Annals of Anatomy 226 (2019) 23–28

Contents lists available at ScienceDirect

Annals of Anatomy

journal homepage: www.elsevier.com/locate/aanat

Research article

Implication of the inferolateral trunk of the cavernous internal CAROTID artery in cranial nerve blood supply: Anatomical study and review of the literature

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ARTICLE INFO

Article history:
Received 27 January 2019
Received in revised form 18 June 2019
Accepted 1 July 2019

Keywords:
Inferolateral trunk
Cranial nerves blood supply
Meningohypophyseal trunk

ABSTRACT

The inferolateral trunk (ILT) is one of the two more common branches of the cavernous internal carotid artery (ICA). Its knowledge is important for skull base surgery and endovascular interventional procedures. The ILT is described with superior, anterior and posterior branch, which is the complete form. These branches vascularize the oculomotor, trochlear, trigeminal and abducens nerves into the cavernous sinus and superior orbital fissure (SOF) courses, and through the foramens rotundum and ovale.

We performed 21 injected embalmed cadaveric dissections combined with six specimen tomodensitometry.

The ILT originates from the horizontal ICA segment and passes above the abducens nerve. Three branches arise from the ILT between the cavernous ICA and the ophthalmic and maxillary nerves initial courses. The main differences with the literature are the number of branches and their cranial nerves' blood supply. The more frequent ILT conformation is the incomplete form with anterior and posterior branch (13/21); the complete form is present in 5/13 sides (38%) and the ILT is in common with the meningohypophyseal trunk in 3/21 (14%) sides. The anterior branch always vascularizes the cranial nerves into the SOF course and most often the maxillary nerve through the foramen rotundum. The posterior branch always vascularizes the mandibular nerve through the foramen ovale course and sometimes the maxillary nerve. This study has demonstrated that there are anastomoses between these branches and arteries arising from the external carotid.

This study explains why the sacrifice of a branch of the ILT does not implicate cranial nerve palsy.

1. Introduction

The inferolateral trunk (ILT), also called the artery of the inferior cavernous sinus, was first mentioned by Parkinson in 1964 (Parkinson, 1964). The ILT is one of the two more common branches of the cavernous internal carotid artery (ICA). It is a small vessel that can be difficult to recognize angiographically in a healthy subject, but can become enlarged with supplying vascular malformations and tumors such as meningioma, or when collateral channels act between the external carotid and internal carotid circulations (Waldron et al., 2011; Capo et al., 1991). The ILT is involved in the oculomotor, trochlear, abducens and trigeminal cranial nerve blood supply in the middle cranial base and cavernous courses and middle skull base dura mater blood supply (Capo et al., 1991; Ozanne et al., 2008; Rhoton, 2002; Martins et al., 2005).

This study attempted to improve the ILT knowledge through dissections combined with tomodensitometry and with literature analysis, to understand whether the sacrifice of one branch of the ILT is always responsible for cranial nerve ischemia.

2. Materials and methods

Thirteen fresh cadavers without intracranial pathology were dissected for this study (five men and eighth women). Twenty-one sides were studied; five were not dissected because of defective injection. Local Institutional Review Board and Ethics Committee approval was obtained for the use of human anatomical specimens.

Seven specimens were injected with respectively 20 ml and 10 ml of red latex neopren simultaneously into both common carotid arteries (CCA) and both vertebral arteries. Six specimens

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https://doi.org/10.1016/j.aanat.2019.07.004
0940-9602/

were injected following the same protocol but with red colored sulfate baryum to visualize arteries on Computer Tomodensitometry (CT-scan).

2.1. Dissections

With each specimen, a few burr hole trepanations and localized dura openings were made. All specimens were fixed in 10% formal saline for approximately two months. A large bifrontoparietal craniectomy was performed. The brain was removed above the optic chiasm and optic tracts to keep the brainstem and the cranial nerve intact. The dissections were performed under magnifying glasses and using 4× to 20× magnification of the surgical microscope (Carl ZEISS universal S3 microscope, Inc., Göttigen, Germany).

The cavernous sinuses were dissected progressively to expose the ILT and its branches. The roof, lateral and posterior walls were removed. The outer layer of the dura was peeled away from the lateral wall of the cavernous sinus and Meckel's cave. The trochlear and oculomotor nerves, the trigeminal ganglion and ophthalmic, maxillary and mandibular nerves were exposed. Then the abducens nerve was exposed; the superior petrosal sinus, the superior ophthalmic venous, and the pericavernous venous plexus were removed to expose the ICA and its intracavernous branches. The trigeminal ganglion and its branches were removed to expose the intracavernous branches of the ICA completely.

In some cases the anterior clinoid was drilled to improve visualization. The diaphragm sellae, the dura mater of the middle cranial fossa and the clivus and the cerebellar tentorium were removed progressively to follow the arteries arising from the meningohypophyseal trunk and entering the inferolateral trunk.

The origin of the ILT, the complete or incomplete form, the element vascularized by these branches of the ILT and the anastomoses were studied.

2.2. Cerebral tomodensitometry

For six specimens, cranial computer tomographies were performed to identify the inferolateral trunk and its branches.

3. Results

The ILT conformation was not always symmetrical for each specimen.

3.1. Origin

For 18/21 sides (86%) the ILT arose from the lateral and inferior side of the midportion of the horizontal segment of the intracavernous ICA (Fig. 1). For two sides the ILT arose from the first curve of the ICA. For one case the ILT arose from the superior portion of the horizontal segment of the ICA, in this case, the ILT gave rise to the meningeal tentorial artery (MTA.) For all specimens, the ILT passed above the abducens nerve in 100% (Fig. 2). The ILT origin and the proximal part of these branches were between the ICA and the internal layer of the lateral wall of the cavernous sinus (CS) according to Campero et al. (2010).

3.2. Complete form

The complete form was not the principal form of the ILT in our study. We found five complete forms of ILT (Figs. 1 and 2) with three rami (superior, anterior and posterior).

In these forms, the superior branch supplied the roof of the cavernous sinus, the third and fourth cranial nerves in their cavernous course and gave rise to the MTA in 3/5 sides (60%) (Figs. 1 and 2). The anterior branch did not divide and supplied the abducens nerve

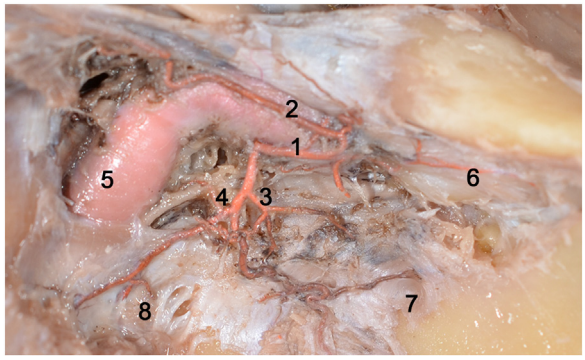

Fig. 1. Origin of the inferolateral trunk.
Lateral view of the right intracavernous ICA after opening of the lateral wall of the cavernous sinus; the Inferolateral trunk (ILT) arose from the lateral side of the midportion of the horizontal segment of the intracavernous ICA.
1, superior branch of the ILT; 2, meningeal tentorial artery (MTA); 3, anterior branch of the ILT; 4, posterior branch of the ILT; 5, ICA; 6, superior orbital fissure; 7, foramen rotundun; 8, foramen ovale.

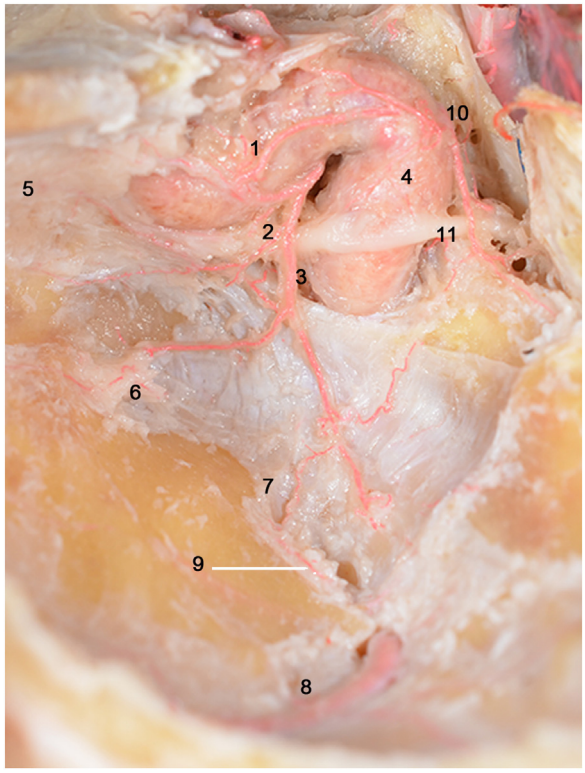

Fig. 2. Complete form of the ILT.
Lateral view of the left intracavernous ICA after opening of the lateral wall of the cavernous sinus; ILT passed above the abducens nerve, the posterolateral branch was anastomosing with the middle meningeal artery close to the spinosum foramen.
1, superior branch of the ILT; 2, anterior branch of the ILT; 3, posterior branch of the ILT; 4, ICA; 5, superior orbital fissure; 6, foramen rotundun; 7, foramen ovale; 8, middle meningial artery (MMA); 9, anastomosis between posterior branch of the ILT and the MMA; 10, meningohypophysial trunk (MHT); 11, abducens nerve.

in its intracavernous course and passed toward the superior orbital fissure (SOF) and supplied the oculomotor, trochlear, ophthalmic and abducens nerves. In one case the anterior branch divided into three branches, one for the SOF, one for the foramen rotundum and one for the gasserian ganglion. The posterior branch divided into a medial and lateral branch in all sides. The posteromedial branch passed toward the foramen rotundum and supplied the adjacent dura and maxillary nerve. The posterolateral branch passed toward the foramen ovale and supplied the adjacent dura and mandibular

Table 1
Incomplete form of ILT: branch number and area supplying.

	1 branch	2 branches	3 branches	SOF	Roof of cavernous sinus	FR	FO
Anterior branch	**5/13**	**6/13**	2/13	**13/13**	1/13	7/13	1/13
Posterior branch	3/13	**9/13**	1/13	0/13	0/13	7/13	**13/13**

SOF, superior orbital fissure; FR, foramen rotundum; FO, foramen ovale.
The bold values represent the most frequent branch number.

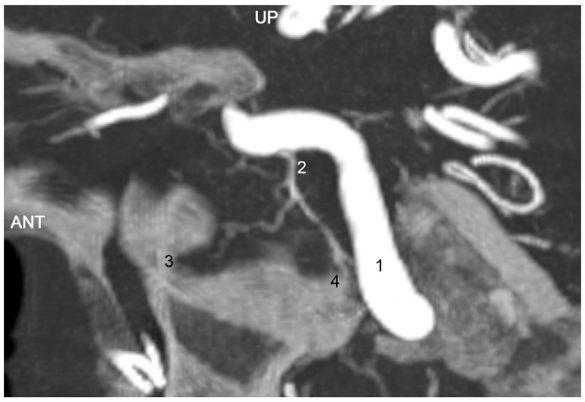

Fig. 3. Computer tomography scan of incomplete form of ILT.
Computer tomography of the right ILT in sagittal plane. The anterior branch is not represented and the posterior branch sent two rami supplying the foramen rotundum and ovale.
1, ICA; 2, posterior branch; 3, foramen rotundum; 4, foramen ovale.

nerve. This branch was anastomosing with the middle meningeal artery close to the spinosum foramen (Fig. 2). The three branches of the ILT were between the ophthalmic nerve and the intracavernous ICA.

3.3. Incomplete form

We found 13/21 incomplete forms of ILT with numerous forms (Table 1).

The ILT gave rise to two branches, one anterior and one posterior. Each branch gave rise to between one to three rami (most often two rami for each branch). The anterior branch always vascularized the SOF and its content (13/13) the foramen rotundum and the maxillary nerve in about 50% (7/13) and for just one case the roof of the cavernous sinus. The posterior branch always supplied the gasserian ganglion, the foramen ovale and the mandibullary nerve (13/13) and the foramen rotundum and the maxillary nerve in 7/13 (54%) sides.

For the most frequent form (5/13, 38%), the anterior branch sent one ramus supplying the SOF, and the posterior branch sent two rami supplying the foramen rotundum and ovale and their contents (Fig. 3).

In one case, each branch anterior and posterior had three terminal branches after a common trunk. The terminal branches of the anterior branch supplied the roof of the cavernous sinus and the SOF. The three terminal branches of the posterior branch supplied the maxillary and mandibulary and the anterior part of the gasserian ganglion and the rotundum and ovale foramen (Fig. 4A).

In 3/13 (23%) sides the anterior branch had two rami supplying the SOF and the rotundum foramen and the posterior branch had two rami for the ovale foramen (Fig. 4B).

In 3/13 (23%) sides, the anterior branch gave rise to two rami supplying the SOF and the rotundum foramen and the posterior branch gave rise to one ramus supplying the foramen ovale (Fig. 4C and D).

In 1/13 (8%) sides, the anterior branch sent three rami for the SOF, rotundum and ovale foramens and the posterior branch sent two rami for the foramen ovale.

3.4. Anastomoses

In most specimens (17/21, 81%) the posterior branch of the ILT anastomosed with a ramus of the middle meningeal artery (MMA) (cavernous branch of the MMA) (Fig. 2) and the anterior branch anastomosed with the deep recurrent artery from the ophthalmic artery (15/21, 71%).

3.5. Common trunk with the meningohypophysial trunk (MTH)

We found in 3/21 (14%) sides that the ILT was mixed with some branches of the MHT and the origin was the first curve of the ICA. In one case, this common trunk gave rise to the inferior hypophysial artery, the MTA and the superior, anterior and posterior branches of the ILT. In another case, the anterior and superior branches of the ILT had a common trunk with the MHT and the posterior branch of the ILT arose directly from the ICA. And in one case, the principal branches of the MHT (dorsal meningeal artery, MTA and inferior hypophysial artery) had the same trunk as the ILT.

When the MTA arose from the ILT, it contributes to the blood supply of the cisternal trochlear nerve portion and of the abducens nerve in Dorello's canal.

4. Discussion

The specimen number of our study is comparable to that of the principal articles that have studied the ILT. We have analyzed 21 sides. Lasjaunias et al. (1977) and Martins et al. (2005) each studied 20 sides. The main differences were that we found the number and organization of ILT branches and the cranial nerve blood supply.

Knowledge of ILT anatomy and its variations is very important and may be implicated in several pathologies such as dural fistulae, afferences of dural artriovenous malformation or in the supply of middle skull base meningiomas, notably cavernous meningiomas.

4.1. Origin

We found the same principal origin of the ILT as the literature description by Inoue et al. (1990) and Lasjaunias et al. (1977). It arose from the inferior or lateral surface of the horizontal segment of the cavernous ICA in 94% in the literature (Inoue et al., 1990) and in 18/21 (85%) sides in our study. Inoue et al. (1990) and Reisch et al. (1996) described a common trunk with the TMH in 6 and 8% respectively. In our study, we found 3/21 sides (15%); in these sides the origin of this common trunk was the first curve of the ICA.

4.2. Trajectory

We found the same trajectory of the ILT as the principal description in the literature, it passed above the abducens cranial nerve in 96% and downward medial to the trigeminal division (Lasjaunias et al., 1977; Martins et al., 2005; Inoue et al., 1990).

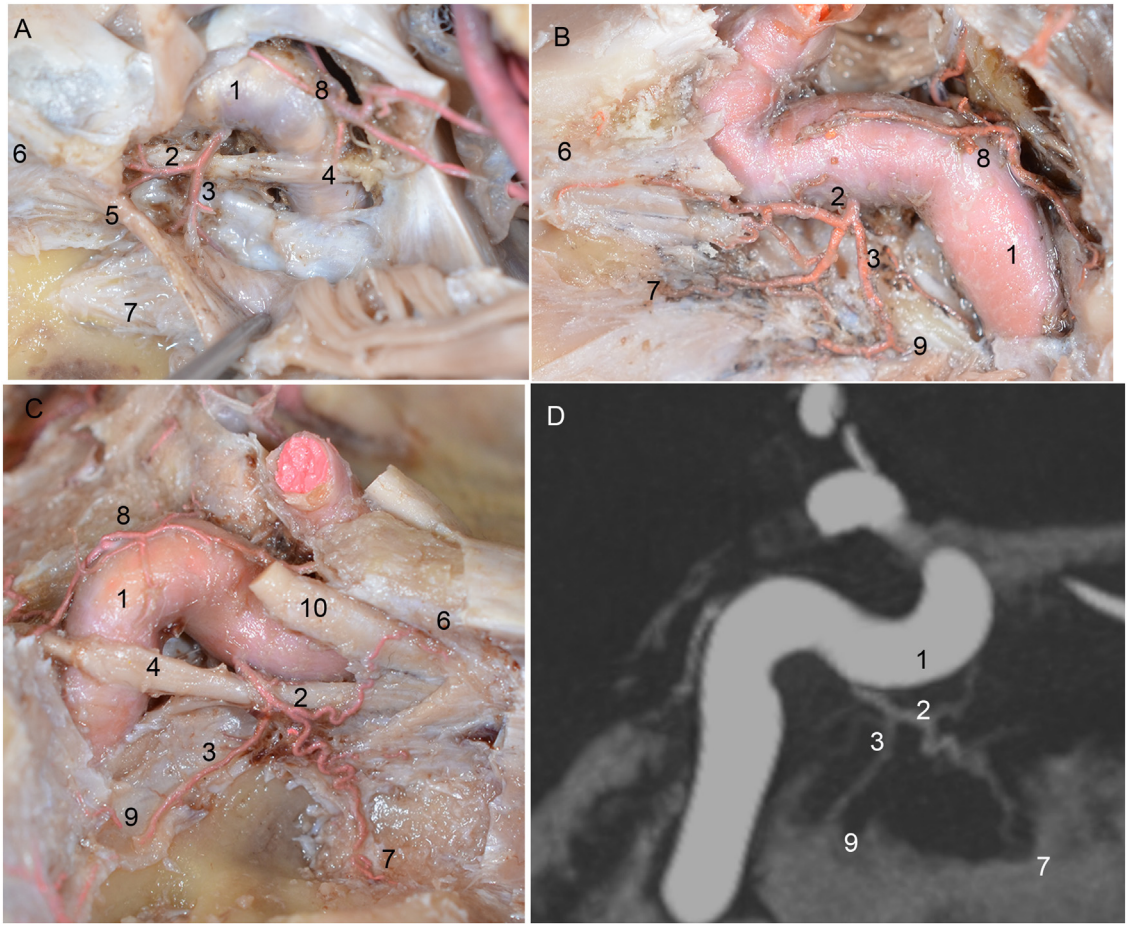

Fig. 4. Incomplete forms of ILT.
(A and B) Lateral views of the left intracavernous ICA after opening of the lateral wall of the cavernous sinus. (A) Posterior and anterior branches of the ILT (after a common trunk), anterior and posterior branches gave rise to three rami. (B) The anterior branch had two rami supplying the SOF and the posterior branch had two rami for the foramen ovale.
(C) Lateral view of right intracavernous ICA and D CT scan of the same specimen: the anterior branch sent two rami one for the SOF and one for the foramen rotundum and the posterior branch sent one ramus supplying the foramen ovale.
1, ICA; 2, anterior branch; 3, posterior branch; 4, abducens nerve; 5, ophthalmic nerve; 6, SOF; 7, foramen rotundum; 8, meningohypophysial trunk (MHT); 9, foramen ovale: 10, oculomotor nerve.

4.3. Complete and incomplete forms of the ILT

4.3.1. Complete form

In the literature, the authors stated that the complete ILT form is composed of three branches (superior anterior and posterior) (Capo et al., 1991; Martins et al., 2005; Lasjaunias et al., 1977; Robinson et al., 1999). However, in our study this form was only found in 5/21 (24%) sides. The incomplete form with anterior and posterior braches was the principal form in our study (13/21, 62%).

For the complete form, we found the same results as the literature descriptions by Ozanne et al. (2008), Martins et al. (2005), Lasjaunias et al. (1977), and Robinson et al. (1999). The superior branch supplied the CS roof and the oculomotor and trochlear nerves as they entered the cavernous sinus area. In our study this branch gave rise to the MTA in 3/5 (60%) sides. The anterior branch had two branches, the medial branch supplied the superior orbital fissure (SOF) and its contents (abducens, trochlear and oculomotor nerves), the lateral branch extended toward the foramen rotundum, which supplied the dura of the adjacent temporal fossa and the nerve (Martins et al., 2005; Lasjaunias et al., 1977; Robinson et al., 1999).

According to the literature and our study, the posterior branch had two branches. According to the literature, the medial supplying the abducens nerve, the medial third of gasserian ganglion, the mandibular nerve and the motor root of the trigeminal nerve (Hendrix et al., 2014) and the lateral branch supplied the middle and lateral thirds of the gasserian ganglion and adjacent dura (Martins et al., 2005; Lasjaunias et al., 1977). In our study, unlike the literature description, the medial branch of the posterior branch of the ILT supplied the foramen rotundum and the maxillary nerve and the lateral branch the ovale foramen and the mandibular nerve.

The MTA may be one of the branches of the ILT in 5% (Peltier et al., 2010). The superior branch of the ILT gives rise to the MTA, according to Lasjaunias et al. (1977) 8/20 times and according to Martins et al. (2005) in 40% of cases. Our study confirms this variation of the MTA origin. We found that the MTA arose from the ILT in 3/21 (14%) sides, and directly from a common MTH/ILT in one case.

4.3.2. Incomplete form

To our knowledge, there is no description of the incomplete form of ILT. This was the form we found most frequently in our study. The ILT gave rise to two branches, one anterior and one posterior. The anterior branch always vascularized the SOF and its content, and the maxillary nerve through the foramen rotundum. The pos-

terior branch always vascularized the gasserian ganglion and the mandibullary nerve through the foramen ovale, and the maxillary nerve through the foramen rotundum.

4.4. Cranial nerve blood supply

According to Ozanne et al. (2008) and Peltier et al. (2010), the oculomotor, trochlear, abducens and trigeminal nerves, in their cavernous course and through the SOF, are supplied by the MTA and the ILT branches only. The trigeminal ganglion in Meckel's cave is supplied by the lateral artery of the trigeminal ganglion (that arises from the vertical portion of the intracavernous ICA) and by the cavernous branches from the MMA. Maxillary nerve and mandibular nerves are supplied by the ILT branches (Ozanne et al., 2008). Our study demonstrated that the blood supply of oculomotor, trochlear and abducens nerves and gasserian ganglion and the three trigeminal rami until their skull base arose from the branches of the ILT. When the MTA arises from the ILT, it contributes to the blood supply of the cisternal trochlear portion and of the abducens nerve in Dorello's canal (Peltier et al., 2010).

4.5. External carotid branch anastomosis

The presence of anastomosis between the ILT and maxillary artery is explained by the embryological development. The branches of the intracavernous ICA can be divided on the basis of the embryology into two groups: a dorsomedial group that includes the inferior hypophyseal artery, the medial clival artery, the dorsal meningeal artery, the MTA and Mac Connells' capsular artery (remnant of the trigeminal artery), and a lateral group composed of the ILT (which is the remnant of the primitive dorsal ophthalmic artery) (Capo et al., 1991; Martins et al., 2005; Duncan and Fourie, 2003). The ILT corresponds to the proximal (carotid) remnant of the primitive dorsal ophthalmic artery of the human embryo, while the distal remnant corresponds to the deep recurrent ophthalmic artery (Lasjaunias et al., 1977). The oculomotor, trochlear, abducens and ophthalmic nerves are under the control of the ophthalmic artery, whose vestige is the ILT (Ozanne et al., 2008).

Several anastomotic arteries are present between the ICA and external carotid artery (ECA) and regress before birth and the remnants of these anastomotic branches of the ICA become the branches of the ILT (Kiyosue et al., 2015). The posterior branch of the ILT anastomoses with three arteries. Near to the foramen ovale, the posterior branch anastomoses with the accessory meningeal artery (arising from the maxillary artery). Furthermore, the posterior branch of the ILT may anastomose directly with a cavernous branch of the MMA, which we found in our study. And through the foramen rotundum, the posterior branch anastomoses with the artery of the foramen rotundum (arising from the maxillary artery) (Martins et al., 2005; Lasjaunias et al., 1977; Inoue et al., 1990; Kiyosue et al., 2015).

The anterior branch of the ILT, called the deep recurrent ophthalmic artery when it passes through the SOF, anastomoses with the recurrent branch of the lacrymal artery (Capo et al., 1991). Kiyosue has described another anastomosis as an arterial variation explained by the embryological development, between the artery of the SOF (arising from the third segment of the maxillary artery) and the anterolateral branch of the ILT (Kiyosue et al., 2015).

These anastomoses provide collateral circulation between the external carotid artery and the ICA systems (Capo et al., 1991). These anastomoses are described as being mainly sufficient in supplying the cranial nerves in case of ILT obstruction (Waldron et al., 2011; Robinson et al., 1999). Nevertheless in rare cases, notably if the AMM or lacrymal arteries are occluded, the anastomoses are insufficient and the ILT syndrome (representing a III, V1 and V2 palsy) may appear, for example, in an internal carotid balloon occlusion (Waldron et al., 2011; Capo et al., 1991; Le et al., 2013). However, using current endovascular techniques and equipment the endovascular procedures and embolization of the ILT branch are now most effective efficient and safe (Robinson et al., 1999).

5. Conclusions

With this study, we have demonstrated that the incomplete form is the most frequent form of the ILT. The anterior branch always gave rise to a branch for the SOF and its content and the posterior branch for the foramen ovale and its content. The maxillary nerve and its foramen may be vascularized by these two branches. The literature analysis has demonstrated the anastomosis between ILT and ECA branches. These anastomoses are more often sufficient to avoid cranial nerve injury in case of ILT branch sacrifice.

Ethical statement

Local Institutional Review Board and Ethics Committee approval was obtained for use of human anatomical specimens.

Author contributions

Author names and order

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Author number	1	2	3	4
Author initials	CS	CD	SP	AH
Conception and design	X			
Acquisition and data	X			
Analysis and interpretation of data	X			
Drafting of the manuscript	X			
Critical revision of the manuscript	X	X	X	X
Administrative, technical or material support	X			X
Supervision		X	X	X

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