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The Anatomical, Radiological and Surgical Correlation of Arterial Variations and Anomalies in the Anterior and Posterior Intracranial Circulation

Ön ve Arka İntrakranyal Sirkülasyonun Arteryel Varyasyon ve Anomalilerinin Anatomik, Radyolojik ve Cerrahi Korelasyonu

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ABSTRACT

OBJECTIVE: The variations and anomalies of intracranial arteries may affect the treatment strategy and patients' outcome during neurosurgical and interventional neuroradiological procedures.

METHODS: The construction of intracranial arteries was evaluated on cerebral angiograms in patients admitted to the interventional neuroradiology unit. The carotid and vertebrobasilar systems were also studied on 30 cadaveric head specimens (bilaterally) during dissections by different skull base approaches. This data was reviewed taking the surgical correlation into consideration with the relevant literature.

RESULTS: A persistent trigeminal artery (PTA) and an extradural posterior inferior cerebellar artery (e-PICA) were observed during cadaveric dissections. The following variations were observed on cerebral angiograms in patients with aneurysms, arteriovenous malformations or other vascular pathologies, and on angiograms without any pathological condition: persistent trigeminal artery (PTA), extradural posterior inferior cerebellar artery (e-pica), median callosal artery (accessory), agenesis of the A1 segment, fenestrated and accessory middle cerebral artery, early bifurcation of middle cerebral artery and ophthalmic artery originating from the cavernous carotid artery.

CONCLUSION: In neurosurgical and interventional neuroradiological practice, pre- and perprocedure studies should be performed meticulously to observe different variations of cerebral arteries.

KEY WORDS: Extradural posterior inferior cerebellar artery, Median callosal artery, Pericallosal azygos artery, Persistent trigeminal artery, Variations of middle cerebral artery

ÖZ

AMAÇ: İntrakranyal arterlerin varyasyonları ve anomalileri nöroşirürjikal ve girişimsel nöroradyolojik prosedürler esnasında tedavi stratejisini ve sonuçlarını etkileyebilir.

METOD: İntrakranyal arterlerin yapısı intervensiyonel nöroradyoloji ünitesine başvuran hastaların serebral anjiyografilerinde değerlendirildi. Karotid ve baziler sistemler 30 kadavra spesimeninde bilateral olarak farklı kafa tabanı yaklaşımları çalışılırken diseke edildi. Bu veriler cerrahi ilişki göz önünde bulundurularak literatür ışığında tartışıldı.

BULGULAR: Kadavra diseksiyonları esnasında bir persistan trigeminal arter ve bir ekstradural posterior inferior serebellar arter tespit edildi. Anevrizma, arteryovenöz malformasyon ve diğer vasküler patolojiler tespit edilen hasta anjiyografileri ile herhangi bir patolojinin tespit edilmediği anjiyografilerin değerlendirilmesi sonucu şu tip varyasyonlar gözlendi: Persistan trigeminal arter, ekstradural posterior inferior serebellar arter, medyan kallozal arter (aksesuar), A1 segment agenezisi, fenestre ve aksesuar orta serebral arter, orta serebral arterin erken bifurkasyonu, kavernöz karotid arterden orijin alan oftalmik arter.

SONUÇ: Nöroşirürji ve girişimsel nöroradyoloji pratiğinde, serebral arterlerin farklı varyasyonlarını tespit edebilmek amacı ile, pre ve perprosedür çalışmaları dikkatli bir şekilde yapılmalıdır.

ANAHTAR SÖZCÜKLER: Ekstradural posterior inferior serebellar arter, Medyan kallozal arter, Orta serebral arterin varyasyonları, Perikallozal azygos arter, Persistan trigeminal arter

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INTRODUCTION

Anatomical variations of neurovascular structures, if not recognized prior to a neurosurgical or interventional neuroradiological procedure, may be hazardous, even fatal (3, 11, 22, 40, 41, 42, 46, 48, 50, 53, 54, 55, 57, 58). A good example is the extradural posterior inferior cerebellar artery (e-pica) (8, 18, 28, 35, 48, 51, 52). During the far lateral approach, the C1 lamina may be removed or the condyle drilled if required. Opening the dura should be performed by leaving a cuff around the vertebral artery (VA). If the e-pica is not observed before surgery, all these manipulations might lead to a neurological deficit following injury of the artery (19, 20, 21, 31, 36, 46, 50). This study summarizes such types of vascular variations, communications and anomalies of the anterior and posterior cerebral circulation, with anatomical, neuroradiological and surgical correlation.

MATERIALS AND METHODS

The cadaveric dissections of 30 head specimens (bilaterally) and a review of a group patients' normal cerebral angiograms and angiograms with vascular pathologies revealed several variations of cerebral arteries.

RESULTS

Persistent Trigeminal Artery:

A PTA was observed during subtemporal transcavernous dissection. The artery was originating from the ascending or posterior vertical cavernous segments of the left internal carotid artery (ICA) posterolaterally, and medial to the abducens nerve (Figure 1). Coursing inferomedial to the trigeminal artery, the artery communicated with the basilar artery 2 mm inferior to the left superior cerebellar artery. Its overall length was 33 mm, with a mean diameter of 3.5 mm (29, 44). On a normal angiogram of a patient, another PTA was also demonstrated. It was arising from the left ICA and terminating at the basilar artery. The basilar artery proximal to the persistent embryonic anastomosis was hypoplastic and the posterior communicating artery was absent (Figure 2).

Extradural Posterior Inferior Cerebellar Artery: On the specimen, both PICAs were originating from the third segment of the vertebral artery, between the C1 arcus and the foramen magnum extradurally. The left sided one, with a diameter of 2.5 mm at the level of dura, was arising from the posterior medial part of the VA, 11 mm proximal to the point where they were piercing the dura (Figure 3). The right-sided one, with a diameter of 2 mm, was arising from the inferomedial aspect of VA, 8 mm proximal to the point where the arteries were penetrating the dura (28). On a normal angiogram of a patient, another e-PICA was also observed (Figure 4).

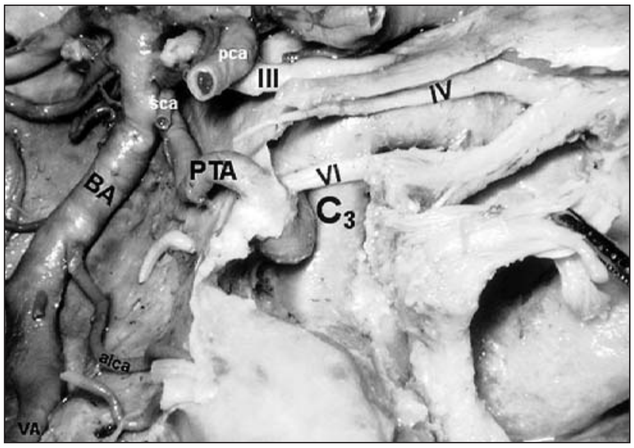

Figure 1: The cadaveric specimen demonstrates a persistent primitive trigeminal artery (PTA). The PTA is originating from the cavernous ICA (C3) and communicating with the basilar artery (BA). The BA, the posterior cerebral arteries (pca) and the superior cerebellar arteries (sca) are supposed to supply by PTA and vertebral arteries (VA). Both posterior communicating arteries are supposed to fill weakly. The abducens nerve (VI) is medial to the PTA and enters the subarachnoid space via the dural ring at the medial wall of the Meckel's cave. (III: oculomotor nerve, IV: trochlear nerve, aica: anterior inferior cerebellar artery).

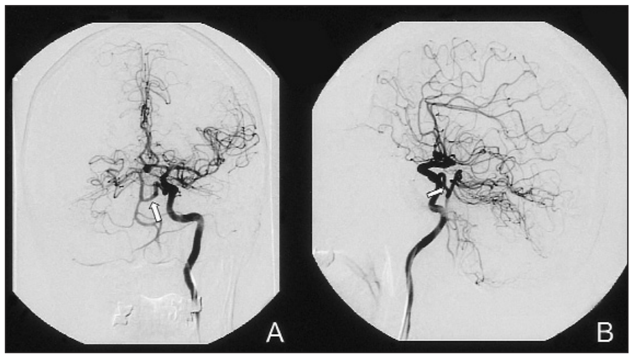

Figure 2: On a patient's anterior (A) and lateral (B) angiograms a PTA arising from left ICA and anastomosing with the basilar artery is demonstrated (arrow). The basilar artery proximal to the persistent embryonic anastomosis is hypoplastic and posterior communicating artery is absent.

Median Callosal Artery (Accessory): On a normal angiogram of a patient, triple paralleling A2 segments were observed representing ACA duplication (Figure 5).

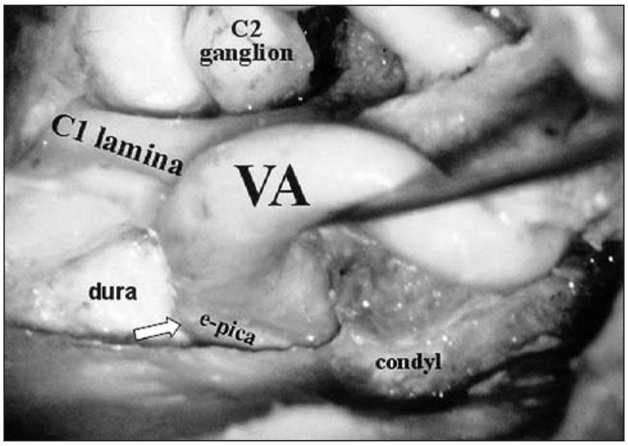

Figure 3: The cadaveric specimen reveals a branch of the vertebral artery (VA), the posterior inferior cerebellar artery, arising extradurally (white arrow). During the far lateral approach, the extradural posterior inferior cerebellar artery (e-pica) should always be taken into consideration during extradural dissection of this area.

Figure 4: The lateral vertebral angiogram shows an extradural origin of the posterior inferior cerebellar artery (white arrow).

Agenesis of the A1 Segment: On a patient presenting with subarachnoid hemorrhage, the right carotid angiogram demonstrated that the A1 segment was absent. The supraclinoid ICA was essentially continuing as the middle cerebral arter (MCA). A left internal carotid angiogram showed that the left ICA was supplying both anterior cerebral arteries (ACA) via a large A1 and anterior communicating artery (AComA). (Figure 6A and B)

Figure 5: Oblique angiogram of right ICA shows triple paralleling A2 segments, representing ACA duplication (in the black circle).

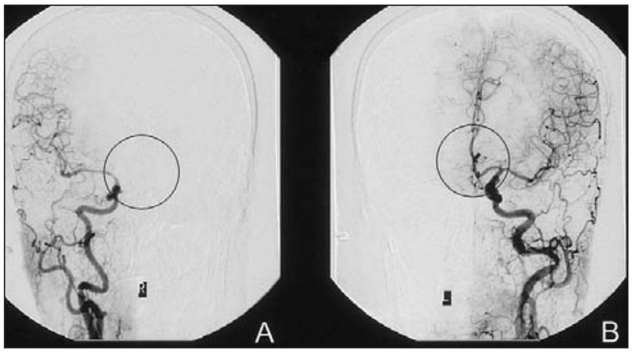

Figure 6: A: Right internal carotid angiogram in arterial phase with anteroposterior projection demonstrates that the A1 segment is absent (in black circle). The supraclinoid ICA essentially continues as the MCA. **B:** Left internal carotid angiogram with the same phase and projection shows that the left ICA supplies both ACA's via a large A1 and AcomA (in the black circle).

Fenestrated and Accessory Middle Cerebral Artery: On another normal angiogram, it was observed that an MCA was arising from ACA, coursing parallel to the M1 segment. Another patient's angiogram with a recanalized aneurysm at the bifurcation of accessory MCA with ACA showed a fenestrated MCA in its proximal segment. This accessory MCA was originating from the ACA. The anterior choroidal artery was originating just below the A1-fenestrated M1 bifurcation (6) (Figure 7A and B).

Early Bifurcation of Middle Cerebral Artery: On a left normal carotid angiogram, early bifurcation of MCA within 10 mm of its origin from the ICA was observed (Figure 8).

Ophthalmic Artery Originating from the Cavernous Carotid Artery: Another normal cerebral angiogram demonstrated an ophthalmic artery originating from the cavernous segment of the ICA (Figure 9).

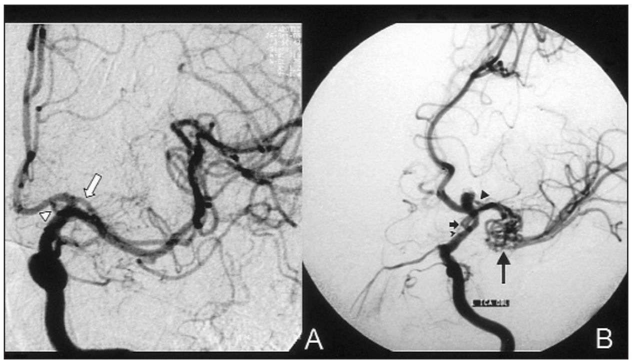

Figure 7: A: Towne oblique angiogram shows an accessory MCA (white arrows). The accessory MCA arises from ACA and courses parallel to the M1 segment. The recurrent artery of Heubner is arising from A1 segment (white arrowhead). **B:** On another patient's Towne oblique angiogram, MCA (large arrow) associated with a recanalized aneurysm at the origin of the accessory MCA (black triangle) from the ACA is demonstrated. The MCA is fenestrated in its proximal segment (small arrow). The anterior choroidal artery has originated just below the A1-fenestrated M1 bifurcation (arrowhead).

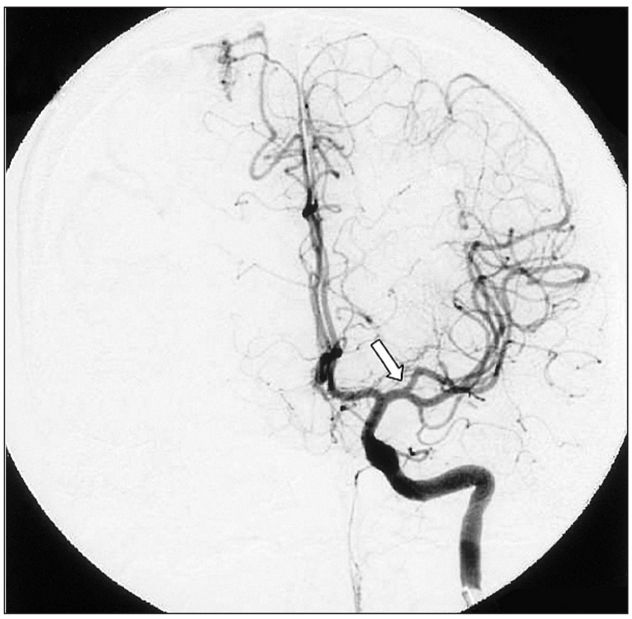

Figure 8: Left carotid angiogram obtained in anteroposterior projection demonstrates a MCA bifurcating within 10 mm of its origin from the ICA, the so-called "early bifurcation of MCA" (white arrow).

Figure 9: The cerebral angiogram demonstrates an ophthalmic artery (white arrow) originating from the cavernous segment of the ICA (C3).

DISCUSSION

The classification of ICA and VA:

It was Fischer who first classified the ICA angiographically, dividing the artery into five segments (11). Except this classification, all other future classifications have numbered the segments of ICA in the direction of the blood flow. Although Bouthillier divided the ICA into seven segments and described the new lacerum segment (5), this classification has been criticized ecause the artery never passes through the lacerum foramen and part of the lacerum foramen lies under the deep dural layer of the cavernous sinus. Consequently, their lacerum segment was actually a part of the very well known cavernous segment. The classification proposed by Ziyal et al. is based on constant anatomical structures closely related to the ICA, such as the carotid foramen and canal, the petrous bone, the petrolingual ligament, and the proximal and distal dural rings (43). This classification is also minimally affected by anatomical variations. The five segments of this new proposed classification is cervical, petrous, cavernous, clinoidal and cisternal (43) (Table I and Table II).

The segments of classification of the VA are universally accepted. The first segment is between the subclavian artery and the transverse foramen of C6. The second segment is between the transverse foramen of C6 and the transverse foramen of the atlas. The third segment is between the transverse foramen of the atlas and the dural entrance point of the artery. The fourth segment is the intradural portion of the VA (Table III).

Persistent Embryonic Communicating Arteries:

These arteries are between the vertebrobasilar and carotid systems and there are four different types: persistent trigeminal, proatlantal, otic and hypoglossal (Table IV). These arteries involute after maturation of the main communicating arteries of the anterior and posterior intracranial arterial system. The PTA is the most frequent communication with an incidence of 0.1-0.2% of cerebral angiograms (2, 7, 10, 12, 15, 17, 18, 23, 24, 26, 27, 29, 30, 33, 34, 38, 39, 44, 46, 47, 49, 56). This artery involutes after development of the posterior communicating arteries. Saltzman proposed in 1959 an angiographical classification for PTA (30) (Table V). Both the cadaveric specimen and the angiographically-demonstrated PTA, presented in this paper, correspond with Saltzman Type I. We formerly classified the PTA by its relationship to the abducens nerve as the lateral (petrosal) and medial (sphenoidal) types (Table VI). In our specimen, the origin of the PTA was medial to the abducens nerve. When the PTA courses lateral to the abducens nerve (lateral or petrosal type), the nerve may be displaced superiorly by the artery. The artery also pierces the dura medially and in close relationship to the sensory root of the trigeminal nerve. This anatomical configuration may cause both trigeminal neuralgia and diplopia (23). In such cases, a neurovascular decompression procedure with different approaches

Table I: A Proposed Internal Carotid Artery Segment Classification (43).

Segment	Name	Description
ICA_1	Cervical	common carotid bifurcation- carotid foramen
ICA_2	Petrous	carotid foramen- anterior border of petrolingual ligament
ICA_3	Cavernous	anterior border of petrolingual ligament - proximal dural ring
ICA_4	Clinoidal	proximal dural ring- distal dural ring
ICA_5	Cisternal	distal dural ring- ICA bifurcation

Table II: The Relationship of Segments of Internal Carotid Artery with Bony and Ligamentous Anatomical Structures (43).

Segment	Name	Relationship with Anatomical Structures
ICA_1	Cervical	Extradural-extracranial
ICA_2	Petrous	Extradural-intraosseous
ICA_3	Cavernous	İnterdural-intracavernous
ICA_4	Clinoidal	interdural-paracavernous
ICA_5	Cisternal	İntradural-intracisternal

Table III: Segments of Vertebral Artery

Segment	Description
V_1	subclavian artery – C6 transverse foramen
V_2	C6 transvers foramen - atlas transverse foramen
V_3	atlas transverse foramen – dural entrance point
V_4	intradural segment

Table IV: Persistent Embryonic Communicating Arteries

Type	Communication
Persistent Trigeminal	cavernous ICA-basilar artery
Proatlantal	cervical ICA-vertebral artery
Otic	petrosal ICA-basilar artery
Hypoglossal	cervical ICA-basilar artery

Table V: The Angiographical Classification of PTA According to Saltzman (30)

Type	Description
Type I	PTA supplies the VBS distal to the anastomosis, incomplete filling of PCom by PTA
Type II	PTA fills both SCAs, PCom's supply both PCA's
Intermediate (Type I + II)	PCom supply the PCA on the same side with PTA, the PTA supplies both SCAs and the PCA on the opposite side

(PTA: persistent trigeminal artery, VBS: vertebrobasilar system, PCom: posterior communicating artery, SCA: superior cerebellar artery, PCA: posterior cerebral artery)

Table VI: The Anatomical Classification of PTA According to Salas (29)

Type	Description
Lateral (Petrosal)	The artery is lateral to the abducens nerve and pierces the dura medially and close to the trigeminal nerve
Medial (Sphenoidal)	The artery is medial to the abducens nerve and pierces the dura of the dorsum sellae

may be necessary (45, 46, 47, 48, 50, 51, 52, 53). When the PTA courses medial to the abducens nerve (medial or sphenoidal type), it pierces the dura of the dorsum sellae. Clinically, a vascular steal phenomenon with transient ischemic attack may be present (33). On the other hand, the incidence of association of intracranial aneurysms with embryonic communications is 25 % (22). The aneurysms of PTA may cause isolated abducens nerve palsy.

Extradural Posterior Inferior Cerebellar Artery:

The PICA usually originates from the intradural segment of the VA. An extradural origin of PICA is reported with an incidence of 5% (8, 20, 21, 28, 36, 40, 41, 48, 51). During extreme or far lateral transcondylar approach, it is possible to injure the extradural PICA and cause lateral medullary infarction (18, 19, 31, 35, 36, 46, 48, 50, 51, 52). Although it is rare, dorsal medullary infarction or massive acute cerebellar infarction may also occur. While the diameter of the artery is around 2 mm, it may be mistaken with a large posterior meningeal branch. Especially when planning surgery for aneurysms of the third and fourth segments of the VA or tumors of this region, the presence of an extradural PICA should always be taken into consideration.

Variations of the Anterior Cerebral Artery:

Pericallosal Azygos Artery:

This is type I ACA variation distal to the AComA. The fusion of both A2 segments of the anterior cerebral artery to form a single artery was initially named 'arteria termatica' (9, 14, 16, 18, 25, 37, 45, 46). The incidence of the pericallosal azygos artery is 0.1-5.0% (4, 9, 16, 40, 41). On the other hand, it has been pointed out that the highest incidence of aneurysm with this variation occurs at the bifurcation of the large unpaired pericallosal arteries (9, 14, 40, 41). Although Ohno reported an incidence of 8-9% (25), an incidence between 13.6% and 25.9% has been reported by several authors (9, 14).

Median Callosal Artery (Accessory):

This is type III ACA variation distal to the AComA. The term 'arteria cerebri anterior mediana' was also used for this additional artery arising from the postero-inferior surface of the anterior communicating artery (18, 25, 45, 46). This 'third' pericallosal artery may be present in 10-35% of brains (16). It courses around the genu of the corpus callosum with the two pericallosal arteries. However, it never reaches the splenium of corpus callosum. On the other hand, the median callosal artery may be confused with duplication of the A2 segment. The supply of median callosal artery may be more prominent than other A2 segments. Therefore, it should be meticulously preserved during surgical procedures.

Agenesis of the A1 Segment:

It is well known that aneurysms of anterior communicating artery occur at the junction with the A1 segment where the blood pressure and flow is high (1, 4, 14, 18, 45, 53). This is the side opposite to the hypoplastic A1. Yasargil proposed that hypoplasia or agenesis may be present in 80 % of cases with AComA aneurysms (40, 41). In Wilson's autopsy study, this incidence was 85 % (42). However, Karazincir et al. reported an incidence of 50% in Turkish population, which was higher in our study based on angiographical diagnosis (1). Surgically, the right-sided craniotomy is preferred for most AcomA aneurysms, but in selected cases a left sided approach should be essential.

Variations of middle cerebral artery:

Fenestrated and Accessory Middle Cerebral Artery: The incidence of accessory MCA is around 0.2-4% (6, 18). This variation might provide blood supply to the anterior temporal lobe. A correlation between aneurysm formation and the accessory MCA was shown (18).

Early Bifurcation of Middle Cerebral Artery: Normally, the MCA constitutes its bifurcation 10 to 12 mm after the carotid bifurcation at the level of the insula and proximal to the genu. Some authors designate an early bifurcation of MCA if this distance is less than 10 mm and others if it is less than 5 mm (6, 18). This variation should be differentiated from a duplicated or accessory MCA. No correlation between aneurysm formation and the accessory MCA was shown (18).

Ophthalmic Artery Originating Outside The Cisternal Segment:

Usually, the ophthalmic artery originates from the cisternal segment of the ICA (13, 18, 32, 46, 53, 54). However, it does not always arise from the supraclinoid portion of the ICA within the subarachnoid space. It may originate from the clinoidal ICA in 6%, from the cavernous ICA in 3% and from the middle meningeal artery in less than 1% (13, 32). If the artery arises from the clinoidal or cavernous segment of the ICA, it passes through the superior orbital fissure instead of the optic foramen. It has been reported that the artery originated from the middle meningeal artery without an orbital contribution from the ICA in two of 170 specimens (13). Although some authors speculate that the ophthalmic artery may be sacrificed without suffering a neurological deficit, it should be preserved as much as possible (32, 46). As pointed out above, an ophthalmic artery with an unusual origin may always be encountered during any related neurosurgical approach.

In conclusion, variations and anomalies of cerebral arteries of the anterior and posterior circulation may always be present. Meticulous pre- and perprocedure studies should be performed when planning a neurosurgical and interventional neuroradiological procedure.

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