IN VIVO *39*: 1414-1421 (2025)
doi: 10.21873/invivo.13943

Expression of BDNF in the Cortex and Hippocampus of Mice With Middle Cerebral Artery Occlusion

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Abstract

Background/Aim: Stroke is a cerebrovascular disease with high mortality and disability, causing motor dysfunction and cognitive impairments. Middle cerebral artery occlusion (MCAO) mouse models of ischemic stroke are used for identifying therapeutic targets. Ischemic insults to the brain alter brain-derived neurotrophic factor (BDNF) expression in cortical and hippocampal neurons. In the present study, we investigated BDNF expression in the cortex and hippocampus of mice following MCAO.

Materials and Methods: Monofilament sutures coated with silicone rubber were introduced into the common carotid artery and occluded middle cerebral artery. The filament was withdrawn for reperfusion after 0.5 h. BDNF protein expression was measured using western blot. Immunofluorescence was performed with anti-NeuN and anti-BDNF antibodies.

Results: BDNF expression in the cerebral cortex and hippocampus was decreased one and three days after MCAO, compared to the control group (unoperated mice). BDNF was expressed in NeuN-positive neurons in the dentate gyrus of the hippocampus and motor cortex of the MCAO and control groups.

Conclusion: MCAO in mice reduced the expression of BDNF in mature neurons of both the motor cortex and hippocampus at one and three days after surgery.

Keywords: MCAO, BDNF, cortex, hippocampus, mouse.

Introduction

Stroke is a major cerebrovascular disease characterized by high mortality, disability, motor dysfunction, and cognitive impairment (1, 2). Strokes can be classified into two types: ischemic and hemorrhagic. The pathology of cerebral ischemia is complex and involves inflammatory reactions, oxidative stress, and apoptosis (3-5). This

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Received January 26, 2025 | Revised February 18, 2025 | Accepted February 19, 2025

phenomenon damages multiple brain cells, such as neurons, astrocytes, and oligodendrocytes (6, 7). Although stroke leads to various types of damage in the cerebral parenchyma, effective therapies for ischemic stroke include recombinant tissue-type plasminogen activators and surgical thrombectomy (8). Middle cerebral artery occlusion (MCAO) in mice is a useful animal model for identifying novel therapeutic targets (9).

Brain-derived neurotrophic factor (BDNF), a member of the neurotrophic factor family, has been studied as a neuroprotective and neurogenic factor in the ischemic brain (10). BDNF is widely distributed throughout the brain, with high expression in the hippocampus, cortex, and striatum (11). Many studies have shown that BDNF inhibits inflammatory factors and neuronal apoptosis (12). BDNF has been reported to be involved in learning, memory impairment, and motor dysfunction in animal ischemic models (13, 14). Guang-Xiao Ni *et al.* showed that BDNF expression is decreased after MCAO surgery, and that neurobehavioral function in rats with MCAO-induced ischemia is improved by BDNF up-regulation (15).

Strokes are associated with motor dysfunction and cognitive impairment. Therefore, it is important to study the motor cortex and hippocampus, which is involved in cognitive functions, together. Ischemic insults to the brain alter BDNF expression in cortical and hippocampal neurons (16). In the present study, we investigated BDNF expression in the cortex and hippocampus following MCAO.

Materials and Methods

Experimental design. Seven- to eight-week-old male C57BL/6 mice were obtained from Damul Laboratory Animals (Daejeon, Republic of Korea). The mice were bred in a controlled environment at a regular temperature of 25˚C and were fed a normal diet. All animal procedures were approved by the Institutional Animal Care and Use Committee of the Chosun University. The surgery was performed on 30 mice (MCAO group) and 20 unoperated mice were assigned to the control group. Tissues for western blotting and immunofluorescence were obtained one and three days after MCAO.

MCAO surgery. Mice were anesthetized with 2.5% isoflurane and maintained with 2.0% isoflurane in a mixture of 30% O_2 and 70% N_2O. Body temperature was maintained at 37±0.5˚C using a rectal probe and temperature controller (JD-OT-06DT, JEUNG-DO BIO, Seoul, Republic of Korea). A midline incision was made in the neck and the left common carotid artery (CCA) was separated from the sheath and vagus nerve. The CCA and external carotid arteries were ligated using 4-0 silk sutures. A 6-0 nylon monofilament suture coated with silicone rubber was introduced into the common carotid artery to occlude the middle cerebral artery. The filament was withdrawn for reperfusion after 0.5 h.

Western blot analysis. All mice were anesthetized using sevoflurane inhalation (1.0∼2.0%, end-tidal concentration) and the left portion of the cortex and hippocampal tissue were isolated. Tissues were homogenized in RIPA buffer containing one tablet of protease inhibitor cocktail (Roche, Indianapolis, IN, USA) in 10 ml of lysis buffer. The supernatant was collected, and the total protein concentration was measured using the Bradford method. After denaturation with SDS, the proteins were separated using SDS-PAGE, transferred to nitrocellulose membranes (GE Healthcare, Piscataway, NJ, USA), and probed with an anti-BDNF antibody (1:1,000, ab108319, Abcam, Cambridge, UK). The ImageJ software was used to quantify the signals. Anti-actin (1:2,000, 66009-1-Ig, Proteintech, Rosemont, IL, USA) was used as an internal control, and data were normalized according to the beta-actin value.

Immunofluorescence (IF). To perform IF in formalin-fixed paraffin-embedded (FFPE) tissues, section slides were dewaxed as follows: three times in 100% xylene for 5 min, twice in 100% ethanol for 3 min, twice in 95% ethanol for 3 min, once in 90% ethanol for 3 min, once in 80% ethanol for 3 min, once in 70% ethanol for 3 min, and once in H_2O. The slide rack was then transferred to a glass container

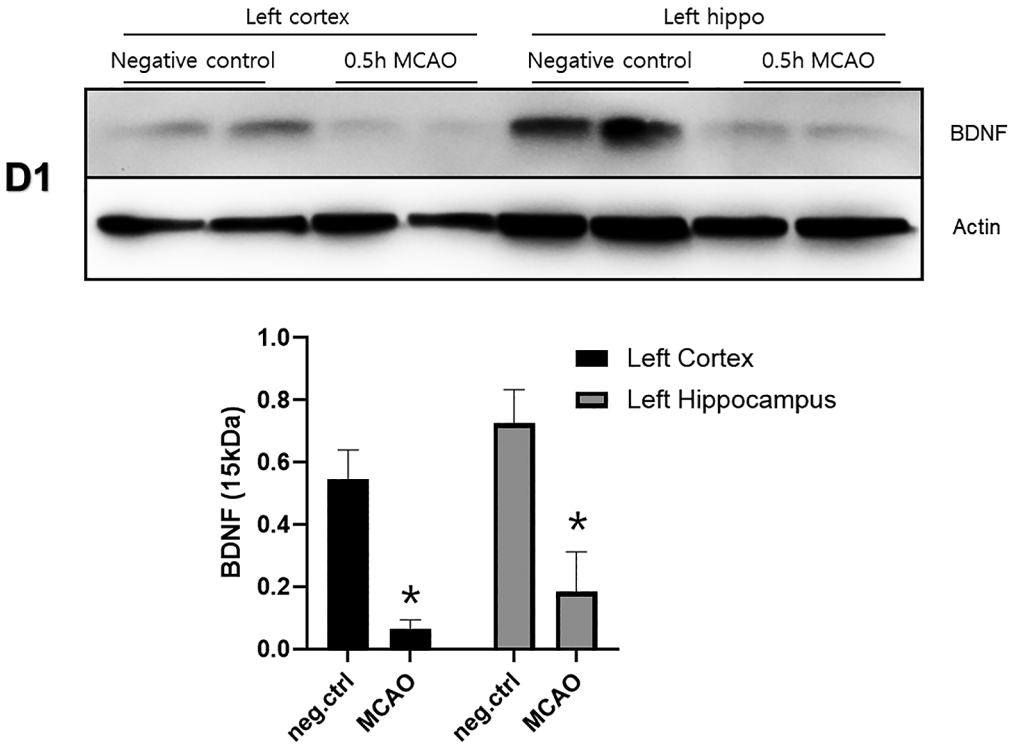

Figure 1. *BDNF expression in the parietal cortex and hippocampus one day after middle cerebral artery occlusion (MCAO). The results were quantified and presented normalized to actin-beta expression. *p<0.05. neg-ctrl: Negative control.*

filled with 10 mM citrate buffer (pH 6.0). Antigen retrieval was performed for 10 min in a microwave, and then kept at room temperature (RT) for 30 min. After several washes with TBS-0.1% Tween20 (TBST) buffer, slides were wiped around the section to create an 'island' with ImmEdge pen (hydrophobic barrier pen). Immunofluorescence labeling was conducted as follows: The sections were blocked with 10% FBS solution for 30 min at RT, primary antibodies were incubated with 5% FBS solution for 24 h at 4˚C. After washing three times with TBST, the tissues were incubated with a secondary antibody conjugated to the appropriate fluorochrome for 1 h at RT. The following antibodies were used for IF labeling: anti-NeuN (1:50, MAB377, Millipore, Burlington, MA, USA) and anti-BDNF (1:50, ab108319, Abcam). Rhodamine and fluorescein isothiocyanate-conjugated secondary antibodies (1:200; Jackson ImmunoResearch, Baltimore Pike, PA, USA) were used. Finally, tissue slides were mounted with fluoroshield mounting medium with DAPI and analyzed using the confocal microscopy LSM800 imaging system (Carl Zeiss, Oberkochen, Germany).

Results

One day after MCAO, the expression of mature BDNF protein (15 kDa) was examined in the parietal cortex and hippocampus of the mice. BDNF protein levels were significantly lower in the left cortex and hippocampus (damaged side) of the MCAO group compared to the control group (Figure 1). In the cortex, BDNF protein in both the control and MCAO group mice was expressed in NeuN-positive neurons in the external granular layer (Figure 2). In the hippocampus, BDNF was expressed in NeuN-positive neurons in the dentate gyrus of both groups (Figure 2).

Three days after MCAO, BDNF protein expression in the left cortex and hippocampus of the MCAO group was

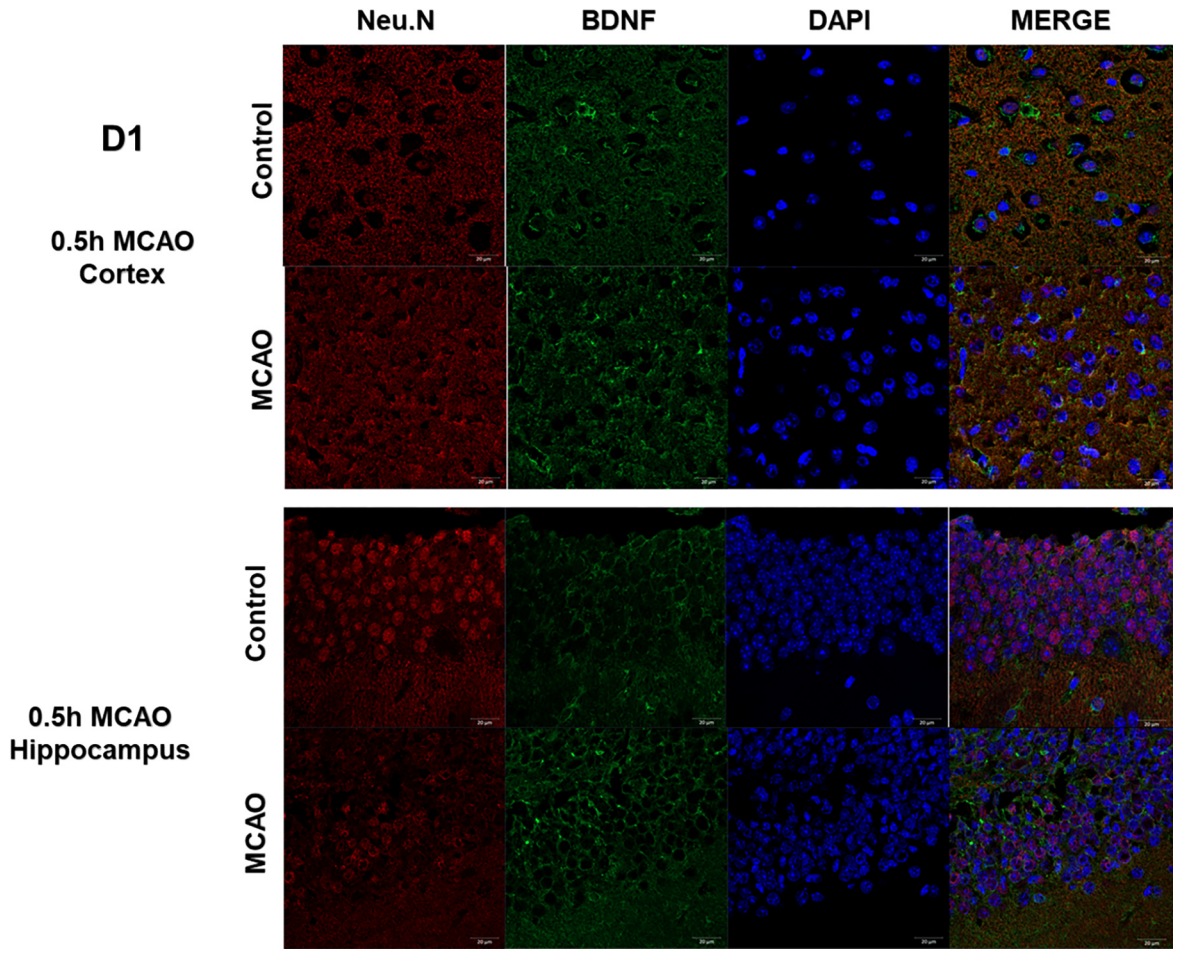

Figure 2. I*mmunofluorescent staining for BDNF in parietal cortex and dentate gyrus of hippocampus one day after middle cerebral artery occlusion (MCAO).*

lower than that in the control group, similar to the findings at one day after MCAO (Figure 3). In the external granular layer of the cortex and dentate gyrus of the hippocampus, BDNF was expressed in NeuN-positive neurons, similar to the pattern observed one day after MCAO (Figure 4).

Discussion

We studied the expression of endogenous BDNF in the parietal cortex and hippocampus. The amount of exogenous BDNF that permeates the brain parenchyma is very small because it does not easily pass through the blood-brain barrier (BBB) (17). Endogenous BDNF expression plays a key role in the repair of damaged neurons (18). BDNF induces neuronal cell proliferation, maturation, and repair following ischemic insult (19, 20).

In the cortex, BDNF protein expression was lower in the MCAO group at one and three days after MCAO. One and three days after MCAO represent the acute phase of stroke (21). During this phase, neuroinflammation occurs due to BBB leakage (22). The NF-κB pathway regulates proinflammatory cytokine release through the BDNF/ERK/REB pathway (23). This study suggested that the BDNF reduction in the parietal cortex, similar to our results, is associated with inflammatory

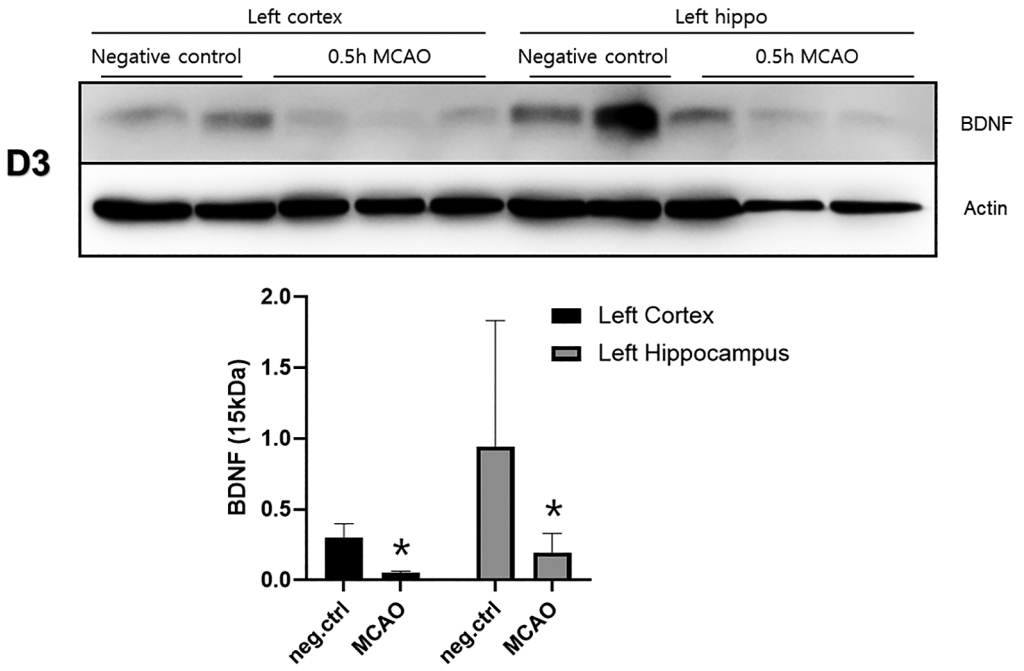

Figure 3. *BDNF expression in the parietal cortex and hippocampus three days after middle cerebral artery occlusion (MCAO). The results were quantified and presented normalized to actin-beta expression. *p<0.05. neg-ctrl: Negative control.*

dysregulation. One study showed that BDNF expression levels and TrkB signaling in the cortex of rats after MCAO regulate apoptosis-related protein expression (24). Another study reported that BDNF activates PI3K/Akt signaling and antagonizes proapoptotic actions (25). Wu *et al.* reported that the anti-apoptotic effect of BDNF activation in an ischemic stroke model improves motor behavior (26). These studies have shown that BDNF in the cortex of the ischemic region is related to apoptotic reactions and affects neuronal cells in the motor cortex. We have previously reported that BDNF is expressed in mature neurons in the motor cortex. Zhang *et al.* showed that BDNF down-regulation affects the migration of neurons from the subventricular zone to the cortex *via* the AKT/mTOR signaling pathway (27). Another study showed that newborn cell (BrdU-positive) survival in the penumbra of the cortex after MCAO induction is affected by BDNF expression (28). Espinera *et al.* reported that BDNF activation enhances neurovascular regeneration and motor recovery after ischemic stroke in mice (29). We suggest that BDNF protein expression in the motor cortex regulates the survival of mature neurons and is associated with motor function.

In the hippocampus, the expression of BDNF protein was lower in the MCAO group at one and three days after MCAO, similar to that in the cortex. Interestingly, BDNF protein expression in the control group was very high in the hippocampus.

It has been noted that BDNF is highly expressed in the hippocampus region (30). Zhu *et al.* reported that the reduction in BDNF expression in rats subjected to MCAO involves neuroinflammation and oxidative stress (31). Yi *et al.* showed that BDNF levels decreased after MCAO, similar to our results, and up-regulation of the expression of BDNF and CREB proteins in the hippocampus improved cognitive dysfunction (32). Other studies have reported that MCAO induces neuronal apoptosis by altering the expression of BDNF and apoptotic genes in the hippocampus (33).

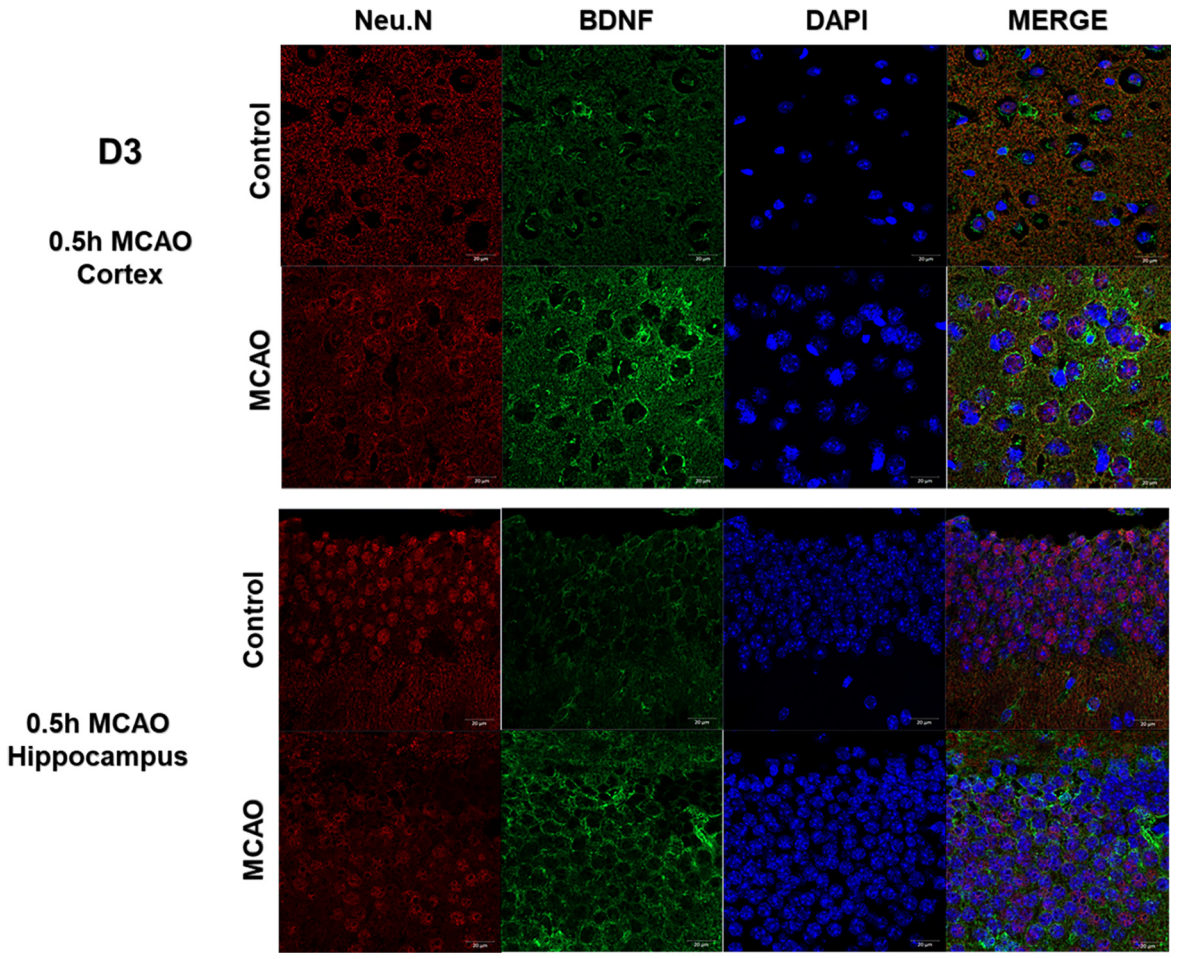

Figure 4. *Immunofluorescent staining for BDNF in parietal cortex and dentate gyrus of hippocampus three days after middle cerebral artery occlusion (MCAO).*

We showed that BDNF is expressed in mature neurons in the dentate gyrus of the hippocampus. The dentate gyrus is a neurogenic region of the forebrain (34). Taei *et al.* reported that BDNF expression regulates neuronal survival in the dentate gyrus and neuronal cell migration (35). Another study showed that activation of the BDNF receptor was related to neurogenesis in the dentate gyrus and improved learning and memory dysfunction after MCAO (36). Our results suggested that MCAO reduces BDNF expression in the hippocampus and affects neuronal survival in the hippocampal dentate gyrus.

Although we examined the expression level of BDNF protein after MCAO, this study did not include motor or cognitive behavioral tests. Further studies are needed to examine behavioral changes after MCAO.

Conclusion

MCAO in mice reduced the expression of BDNF in mature neurons of the motor cortex and hippocampus one and three days after surgery.

Conflicts of Interest

The Authors reported that they have no competing interests in relation to this study.

Authors' Contributions

YHJ designed the study. DJK, HKS, and YYC performed the surgical procedures. HIH analyzed the data. HIH performed the western blot analyses. All the Authors approved the final manuscript.

Acknowledgements

This study was supported by research funds from the Chosun University (2023).

References

1 Ananth CV, Brandt JS, Keyes KM, Graham HL, Kostis JB, Kostis WJ: Epidemiology and trends in stroke mortality in the USA, 1975-2019. Int J Epidemiol 52(3): 858-866, 2023. DOI: 10.1093/ije/dyac210

2 Einstad MS, Saltvedt I, Lydersen S, Ursin MH, Munthe-Kaas R, Ihle-Hansen H, Knapskog AB, Askim T, Beyer MK, Næss H, Seljeseth YM, Ellekjær H, Thingstad P: Associations between post-stroke motor and cognitive function: a cross-sectional study. BMC Geriatr 21(1): 103, 2021. DOI: 10.1186/s12877-021-02055-7

3 Mao Y, Weng J, Xie Q, Wu L, Xuan Y, Zhang J, Han J: Association between dietary inflammatory index and Stroke in the US population: evidence from NHANES 1999-2018. BMC Public Health 24(1): 50, 2024. DOI: 10.1186/s12889-023-17556-w

4 Sun YY, Zhu HJ, Zhao RY, Zhou SY, Wang MQ, Yang Y, Guo ZN: Remote ischemic conditioning attenuates oxidative stress and inflammation *via* the Nrf2/HO-1 pathway in MCAO mice. Redox Biol 66: 102852, 2023. DOI: 10.1016/j.redox.2023.102852

5 Liu X, Ye Q, Huang Z, Li X, Zhang L, Liu X, Wu YC, Brockmeier U, Hermann DM, Wang YC, Ren L: BAG3 overexpression attenuates ischemic stroke injury by activating autophagy and inhibiting apoptosis. Stroke 54(8): 2114-2125, 2023. DOI: 10.1161/strokeaha.123.041783

6 Zhou J, Zhang L, Peng J, Zhang X, Zhang F, Wu Y, Huang A, Du F, Liao Y, He Y, Xie Y, Gu L, Kuang C, Ou W, Xie M, Tu T, Pang J, Zhang D, Guo K, Feng Y, Yin S, Cao Y, Li T, Jiang Y: Astrocytic LRP1 enables mitochondria transfer to neurons and mitigates brain ischemic stroke by suppressing ARF1 lactylation. Cell Metab 36(9): 2054-2068.e14, 2024. DOI: 10.1016/j.cmet.2024.05.016

7 Gu L, Chen H, Geng R, Sun M, Shi Q, Chen Y, Chang J, Wei J, Ma W, Xiao J, Bao X, Wang R: Single-cell and spatial transcriptomics reveals ferroptosis as the most enriched programmed cell death process in hemorrhage stroke-induced oligodendrocyte-mediated white matter injury. Int J Biol Sci 20(10): 3842-3862, 2024. DOI: 10.7150/ijbs.96262

8 Shehjar F, Maktabi B, Rahman ZA, Bahader GA, James AW, Naqvi A, Mahajan R, Shah ZA: Stroke: Molecular mechanisms and therapies: Update on recent developments. Neurochem Int 162: 105458, 2023. DOI: 10.1016/j.neuint.2022.105458

9 Zhou L, Jin Y, Wu D, Cun Y, Zhang C, Peng Y, Chen N, Yang X, Zhang S, Ning R, Kuang P, Wang Z, Zhang P: Current evidence, clinical applications, and future directions of transcranial magnetic stimulation as a treatment for ischemic stroke. Front Neurosci 17: 1177283, 2023. DOI: 10.3389/fnins.2023.1177283

10 Yılmaz E, Baltaci SB, Mogulkoc R, Baltaci AK: The impact of flavonoids and BDNF on neurogenic process in various physiological/pathological conditions including ischemic insults: a narrative review. Nutr Neurosci 27(9): 1025-1041, 2024. DOI: 10.1080/1028415x.2023.2296165

11 Liu YF, Chen HI, Wu CL, Kuo YM, Yu L, Huang AM, Wu FS, Chuang JI, Jen CJ: Differential effects of treadmill running and wheel running on spatial or aversive learning and memory: roles of amygdalar brain-derived neurotrophic factor and synaptotagmin I. J Physiol 587(Pt 13): 3221-3231, 2009. DOI: 10.1113/jphysiol.2009.173088

12 Wang M, Pan W, Xu Y, Zhang J, Wan J, Jiang H: Microglia-mediated neuroinflammation: a potential target for the treatment of cardiovascular diseases. J Inflamm Res 15: 3083-3094, 2022. DOI: 10.2147/JIR.S350109

13 Yu L, Liu S, Zhou R, Sun H, Su X, Liu Q, Li S, Ying J, Zhao F, Mu D, Qu Y: Atorvastatin inhibits neuronal apoptosis via activating cAMP/PKA/p-CREB/BDNF pathway in hypoxic-ischemic neonatal rats. Faseb J 36(4): e22263, 2022. DOI: 10.1096/fj.202101654RR

14 Longo V, Barbati SA, Re A, Paciello F, Bolla M, Rinaudo M, Miraglia F, Alù F, Di Donna MG, Vecchio F, Rossini PM, Podda MV, Grassi C: Transcranial direct current stimulation enhances neuroplasticity and accelerates motor recovery in a stroke mouse model. Stroke 53(5): 1746-1758, 2022. DOI: 10.1161/strokeaha.121.034200

15 Ni GX, Liang C, Wang J, Duan CQ, Wang P, Wang YL: Astragaloside IV improves neurobehavior and promotes hippocampal neurogenesis in MCAO rats though BDNF-TrkB signaling pathway. Biomed Pharmacother 130: 110353, 2020. DOI: 10.1016/j.biopha.2020.110353

16 Andsberg G, Kokaia Z, Klein RL, Muzyczka N, Lindvall O, Mandel RJ: Neuropathological and behavioral consequences of adeno-associated viral vector-mediated continuous intrastriatal neurotrophin delivery in a focal ischemia model in rats. Neurobiol Dis 9(2): 187-204, 2002. DOI: 10.1006/nbdi.2001.0456

17 Li Y, Xiang L, Wang C, Song Y, Miao J, Miao M: Protection against acute cerebral ischemia/reperfusion injury by Leonuri Herba Total Alkali via modulation of BDNF-TrKB-PI3K/Akt signaling pathway in rats. Biomed Pharmacother 133: 111021, 2021. DOI: 10.1016/j.biopha.2020.111021

18 Zheng J, Zhang J, Han J, Zhao Z, Lin K: The effect of salidroside in promoting endogenous neural regeneration after cerebral

ischemia/reperfusion involves notch signaling pathway and neurotrophic factors. BMC Complement Med Ther 24(1): 293, 2024. DOI: 10.1186/s12906-024-04597-w

19 Zhou X, Deng X, Liu M, He M, Long W, Xu Z, Zhang K, Liu T, So KF, Fu QL, Zhou L: Intranasal delivery of BDNF-loaded small extracellular vesicles for cerebral ischemia therapy. J Control Release 357: 1-19, 2023. DOI: 10.1016/j.jconrel.2023.03.033

20 Zhu ZH, Jia F, Ahmed W, Zhang GL, Wang H, Lin CQ, Chen WH, Chen LK: Neural stem cell-derived exosome as a nano-sized carrier for BDNF delivery to a rat model of ischemic stroke. Neural Regen Res 18(2): 404-409, 2023. DOI: 10.4103/1673-5374.346466

21 Nguyen JN, Mohan EC, Pandya G, Ali U, Tan C, Kofler JK, Shapiro L, Marrelli SP, Chauhan A: CD13 facilitates immune cell migration and aggravates acute injury but promotes chronic post-stroke recovery. J Neuroinflammation 20(1): 232, 2023. DOI: 10.1186/s12974-023-02918-3

22 Hou W, Yao J, Liu J, Lin X, Wei J, Yin X, Huang H, Chen X, Yang GY, He X: USP14 inhibition promotes recovery by protecting BBB integrity and attenuating neuroinflammation in MCAO mice. CNS Neurosci Ther 29(11): 3612-3623, 2023. DOI: 10.1111/cns.14292

23 Wang D, Li T, Han X, He W, Yan Y: Xingnao Jieyu decoction reduces neuroinflammation through the NF-κB pathway to improve poststroke depression. Evid Based Complement Alternat Med 2021: 8629714, 2021. DOI: 10.1155/2021/8629714

24 Li X, Zheng W, Bai H, Wang J, Wei R, Wen H, Ning H: Intravenous administration of adipose tissue-derived stem cells enhances nerve healing and promotes BDNF expression via the TrkB signaling in a rat stroke model. Neuropsychiatr Dis Treat 12: 1287-1293, 2016. DOI: 10.2147/NDT.S104917

25 Zhou Q, Chen Y, Tang H, Zhang L, Ma Y, Bai D, Kong Y: Transcranial direct current stimulation alleviated ischemic stroke induced injury involving the BDNF-TrkB signaling axis in rats. Heliyon 9(4): e14946, 2023. DOI: 10.1016/j.heliyon.2023.e14946

26 Wu CT, Yang TH, Chen MC, Chung YP, Guan SS, Long LH, Liu SH, Chen CM: Low intensity pulsed ultrasound prevents recurrent ischemic stroke in a cerebral ischemia/reperfusion injury mouse model *via* brain-derived neurotrophic factor induction. Int J Mol Sci 20(20): 5169, 2019. DOI: 10.3390/ijms20205169

27 Zhang Q, Zhao Y, Xu Y, Chen Z, Liu N, Ke C, Liu B, Wu W: Sodium ferulate and n-butylidenephthalate combined with bone marrow stromal cells (BMSCs) improve the therapeutic effects of angiogenesis and neurogenesis after rat focal cerebral ischemia. J Transl Med 14(1): 223, 2016. DOI: 10.1186/s12967-016-0979-5

28 Wang RY, Yang YR, Chang HC: The SDF1-CXCR4 axis is involved in the hyperbaric oxygen therapy-mediated neuronal cells migration in transient brain ischemic rats. Int J Mol Sci 23(3): 1780, 2022. DOI: 10.3390/ijms23031780

29 Espinera AR, Ogle ME, Gu X, Wei L: Citalopram enhances neurovascular regeneration and sensorimotor functional recovery after ischemic stroke in mice. Neuroscience 247: 1-11, 2013. DOI: 10.1016/j.neuroscience.2013.04.011

30 Pahlavani HA: Exercise therapy to prevent and treat Alzheimer's disease. Front Aging Neurosci 15: 1243869, 2023. DOI: 10.3389/fnagi.2023.1243869

31 Zhu XQ, Gao D: Naringenin alleviates cognitive dysfunction in rats with cerebral ischemia/reperfusion injury through up-regulating hippocampal BDNF-TrkB signaling: involving suppression in neuroinflammation and oxidative stress. Neuroreport 35(4): 216-224, 2024. DOI: 10.1097/WNR.0000000000001989

32 Yi CA, Jiang YH, Wang Y, Li YX, Cai SC, Wu XY, Hu XS, Wan XG: Black bamboo rhizome extract improves cognitive dysfunction by upregulating the expression of hippocampal BDNF and CREB in rats with cerebral ischaemia-reperfusion injury. Neuropsychiatr Dis Treat 17: 2257-2267, 2021. DOI: 10.2147/NDT.S314162

33 Torfeh A, Abdolmaleki Z, Nazarian S, Shirazi Beheshtiha SH: Modafinil-coated nanoparticle increases expressions of brain-derived neurotrophic factor, glial cell line-derived neurotrophic factor and neuronal nuclear protein, and protects against middle cerebral artery occlusion-induced neuron apoptosis in the rat hippocampus. Anat Rec (Hoboken) 304(9): 2032-2043, 2021. DOI: 10.1002/ar.24581

34 Fang S, Wu Z, Guo Y, Zhu W, Wan C, Yuan N, Chen J, Hao W, Mo X, Guo X, Fan L, Li X, Chen J: Roles of microglia in adult hippocampal neurogenesis in depression and their therapeutics. Front Immunol 14: 1193053, 2023. DOI: 10.3389/fimmu.2023.1193053

35 Asgari Taei A, Dargahi L, Khodabakhsh P, Kadivar M, Farahmandfar M: Hippocampal neuroprotection mediated by secretome of human mesenchymal stem cells against experimental stroke. CNS Neurosci Ther 28(9): 1425-1438, 2022. DOI: 10.1111/cns.13886

36 Balseanu AT, Grigore M, Pinosanu LR, Slevin M, Hermann DM, Glavan D, Popa-Wagner A: Electric stimulation of neurogenesis improves behavioral recovery after focal ischemia in aged rats. Front Neurosci 14: 732, 2020. DOI: 10.3389/fnins.2020.00732