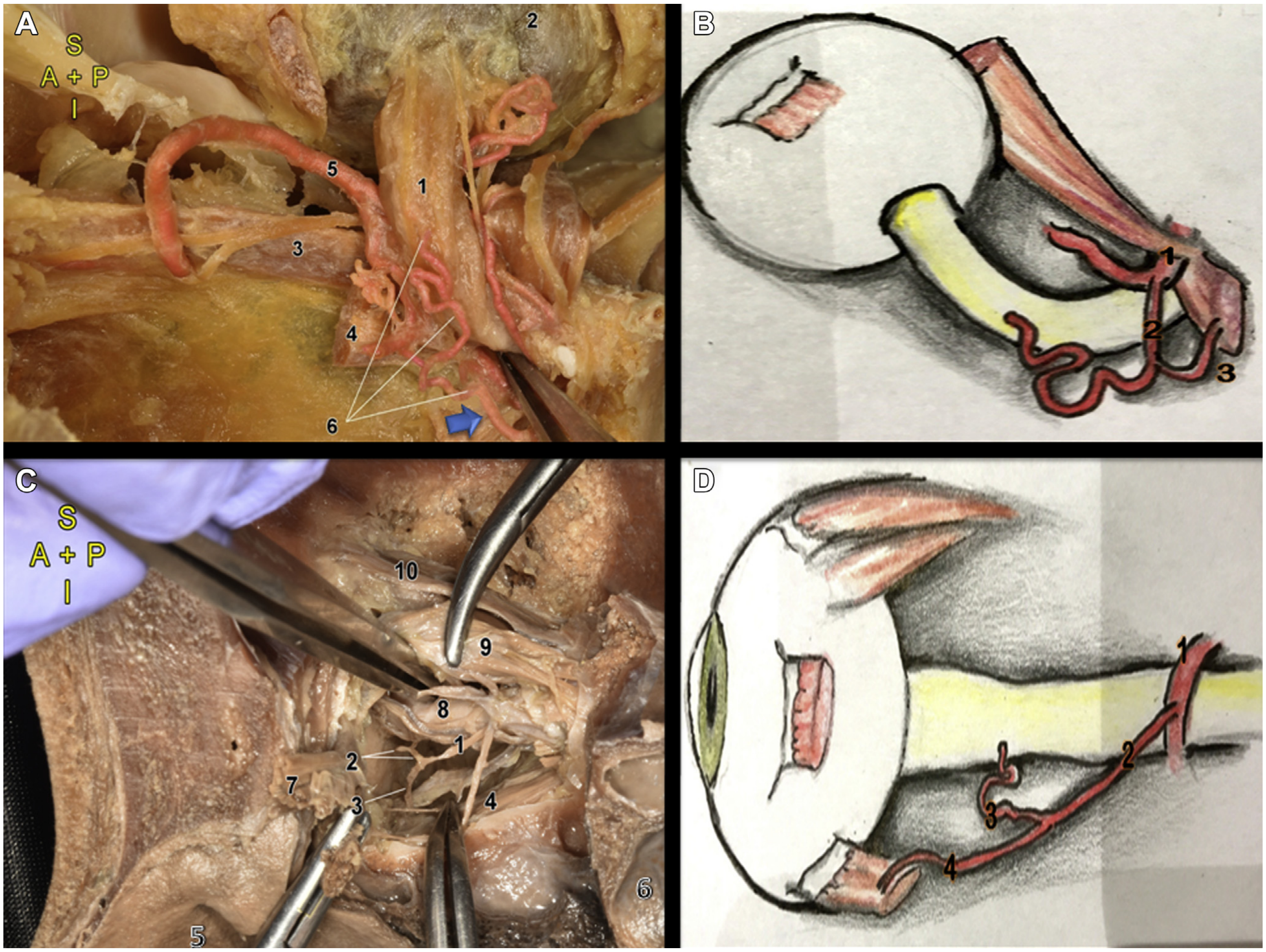


Figure 8. (**A**) Lower view of a left orbit. Optic nerve (*1*); eyeball reclined upward (*2*); opper oblique muscle of the eye (*3*); medial rectus muscle of the eye (*4*); ophthalmic artery (*5*); central retinal artery (*6*). The *blue arrow* marks the collateral branch of the central retinal artery (CRA) (a muscular artery). (**B**) Scheme of **A**. The eyeball was reclined in the upper medial direction. The central artery of the retina originates as a collateral branch of the ophthalmic artery. Ophthalmic artery (*1*); CRA (*2*); muscular artery (collateral branch of the CRA) (*3*). (**C**) Medial view of a sagittal section of the head (right segment). The medial wall of the orbit was removed and the adipose tissue was removed to observe the different structures contained in the orbital cavity. In addition, the medial rectus muscle of the eye (*7*) was incised to better appreciate its content. Common trunk (*1*) between the central retinal artery (*2*) and a muscular artery (*3*), which is directed to the inferior rectus muscle of the eye (*4*); nasal septum (*5*); sphenoid sinus (*6*); optic nerve (*8*); superior oblique muscle of the eye (*9*); elevating muscle of the upper eyelid (*10*). (**D**) Scheme of **C**. Origin of the CRA through a common trunk with a muscular artery. Ophthalmic artery (*1*); common trunk between the CRA and a muscular artery (*2*); CRA (*3*); muscular artery (*4*). S, superior; I, inferior; A, anterior; P, posterior.

Distance Between the Dural Perforation Point of the CRA and the Optic Disc

Eighteen articles (45%) have not taken this objective into account (Table 9). Of the 22 articles that analyze this objective, 54.54% (12 articles) affirm that this distance is 10 mm and the rest differs widely among the articles (Table 9).

Specific Site of Dural Penetration of the CRA

Nineteen articles (47.5%) did not study this parameter (Table 10). Of the rest, 52.38% (11 articles) stated that this site was on the inferior side of the optic nerve, but this description was not specific. On the other hand, 38.09% (8 articles) was more precise in terms of the penetration site in the dural sheath of the optic nerve, stating that it was located on the inferomedial side of the nerve. The rest differs from each other (Table 10).

Direction of Dural Penetration

Thirty-seven articles (92.5%) did not study this characteristic (Table 11). In the 3 remaining articles, the direction of penetration was perpendicular.

Diameter and Area

Of the articles reviewed, 72.5% did not study the diameter (Table 12A). The average diameter in the rest of the articles was

Table 14. Presence of Collateral Branches of the CRA in Each of the Orbits Analyzed

Orbit Number (side)	Collateral Branch
1 (left)	No
2 (right)	No
3 (left)	No
4 (right)	No
5 (left)	Yes (one muscular collateral branch)
6 (left)	No
7 (right)	No
8 (right)	No
9 (left)	No
10 (right)	No
11 (right)	No

CRA, central retinal artery.

Table 15A. Number of Open Curves, Closed Curves, and Total Number of Curves of the CRA for Each Orbit of the Case Study. Also Shown Are the Mean, Median, and Mode for the Total Number of Open Curves, Closed Curves, and the Total Number of Curves

Orbit Number	Totality of Curves	Totality of Open Curves	Totality of Closed Curves	Totality of Curves (Mean)	Totality of Curves (Median)	Totality of Curves (Mode)
1	6	3	3	4.4	4	6
2	3	1	2			
3	6	3	3	Totality of open curves (mean)	Totality of open curves (median)	Totality of open curves (mode)
4	7	5	2	2.45	3	3
5	7	6	1			
6	3	1	2	Totality of closed curves (mean)	Totality of closed curves (median)	Totality of closed curves (mode)
7	4	1	3	1.90	2	2
8	5	3	2			
9	4	4	0			
10	1	0	1			
11	2	0	2			

CRA, central retinal artery.

Table 15B. Location of Each Curve of the CRA According to the Clock Point and the Orbitary Quadrant for Each One of the Orbits of the Casuistry

Orbit Number	Number of Curve	Clock Point	Orbitary Quadrant
1	1	5	Lower temporal
	2	2	Upper temporal
	3	5	Lower temporal
	4	6	Lower temporal nasal
	5	8	Lower nasal
	6	6	Lower temporal nasal
2			
	1	6	Lower temporal nasal
	2	6	Lower temporal nasal
	3	6	Lower temporal nasal
3			
	1	5	Lower temporal
	2	5	Lower temporal
	3	5	Lower temporal
	4	6	Lower temporal nasal
	5	6	Lower temporal nasal
	6	7	Lower nasal
4			
	1	8	Lower temporal
	2	8	Lower temporal
	3	7	Lower temporal
	4	6	Lower temporal nasal
	5	6	Lower temporal nasal
	6	6	Lower temporal nasal
	7	4	Lower nasal
	8	6	Lower temporal nasal
5			
	1	6	Lower temporal nasal
	2	5	Lower temporal
	3	5	Lower temporal
	4	3	Upper lower temporal
	5	6	Lower temporal nasal
	6	7	Lower nasal
	7	6	Lower temporal nasal
6			
	1	3	Upper lower temporal
	2	6	Lower temporal nasal
	3	8	Lower nasal

Continues

Table 15B. Continued

Orbit Number	Number of Curve	Clock Point	Orbitary Quadrant
7			
	1	7	Lower temporal
	2	7	Lower temporal
	3	7	Lower temporal
	4	7	Lower temporal
8			
	1	6	Lower temporal nasal
	2	6	Lower temporal nasal
	3	6	Lower temporal nasal
	4	6	Lower temporal nasal
9			
	1	6	Lower temporal nasal
	2	9	Upper lower nasal
	3	8	Lower nasal
	4	9	Upper lower nasal
10			
	1	5	Lower nasal
11			
	1	6	Lower temporal nasal
	2	7	Lower temporal

CRA, central retinal artery.

0.4 mm. None of the articles of the case study mention the area of the CRA (consult tables for more information) (Table 12A).

Type of Origin

These articles compare the cadaveric dissection results and data obtained from bibliographic review According to our casuistry, the predominant origin of the CRA corresponds to the bibliographic report in 2 types of origins. These are through a common trunk with a ciliary artery (either posterolateral or posteromedial) and as a collateral branch of the ophthalmic artery. But none of the articles reviewed mention that the predominant type of origin of the CRA is through a common trunk with a muscular artery.

Curves

Although the bibliographic review mentions the presence of curves, they are not specific We established a pattern to determine whether the curves were closed or open according to the angle, which, unlike the articles analyzed, only mention in which portion of the CRA path these curves could be found. Except in one case,[7] where it mentions that the curves found are of open angles. It does not establish the criteria to classify them in this way. We classify the anatomic location of these curves based on the clock points and the quadrants of the opening of the orbit (base of the orbit).

Table 15C. The Mean, Median, and Mode of the Hourly Positions of Each Curve of the CRA and the Orbitary Quadrant Where Most of the Curves of this Vessel Were Found, Understood as the Mode of the Totality of the Positions of the Orbitary Quadrants

Orbitary Quadrant (Mode)	Lower Temporal Nasal
Clock point (mean)	6.08
Clock point (median)	6
Clock point (mode)	6

CRA, central retinal artery.

Direction of Dural Penetration

Unlike the articles reviewed that described a direction of dural perforation of the optic nerve perpendicularly, in our casuistry in the majority said that the direction was not perpendicular (oblique).

Specific Site of Dural Penetration of the CRA

Our results differ from those obtained from the bibliographic review, as we obtained that this site is at the midpoint of the inferior aspect of the optic nerve.The reviewed articles that do specify the perforation site state that it is in the inferomedial side of the optic nerve (Figure 9).

Distance Between the Dural Puncture Point of the CRA and the Optic Disc

Unlike the articles reviewed (10 mm), the prevalence of this distance found in our casuistry was 8.36 mm.

Diameter and Area

Differences were observed between the diameter values obtained by the analyzed articles and the results of the present study (Table 13B and Table 21). Of the articles reviewed that carried out a study on the

Table 16. Direction of the CRA Perforation in the Dural Sheath of the Optic Nerve for Each of the Orbits Studied

Orbit Number	Direction
1	Perpendicular
2	Perpendicular
3	Perpendicular
4	Oblique
5	Oblique
6	Oblique
7	Oblique
8	Oblique
9	Oblique
10	Oblique
11	Oblique

CRA, central retinal artery.

Table 17. Length of the Optic Nerve of Each Orbit Studied and the Mean, Median, and Mode

Orbit Number	Length (mm)	Mean (mm)	Median (mm)	Mode (mm)
1	29.08	24.632	24.48	-
2	24.66			
3	26.85			
4	27.53			
5	24.3			
6	23.95			
7	21.96			
8	22.03			
9	25			
10	18.1			
11	27.86			

diameter, only 2[12,37] of them mentioned that part of the journey of the CRA (Table 12A). Regarding the area, none of the articles of the casuistry study used this parameter. Articles No. 5-9-11 made a comment about the caliber, but it is nonspecific (Table 12A).[5,9,11]

Clinical Correlation

The CRA is susceptible to an occlusion (CRAO, central retinal artery occlusion) causing ischemia and the consequent infarction of the retina.[5,6,43-46]

The main cause is embolism due to the atheromatous plaques in the internal carotid artery. Carotid stenosis and the heart are other important sources of emboli. It is equally probable that an occlusive thrombus at the level immediately posterior to the eye also causes CRAO.[5] Other causes[6] include the following: polyarteritis nodosa, Wegener's granulomatosis, Churge Strauss syndrome, Behcet's disease, sarcoidosis, sickle cell disease, carotid artery dissection, internal carotid artery aneurysm, high levels of homocysteine, high lupus anticoagulant, acquired immunodeficiency syndrome, leukemia, non-Hodgkin's lymphoma, T-cell lymphoma, oral contraceptives, pigmentary incontinence, Fabry's disease, cat scratch disease, and severe fractures such as trauma and perioperative CRAO. It has even been described after the bite of a snake.[43]

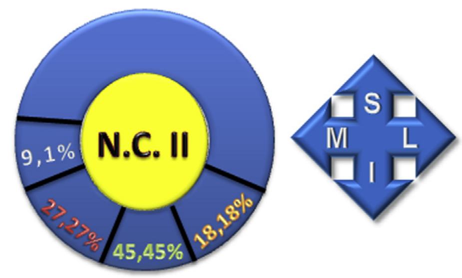


Figure 9. Scheme of the results of the perforation sites of the central retinal artery in the dural sheath of the optic nerve. S, superior; I, inferior; M, medial; L, lateral.

The small area and diameter calculated in the orbits of the present study (average of the area and diameter, 0.132 mm^2 and 0.36 mm, respectively) could explain the predisposition that the CRA has to the occlusive pathology (embolic and thrombotic).

Surgical Correlation

The location of the CRA is important during surgical approaches in the intraorbital space, especially in those lesions that affect the orbital apex.[12] (Acording to our study, these are the anterior third of the optic

Table 18. Location of the CRA Perforation in the Dural Sheath of the Optic Nerve According to Each Orbit Analyzed

Orbit Number	Third of the Dural Sheath of the Optic Nerve Perforated	Site of Perforation in the Dural Sheath of the Optic Nerve
1	Anterior	Middle point of the lower face
2	Anterior	Middle point of the lower face
3	Medium	Inferomedial side
4	Anterior	Middle point of the lower face
5	Medium	Middle point of the lower face
6	Medium	Inferomedial side
7	Medium	Inferolateral side
8	Medium	Middle point of the lower face
9	Anterior	Inferomedial side
10	Anterior	Inferomedial side
11	Anterior	Inferolateral side

CRA, central retinal artery.

Table 19. Distance From the Perforation in the Dural Sheath of the Optic Nerve of the CRA to the Optic Disc for Each Orbit Studied and the Mean, Median, and Mode

Orbit Number	Distance (mm)	Mean (mm)	Median (mm)	Mode (mm)
1	8	8.36	8.81	8
2	7.53			
3	12.52			
4	8.81			
5	10.05			
6	11			
7	9.06			
8	8.82			
9	8			
10	3.21			
11	4.97			

CRA, central retinal artery.

Table 20. Presence and Types of Curves in the Journey of the CRA in the Sheath of Optic Nerve for Each Orbit Analyzed

Orbit Number	Intradural Journey
1	There are no curves
2	There are no curves
3	There are no curves
4	There are no curves
5	Presents a closed curve
6	Presents a closed curve
7	Presents a closed curve
8	Presents a closed curve
9	There are no curves
10	There are no curves
11	There are no curves

CRA, central retinal artery.

nerve and/or its underside.) It acquires relevance for neurosurgeons when the most common tumor of the optic nerve sheath compromises the intracranial space and should be operated such as meningioma (primary and secondary). However, a few rare tumors of the sheath may be present, like schwannomas.[47]

It is important to take into account in a surgical approach according to our results. The CRA perforates the middle point of the inferior aspect of the sheath of the optic nerve (secondarily the inferomedial aspect) and especially the anterior third of this nerve (secondarily the middle third). Also the location of the curves of the CRA is predominantly in the clock point 6 and in the lower temporal quadrant.

These approaches, through the lower temporal quadrant or in the clock point 6, have a major risk to damage the CRA. As we get closer to the optic nerve and its inferior part, the CRA is at most risk. Thus, a superior surgical route (through the upper temporal or nasal quadrant) to the optic nerve protects the CRA from injury. However, careful surgical maneuvers are recommended once the periorbital tissue is opened and the tumor is dissected. Avoid cuts with microscissors and bipolar cauterization (replace them with a blunt dissection). Thus, a detailed knowledge of this vascular anatomy remains mandatory to achieve the best surgical result.

CONCLUSIONS

The fact that the CRA is susceptible to be damaged in numerous pathologies with the consequent blindness puts in relevance its anatomic study.

None of the articles reviewed showed a detailed analysis of the curvatures and area of the CRA. They mentioned that the caliber decreased somewhere along the way, but did not mention by how much. Neither the method to arrive at such a result. On the other hand, the analysis of the curvatures was not complete, it was only affirmed that the artery presented a winding, tortuous, or redundant path.

Our anatomic study results in these last 2 mentioned aspects of the CRA. Realizing not only a simple count of the number of curves, but even, analyzing the angle presented by each of them, based on photos obtained in high definition with a digital program to reduce the margin of error. These curvatures of the CRA were classified according to their spatial disposition within the orbital cavity based on a pattern that is easy to interpret and useful for any doctor or health specialist.

Because the anatomy of the CRA is extremely variable in all of its aspects, it is necessary to have an accurate knowledge of it and its relationships. The surgical approach chosen without damage or carring out a study of the CRA make a knowledge of its anatomy extremely important.

Table 21. Area and Diameter of Each CRA at the Point of Perforation in the Dural Sheath of Optic Nerve According to Each Orbit in the Casuistry and the Mean, Median, and Mode

Orbit Number	Area (mm²)	Diameter	Area—Mean (mm²)	Area—Median (mm²)	Area—Mode (mm²)
1	0.1	0.4	0.13	0.1	0.1
2	0.1	0.3			
3	0.2	0.4			
4	Not included	Not included			
5	Not included	Not included	Diameter—mean (mm)	Diameter—median (mm)	Diameter—mode (mm)
6	Not included	Not included	0.36	0.37	0.4
7	Not included	Not included			
8	Not included	Not included			
9	0.1	0.35			
10	0.2	0.5			
11	0.09	0.2			

CRA, central retinal artery.

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