ORIGINAL ARTICLE

Medical Journal of Western Black Sea
Batı Karadeniz Tıp Dergisi

Med J West Black Sea 2022;6(1): 9-15
DOI: 10.29058/mjwbs. 1082490

A Magic Relationship Between Trigeminal Network and Carotico-Vertebrobasilar Vasculature Following Bilaterally Common Carotid Artery Ligation: Preliminary Study

Bilateral Ortak Karotis Arter Ligasyonu Sonrası Trigeminal Ağ ve Karotiko-Vertebrobaziler Vaskülatürü Arasındaki Sihirli İlişki: Ön Çalışma

Abdulkerim OLGUN[1], Rabia DEMİRTAS[2], Aslihan DUMAN[3], Mehmet Kursad KARADAG[4], Mehmet Hakan SAHİN[4], Sevilay OZMEN[2], Mehmet Dumlu AYDIN[4]

[1] Ataturk University Faculty of Medicine, Department of Plastic Reconstructive and Aesthetic Surgery, Erzurum, Turkey
[2] Ataturk University Faculty of Medicine, Department of Pathology, Erzurum, Turkey
[3] Gaziantep State Hospital, Department of Pathology, Gaziantep, Turkey
[4] Ataturk University Faculty of Medicine, Department of Neurosurgery, Erzurum, Turkey

ORCID ID: Abdulkerim Olgun 0000-0002-1493-5152, Rabia Demirtas 0000-0001-8743-1847, Aslihan Duman 0000-0002-3629-0906, Mehmet Kursad Karadag 0000-0001-9123-0597, Mehmet Hakan Sahin 0000-0002-5309-4165, Sevilay Ozmen 0000-0002-1973-6101, Mehmet Dumlu Aydın 0000-0002-0383-9739

Cite this article as: Olgun A et al. A magic relationship between trigeminal network and carotico-vertebrobasilar vasculature following bilaterally common carotid artery ligation: Preliminary study. Med J West Black Sea. 2022;6(1):9-15.

Corresponding Author
Abdulkerim Olgun

E-mail
abdulkerimolgun@gmail.com

Received
03.03.2022

Revision
04.04.2022

Accepted
05.04.2022

ABSTRACT

Aim: Steno-occlusive carotid artery disease causes increased intraluminal pressure, retrograde blood flow, intraluminal enlargement, vessel wall thinning, convolution, vascular remodeling, angiogenesis, and aneurysm formation. We investigated whether there was a relationship between trigeminal ganglion (TGG) ischemia and external and internal carotid artery luminal area (ECA/ICA) values after common carotid artery ligation (BCCAL).

Material and Methods: This study was performed on 20 hybrid male rabbits as a control group (GA;n=5), SHAM (GB;n=5), and study group (GC,n=10). After an anterior mid-cervical incision, permanent BCCAL was performed only in GC, and the animals were sacrificed after three months under general anesthesia. The density of degenerated neurons after (DN) in the density TGGs and the values of the lumen surface area of the ECAs/ICAs were estimated by Cavalieri and stereological methods. In the carotid vasculature, lumen enlargement, wall thinning, elongation, convolution, and dolichoectasia were detected.

Results: The mean DN density of TGG was 12±4 in GA, 53±11 in GB, and 960±112 in GC. The mean number of ECA branches was calculated as 4±1/GA, 7±2/GB, and 11±3/GC. Total surface values of ECA/ICA (as mm^2): 4.8±1.2/GA; 3.9±0.8/GB and 3.6±0.4/GC.

Conclusion: The low density of DN in TGG might have a beneficial effect on neovascularization, collateral development, a renormalization of the carotid circulation, and prevention of ischemic damage supplied by the ECA/ICA of a study group.

Keywords: Carotid ligation, Trigeminal ganglion, External carotid artery, Internal carotid artery, Revascularisation

ÖZ

Amaç: Steno-tıkayıcı karotid arter hastalığı, intralüminal basınç artışına, retrograd kan akışına, intralüminal genişlemeye, damar duvarı incelmesine, konvolüsyona, vasküler yeniden şekillenmeye,

anjiyogenez ve anevrizma oluşumuna yol açar. Bu çalışmada bilateral ortak karotis arter ligasyonu (BCCAL) sonrası eksteral/internal karotis arterlerin (ECA/ICA) luminal yüzey alanı değerleri ile trigeminal ganglion (TGG) iskemisi arasında bir ilişki olup olmadığını ortaya koymayı amaçladık.

Gereç ve Yöntemler: Bu çalışma, kontrol (GA;n=5), SHAM (GB;n=5) ve çalışma grubu (GC,n=10) olmak üzere 20 melez erkek tavşan üzerinde gerçekleştirildi. Anterior mid-servikal insizyonu takiben, sadece GC için kalıcı BCCAL uygulandı ve denekler üç ay sonra genel anestezi altında sakrifiye edildi. TGG'lerin dejenere nöron (DN) yoğunluğu ve ECA/ICA'ların luminal yüzey değerleri Cavalieri ve Stereolojik yöntemler ile tahmin edildi. Karotis arter vaskülatüründe lümen genişlemesi, duvar incelmesi, uzama, konvolüsyon ve dolikoektazi varlığı tespit edildi.

Bulgular: TGG'nin ortalama DN yoğunluğu GA'da 12±4, GB'de 53±11 ve GC'de 960±112 idi. ECA'nı ortalama dal sayısı 4±1/GA, 7±2/GB ve 11±3/GC olarak hesaplandı. ECA/ICA'nın toplam yüzey değerleri (mm^2 olarak) 4,8±1,2/GA; 3,9±0,8/GB ve 3,6±0,4/GC şeklinde hesaplandı.

Sonuç: TGG'deki düşük DN yoğunluğunun, çalışma grubunda, neovaskülarizasyon, kollateral gelişimi, karotis dolaşımının yeniden normalleşmesi ve çalışma grubunda ECA/ICA nedeniyle oluşan iskemik hasarın önlenmesi üzerinde faydalı bir etkisi olabilir.

Anahtar Sözcükler: Karotis ligasyonu, Trigeminal ganglion, Eksteral karotis arter, İnternal karotis arter, Revaskülarizasyon

INTRODUCTION

Bilateral common carotid artery ligation (BCCAL) results in a significant redistribution of blood flow from the vertebrobasilar regions to the head with retrograde blood flow due to increased vertebrobasilar pressure. After fifteen weeks, vascular changes have largely normalized due to the development of numerous collateral vessels throughout the neck region, brain, and upper spinal cord. (1). The carotid bodies (CB) play an essential role in maintaining tissue oxygenation and regulating pH. They are mainly supplied by the ECA and rarely by the ICA. It has been reported that the functions of CB can be restored to normal one week after BCCAL thanks to the recirculation mechanism, provided that CB is partially atrophied. (2). After BCCAL, all vertebrobasilar arteries and their branches are forced to develop disruption of the internal elastic lamina, endothelial desquamation, thinning of the vessel walls, arterial elongation, convoluted formation, dolichoectasia, and also aneurysm (1). Especially, posterior communicating arteries are more affected because retrograde blood flow has more potential insultive effects. These morphological features have retrograde-increased flow-induced adaptive remodeling. It is suggested that the constancy of the flow may give the arterial tree of the central nervous system these morphological characterizations (3). Bilateral CCA occlusion results in redistribution of blood flow to posterior cerebral arteries with remarkable changes in morphology and perivascular nerve density, suggesting a functional role of perivascular nerves in cerebral autoregulation (4). A meaningful and paradoxical correlation was found between the values of the vasodilation index (VDI) of the basilar artery (BA) and the degenerated neuron density of the superior cervical ganglion (SCG) after BCCAL (5). We have shown that SCG ischemia has a positive effect on the development of recirculation after BCCAL. BCCAL causes morphologic changes in the Circle of Willis. (6). BCCAL may lead to important beneficial and hazardous histomorphological changes at the posterior communicating artery if TGG ischemia is prominent (7). Hemodynamic insult has been speculated to be a critical factor in intracranial aneurysm formation following BCCAL (8). Hemodynamic insults at arterial bifurcations are hypothesized to play a crucial role in intracranial aneurysm formation after common carotid artery ligation (9). The diameters of the posterior cerebral, posterior communicating, and basilar arteries on the brain surface were larger and more tortuous in BCCAL-treated rats (10). These data indicate that smooth muscle cell hyperplasia rather than hypertrophy contributes to increases in vessel mass due to sympathetic overactivity. This study has shown us that preservation of TGG could facilitate revascularization, collateral development, redistribution of occluded vessels, retrograde blood flow, and early revascularization of the craniocervical region, especially the CB, thyroid, and salivary glands, which is essential for maintaining metabolic functions and preventing the dangerous effects of BCCAL.

MATERIAL and METHODS

We used 20 young male New Zealand rabbits (2.5±0.32 kg). The experimental protocols and guidelines were approved by the Ethics Committee of the Medical Faculty of Atatürk University. The rabbits were divided into control (Group A; n=5), SHAM (Group B; n=5), and study group (Group C, n=10). The animals in the control group were not operated on. A balanced, injectable analgesic (metamizole 30 mg/kg body weight) was used for reducing pain and mortality. Anesthesia was induced by isoflurane inhalation, followed by 0.2 mL/kg of the anesthetic combination (Ketamine HCL,150 mg/1.5 mL; xylazine HCL, 30 mg/1.5 mL; 1 mL distilled water combined) was injected subcutaneously before surgery. Intraoperatively, 0.1 mL/kg was used when required. All animals were laid in the supine position and the anterior cervical regions sterilely prepared. A 3-cm mid-cervical incision was made, and the common carotid artery, vagal nerve, jugular vein, and sympathetic chain were identified bilaterally. The common carotid arteries were dissected free (group B and group C) and knotted with silk sutures (only group C). The animals were observed for three months

postoperatively without medical treatment and then sacrificed. Rabbit brains and soft tissues of their cervicofacial regions, including common carotid vasculature, were stored in 10% formalin for seven days. Five µm tissue sections of the CCA vasculatures and TGGs with their root complexes were stained with H&E and GFAP methods to examine Stereological methods. TGGs and common carotid vasculature were examined by histological methods. Degenerated neuron density of TGG; internal carotid artery (ICA)/ external carotid artery (ECA) surface values were estimated by circle surface area calculation methods. Surface values were compared with degenerative neuron densities of TGG.

Statistical Analyzes

The analysis was done with the IBM SPSS 20 statistical analysis program.

The data were presented as mean, standard deviation, percentage, and number. The normal distribution of continuous variables was examined with the Shapiro Wilk-W test.

In the comparison of continuous variables with more than two independent groups, the ANOVA test was used when the normal distribution condition was met and the Kruskal Wallis test was used when the normal distribution condition was not met.

After the ANOVA test, posthoc tests were performed using the Tukey test when the variances were homogeneous and Tamhane's T2 test when the variances were not homogeneous.

The Kruskal Wallis test was performed using the Kruskal Wallis 1-way ANOVA (K samples) test for posthoc tests.

RESULTS

Clinical Findings

Consciousness, convulsions, fever, apnea, cardiac arrhythmia, and respiratory disorders were frequently observed in the three surviving animals and the premortem periods of the deceased animals.

Histopathological Findings

Histopathological examination of the common carotid arteries (CCA) after ligation revealed an increase in lumen diameter, a linearized inner elastic membrane, thinned-shedding endothelial cells, thinning of vascular muscles, and thickening of the adventitia. Minimal inner elastic membrane flattening, greater luminal surface and basilar artery expansion, wall thinning, and increased basilar artery volume were observed in GC. CCA dilatation was more prominent in the GB and GC. CCA elongation and convolution and dolichoectatic configurations were observed macroscopically. Histopathologic examinations of all animals, especially GB and GC, have shown inner elastic membrane flattening, intimal thinning, endothelial cell shrinkage, desquamation and loss of endothelial cells, luminal enlargement, dilatation, and wall thinning following BCCAL. Basilar artery duplication, neovascularization, and/or collateral development in the GB, and GC were detected. Thyroid gland atrophy was more prominent in GB and GC animals. Thyroid gland ischemia has hazardous effects on CCA and neoangiogenesis in GC. Luminal enlargement, wall thinning, elongation, convolutions, and dolichoectatic configurations were detected in the majority of common carotid arteries.

Figure 1 shows the histological representation of the common carotid artery, internal and external carotid arteries, and external carotid branches of a normal rabbit. In addition, narrowed external and internal carotid arteries are observed immediately after common carotid artery ligation. Trigeminal ganglion with normal neurons in a normal rabbit; Moderately degenerated neurons are seen in the SHAM and severely degenerated neurons in the study animals (Figure 2). In Figure 3A, after BCCAL, common carotid artery, external carotid artery, and internal carotid arteries are observed. Figure 3B shows advanced neovascularization in a subject with the better condition of the trigeminal nerve and ganglion. In Figure 3C, moderate neovascularization is observed in a subject with mild ischemic injury to the trigeminal nerve and its ganglion. In Figure 3D, in a subject with severe ischemic damage to the trigeminal nerve and its ganglion, very few neovascularizations with the abnormal histological structure are seen with both H&E and GFAP methods (Figure 4).

Numerical Results

Luminal enlargement, wall thinning, elongation, convolutions, and dolichoectatic configurations were detected in the majority of common carotid arteries. The mean DN density of TGG was highest in the GC. The mean ECA branch counts highest in the GC. The severity of TGG ischemia was significantly higher in the GC animals compared with the GA and GB ($p<0.0001$). The total vessel's surface values of ECA and ICA were 4,8±1,2 mm^2 in control; 3.9±0.8 mm^2 in GB; 3.6±0.4 mm^2; and, 5.4±1.3 mm^2 in the GC. (Table 1).

DISCUSSION

BCCAL causes a prominent redistribution of craniocerebral circulation initially, but that changes largely regressed following three months (1). BCCAL may lead to important hazardous histomorphological changes at the posterior communicating artery. However, the high neuron density of TGG may provide a beneficial effect on posterior communicating artery insult and prevent their dangerous changes (7). Because CBs are fed mainly by ECA and rarely by ICA, BCCAL ischemic insult or atrophy on CB **(2).** Also, BCCAL may result in thyroid gland ischemia or atrophy (4). That complication of BCCAL could be hazardous results in the renormalization process of destructed craniocerebral circulation following BCCAL.

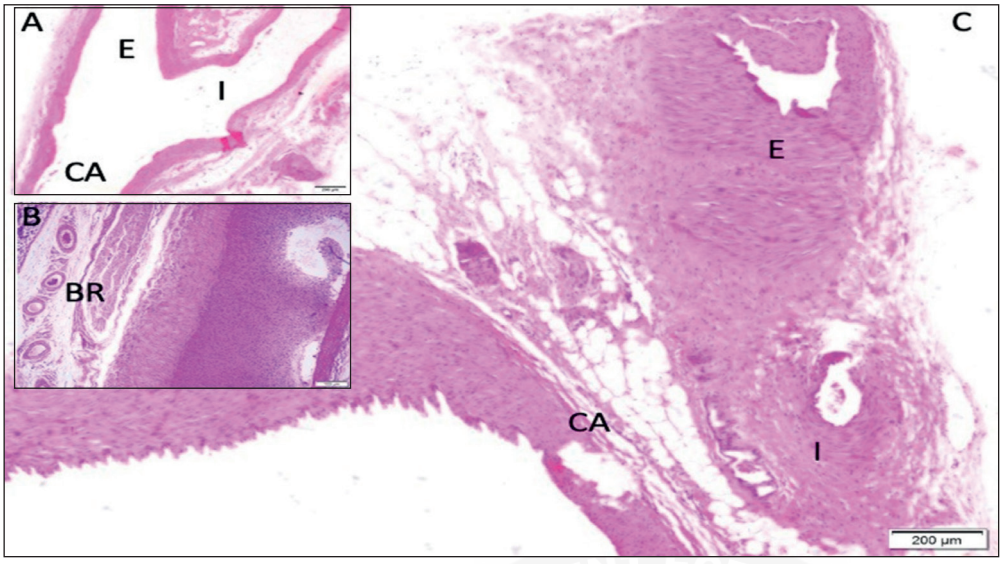

Figure 1: Histological representation of common carotid artery (CA), internal (I), and external (E) carotid arteries (**A:** LM, H&E x4); external carotid branches (BR) (**B:** LM, H&E x4) of a normal rabbit. Also, narrowed external (E) and internal carotid arteries (I) just after common carotid artery ligation (**C:** LM, H&E x4).

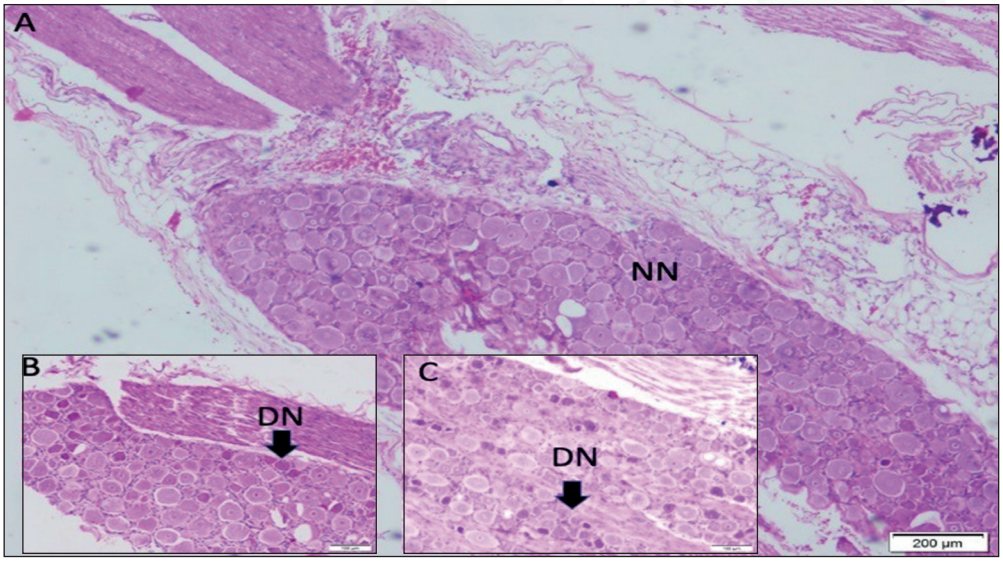

Figure 2: Trigeminal ganglion with normal neurons (NN) (**A:** LM H&E x4) in a normal rabbit; moderately degenerated neurons in SHAM (**C:** LM H&E x4) and with severely degenerated neurons (DN) (**B:** LM H&E x4) in study animal.

Table 1: The relationships between TGG ischemia and branches of carotid arteries.

	GA (Mean±SD)	GB (Mean±SD)	GC (Mean±SD)
DND/TGG (mm^3)	12±4	53±11	960±112
ECA Branch Number (n/mm^2)	4±1	7±2	11±3
Total Surface Values of ECA/ICA (n/mm^2)	4.8±1.2	3.9±0.8	3.6±0.4

DND: Degenerated neuron density, **TGG:** Trigeminal ganglion, **ECA:** External carotid artery, **ICA:** Internal carotid artery, **SD:** Standart deviation.

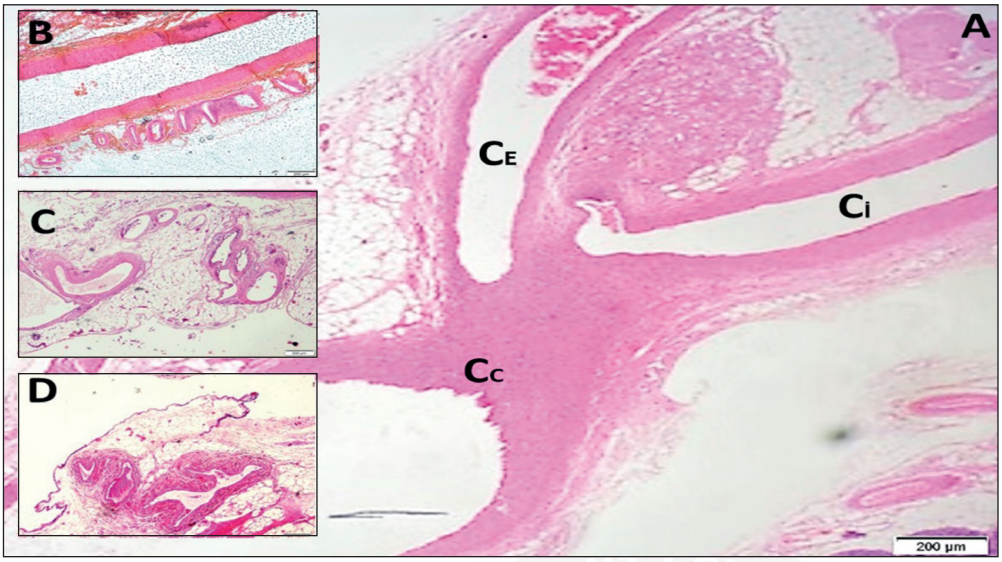

Figure 3: A) Common carotid artery (CC), external carotid artery (CE), and internal carotid artery (Ci) are in BCCAL.
B) A subject with a better condition of the trigeminal nerve and ganglion shows very well-formed neovascularization.
C) A subject with mild ischemic damage to the trigeminal nerve and its ganglion shows moderate neovascularization.
D) A subject with severe ischemic damage to the trigeminal nerve and its ganglion, very few neovascularizations are seen without normal histological structure. (**A-D:** LM, H&E, x4).

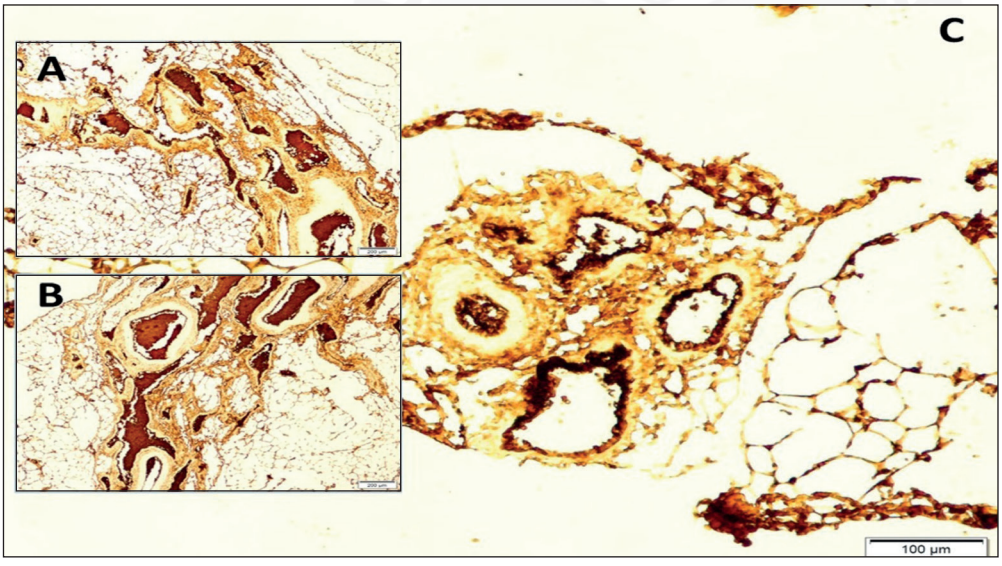

Figure 4: A) A subject with a better condition of the trigeminal nerve and ganglion shows very well-formed neovascularization. In
B) A subject with mild ischemic damage to the trigeminal nerve and its ganglion shows moderate neovascularization.
C) A subject with severe ischemic damage to the trigeminal nerve and its ganglion, very few neovascularizations are seen without normal histological structure. (**A-C:** LM, GFAP, x10).

BCCAL results in histomorphological changes at the Circle of Willis (6). A paradoxical interrelation was explained by BA dilatation and degenerated neuron density of SCG after BCCAL (5). High neuron density of superior cervical ganglia prevents basilar dilatation after BCCAL (11) and aneurysm formation at the posterior circulatory arteries (12). Carotid occlusions are associated with de novo aneurysm formation at the intracranial arteries (13). Hemodynamic insult by BCCAL induces aneurysmal occurrence at the basilar terminus following BCCAL (14). Because increased basilar artery flow results in adaptive basilar artery remodeling and significant structural transformations (15). Hemodynamic insults at arterial bifurcations play an essential role in aneu-

rysm formation after BCCAL (9). Increased diameters and thinned vessel walls trigger aneurysm formation at the posterior circulation arteries (10).

Vascular dilatation flattened and also ruptured inner elastic lamina, flattened-desquamated endothelial, elongated and thinned muscles of arteries, and tortuosity are the most frequent histopathological changes following BCCAL (3). In the late phase of BCCAL, cellular hypertrophy versus cellular hyperplasia is detected following steno-occlusive carotid artery diseases (16).

Changes in the vertebral-basilar and carotid tree can be normalized after 15 weeks post-ligation (1). We interestingly noticed that SCG ischemia renormalization of the carotid body and thyroid gland has a beneficial effect on the renormalization phenomenon of craniocervical region arteries together with well-preserved TGG following BCCAL. The affected craniocervical arteries are more vulnerable in the hypertensive rats than in the normotensive rats (17). There is a linear relationship between the absolute inner elastic membrane length and basilar artery upper rupture limit following bilateral common carotid artery ligation (18). Neurodegeneration of stellate ganglia may have a beneficial effect on the prevention of pulmonary artery spasm-related complications during steno-occlusive carotid artery disease (19). Although a higher neuron density in SCG may provoke excessive sympathetic activity and prevent excessive BA dilatation (5) and aneurysm formation in the posterior circulatory arteries (12, 20). Sympathectomy also has the same useful effect on the same pathologies (11). An inverse relationship between DND TGG and tympanic membrane supplying arteries dilatation (21). The TGG neuron density may be an important factor in the regulation of AChAs diameter following SAH (22).

While hemodynamics are suspended in ICA and ECA after carotid ligation, ischemia, stasis, loss of pulse/contractility, edema, endothelial damage, and plugging occur in the vessel wall in the acute phase. This causes an inflammation of the vessel wall and sometimes necrosis, resulting in carotid body ischemia, acidosis, and acidic burns. The resulting ischemia works by activating the trigeminal and parasympathetic nerves and renormalizing the impaired vascular physiology and hemodynamics. Both mechanisms are triggers to renormalize the circulation of the carotid system through the reverse current from the vertebrobasilar system. While doing this, synapses with target tissues fed externally may continue degenerative processes. In cases, there is minimal neurodegeneration in the trigeminal ganglion in the mechanisms effective in renormalization of recirculation-independent ischemia tissues.

Embryonic shunts may also be opened as a result of dilatation in the common carotids in the proximal part of the ligation, increases in neovascularization, collateral formation, and increased hemodynamics. This mechanism is similar to the logic of opening the closed vessels between angiosomes in the flap delay method described previously. Acidosis due to CB ischemia may be useful for the basic activities required in the tissue repair process, perhaps by preventing thromboembolic phenomena in the early stages. Again, trigeminal ischemia also increases the release of vasodilator anti-inflammatory and anti-edema and initiates very magnificent processes in the renormalization of tissues. However, these pathological treatment mechanisms turn against chronicity. This is essential at this stage.

Finally, we concluded that the trigeminal nerve has an important role in the renormalization of the impaired circulation after carotid stenosis. Ischemic damage to this nerve prevents adequate craniocervical circulation.

In the future, trigeminal nerve stimulation may be recommended for circulation renormalization in cases with carotid stenosis, so craniofacial flap survival may be improved.

Acknowledgment

We thank the histology and pathology staff.

Author Contributions

Concept: **Abdulkerim Olgun, Mehmet Dumlu Aydın,** Design: **Rabia Demirtas, Mehmet Dumlu Aydın,** Data collection or processing: **Mehmet Kursad Karadag, Mehmet Hakan Sahin, Sevilay Ozmen,** Analysis or Interpretation: **Aslihan Duman, Mehmet Dumlu Aydın,** Literature search: **Abdulkerim Olgun, Mehmet Dumlu Aydın,** Writing: **Abdulkerim Olgun, Sevilay Ozmen,** Approval: **Abdülkerim Olgun.**

Conflicts of Interest

All authors declared that no conflict of interest.

Financial Support

No financial Support

Ethical Approval

Ataturk University Animal Ethical Committee

Review Process

Preferred Reviewers are: Prof. Dr. Mehmet Turgut (drmturgut@yahoo.com), Doç. Dr. Ali Ahıskalıoğlu (aliahiskalioglu@hotmail.com).

REFERENCES

1. Oldendorf WH. Trophic changes in the arteries at the base of the rat brain in response to bilateral common carotid ligation. J Neuropathol Exp Neurol 1989;48(5):534-47.
2. Aydin MD, Ozkan U, Gündoğdu C, Onder A. Protective effect of posterior cerebral circulation on carotid body ischemia. Acta Neurochir (Wien) 2002;144(4):369-72.

3. Masuda H, Sugita A, Zhuang YJ. Pathology of the arteries in the central nervous system with special reference to their dilatation: Blood flow. Neuropathology 2000;20(1):98-103.
4. Rots ML, de Borst GJ, van der Toorn A, Moll FL, Pennekamp CWA, Dijkhuizen RM, Bleys RLAW. Effect of bilateral carotid occlusion on cerebral hemodynamics and perivascular innervation: An experimental rat model. J Comp Neurol 2019;527(14):2263-2272.
5. Kilic M, Kilic B, Aydin MD, Kanat A, Yilmaz I, Eseoglu M, Gundogdu B. Paradoxic Relations between Basilar Artery Reconfiguration and Superior Cervical Ganglia Ischemia After Bilateral Common Carotid Artery Ligation. World Neurosurg 2019;125:e658-e664.
6. Tutino VM, Liaw N, Spernyak JA, Ionita CN, Siddiqui AH, Kolega J, Meng H. Assessment of Vascular Geometry for Bilateral Carotid Artery Ligation to Induce Early Basilar Terminus Aneurysmal Remodeling in Rats. Curr Neurovasc Res 2016;13(1):82-92.
7. Aygul R, Aydin MD, Kotan D, Demir R, Ulvi H, Karalar M, Nalbantoglu NG, Eseoglu M. Role of the trigeminal system on posterior communicating artery remodelization after bilateral common carotid artery ligation. Anal Quant Cytopathol Histpathol 2013;35(4):217-25.
8. Xiong Y, Mahmood A, Zhang Y, Meng Y, Zhang ZG, Qu C, Sager TN, Chopp M. Effects of posttraumatic carbamylated erythropoietin therapy on reducing lesion volume and hippocampal cell loss, enhancing angiogenesis and neurogenesis, and improving functional outcome in rats following traumatic brain injury. J Neurosurg 2011;114(2):549-59.
9. Gao L, Hoi Y, Swartz DD, Kolega J, Siddiqui A, Meng H. Nascent aneurysm formation at the basilar terminus induced by hemodynamics. Stroke 2008;39(7):2085-90.
10. Kim SH, Kim EH, Lee BI, Heo JH. Chronic cerebral hypoperfusion protects against acute focal ischemia, improves motor function, and results in vascular remodeling. Curr Neurovasc Res 2008;5(1):28-36.
11. Eseoglu M, Yilmaz I, Karalar M, Aydin MD, Kayaci S, Gundogdu C, Gunaldi O, Onen MR. The role of sympathectomy on the regulation of basilar artery volume changes in stenoocclusive carotid artery modeling after bilateral common carotid artery ligation: An animal model. Acta Neurochir (Wien) 2014;156(5):963-9.
12. Yilmaz I, Eseoglu M, Onen MR, Tanrıverdi O, Kilic M, Yilmaz A, Musluman AM, Aydin MD, Gündogdu C. Inverse Association Between Basilar Artery Volume and Neuron Density in the Stellate Ganglion Following Bilateral Common Carotid Artery Ligation: An Experimental Study. World Neurosurg 2017;100:138-143.
13. Tutino VM, Mandelbaum M, Choi H, Pope LC, Siddiqui A, Kolega J, Meng H. Aneurysmal remodeling in the circle of Willis after carotid occlusion in an experimental model. J Cereb Blood Flow Metab 2014;34(3):415-24.
14. Metaxa E, Tremmel M, Natarajan SK, Xiang J, Paluch RA, Mandelbaum M, Siddiqui AH, Kolega J, Mocco J, Meng H. Characterization of critical hemodynamics contributing to aneurysmal remodeling at the basilar terminus in a rabbit model. Stroke 2010;41(8):1774-82.
15. Hoi Y, Gao L, Tremmel M, Paluch RA, Siddiqui AH, Meng H, Mocco J. In vivo assessment of rapid cerebrovascular morphological adaptation following acute blood flow increase. J Neurosurg 2008;109(6):1141-7.
16. Lehman RM, Owens GK, Kassell NF, Hongo K. Mechanism of enlargement of major cerebral collateral arteries in rabbits. Stroke 1991;22(4):499-504.
17. Fredriksson K, Nordborg C, Johansson BB. The hemodynamic effect of bilateral carotid artery ligation and the morphometry of the main communicating circuit in normotensive and spontaneously hypertensive rats. Acta Physiol Scand 1984;121(3):241-7.
18. Aydin MD, Kanat A, Aydin A, Aydin A, Demirci T, Ozmen S. Estimating basilar artery upper rupture limit by dangerous alarming diameter of arteries (DADA) following bilateral common carotid artery ligation; a new theorem. Int J Neurosci 2020:1-7.
19. Arslan R, Aydin ME, Karadag MK, Caglar O, Karadeniz E, Aydin MD. Stellate ganglion ischemia on the prevention of pulmonary vasospasm during bilateral carotid artery ligation: The first experimental study. Neuropathology 2020;40(5):467-73.
20. Ozkan U, Aydin MD, Gündoğdu C, Onder A. Histopathologic changes in oculomotor nerve and ciliary ganglion in aneurysmatic compression injuries of oculomotor nerve. Minim Invasive Neurosurg 2004;47(2):107-10.
21. Celiker M, Kanat A, Aydin MD, Ozdemir D, Aydin N, Yolas C, Calik M, Peker HO. First emerging objective experimental evidence of hearing impairment following subarachnoid haemorrhage; Felix culpa, phonophobia, and elucidation of the role of trigeminal ganglion. Int J Neurosci 2019;129(8):794-800.
22. Yilmaz A, Gündoğdu C, Aydin MD, Musluman M, Kanat A, Aydin Y. Trigeminal ganglion neuron density and regulation of anterior choroid artery vasospasm: In a rabbit model of subarachnoid hemorrhage. Surg Neurol Int 2011;2:77.