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Original Article

The First Description of Acidic Blood-Induced Kidney Injury Following Subarachnoid Hemorrhage: The First Experimental Study

Subaraknoid Kanamayı Takip Eden Asidik Kana Bağlı Böbrek Hasarının İlk Tanımı: İlk Deneysel Çalışma

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ABSTRACT

Objective: One of the complications of subarachnoid hemorrhage (SAH) is the acidity of blood and cerebrospinal fluid if carotid body/glossopharyngeal-nerve chemoreceptor networks are disrupted. This study aimed to investigate whether the renal arteries and glomeruli are affected by acidic blood pH following SAH.

Method: Twenty-six hybrid rabbits were selected of which 5 were used to analyze interactions between carotid bodies and kidneys, 5 were allocated as the sham group that received injections of 1 cc saline, and 16 of them constituted the SAH group in which 1 cc of autologous arterial blood was injected into the cisterna magna. Deaily pH and blood pressure values of all animals were measured before, during, and after surgery for 2 weeks, and then all animals were decapitated. Carotid bodies and atrophic glomeruli of all animals were determined histopathologically. Only pH values, and number of atrophic glomeruli per mm^3 (n/mm^3) were analyzed statistically.

Results: In the study group severe degeneration of perirenal vagal ganglia, renal artery vasospasm, intrarenal hemorrhage, and renal glomerular degeneration were observed. The mean density of atrophic glomeruli in control, sham, and study groups were estimated as 13±37/mm^3, 24±5/mm^3, and 67±11/mm^3, respectively which differed statistically significantly between control, and sham ($p<0.005$), sham and study ($p<0.0005$), control and study ($p<0.00001$) groups.

Conclusion: The study showed that acidic blood results in degeneration of the epithelial cells and causes severe vasospasm in renal arteries and glomerular atrophy following SAH, which has not previously been described.

Keywords: Subarachnoid hemorrhage, renal artery injury, acidosis, glomerulus atrophy

ÖZ

Amaç: Subaraknoid kanamanın (SAH) komplikasyonlarından biri, karotis cisimcik ve glossofaringeal sinir ağlarının bozulmasına bağlı olarak kan ve beyin omurilik sıvısında gelişen asidozdur. Bu çalışmanın amacı, SAH sonrası asidik kan pH'ının renal arterler ve glomerüller üzerindeki etkisini araştırmaktır.

Yöntem: Çalışmada 26 melez tavşan kullanıldı. Beş tavşan karotis cisimcik ve böbrek ağı analizleri için ayrıldı. Beş tavşan, 1 cc serum fizyolojik uygulanarak SHAM grubuna dahil edildi. On altı tavşana ise sisterna magnaya 1 cc otolog arteriyel kan enjekte edilerek SAH modeli oluşturuldu. Tüm hayvanların pH ve kan basıncı değerleri, ameliyat öncesinde, ameliyat sırasında ve sonrasında 2 hafta boyunca günlük olarak kaydedildi. Çalışma sonunda tüm hayvanlar dekapite edilerek karotis cisimcikleri ve böbrek dokuları histopatolojik olarak incelendi. pH değerleri ve atrofik glomerül sayıları (n/mm^3) istatistiksel analiz edildi.

Bulgular: Çalışma grubunda perirenal vagal ganglion dejenerasyonu, renal arter vazospazmı, intrarenal hemoraji ve glomerüler dejenerasyon saptandı. Kontrol, SHAM ve SAH gruplarında ortalama atrofik glomerül yoğunluğu sırasıyla 13±3, 24±5 ve 67±11 n/mm^3 olarak hesaplandı. Atrofik glomerül sayısı arasındaki ilişki gruplar istatistiksel olarak anlamlı bulundu ($p<0.005$ kontrol/SHAM; $p<0.0005$ SHAM/SAH; $p<0.00001$ kontrol/SAH).

Sonuç: Bu çalışma, SAH sonrası gelişen kan asidozunun epitel hücre dejenerasyonuna yol açtığını ve daha önce tanımlanmamış bir şekilde renal arterlerde artmış vazospazm ile glomerüler atrofiye neden olduğunu ortaya koymaktadır.

Anahtar kelimeler: Subaraknoid kanama, renal arter yaralanması, asidoz, glomerulus atrofisi

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INTRODUCTION

The kidneys are innervated by a complex network that includes thoracolumbar somatosensory fibers, the abdominal sympathetic chain, and vagal nerves. These neural pathways play a crucial role in regulating renal blood flow, blood pressure, and electrolyte balance[1]. Subarachnoid hemorrhage (SAH) is a life-threatening condition that not only affects the central nervous system but also has severe systemic adverse outcomes, including acute kidney injury (AKI)[2]. SAH increases the incidence of AKI and worsens survival outcomes, emphasizing the need to better understand the underlying mechanisms of renal dysfunction in this context[3,4]. While electrolyte imbalances, such as hypokalemia, are known to contribute to SAH-induced renal pathology[5,6], the impact of autonomic nervous system (ANS) dysregulation on renal function is still incompletely understood. The sympathetic and parasympathetic nervous systems exert opposing effects on renal function. Excessive sympathetic activation secondary to vagal nerve dysfunction can lead to renal artery spasms, increased renal blood pressure, and ultimately, renal hypertension[7-9]. Experimental models have demonstrated that vagal nerve lesions, such as cervical vagotomy, exacerbate renal sympathetic activity, triggering renal hypertension[10-12]. Furthermore, ischemia-reperfusion injury, a common complication of SAH, has been linked to sympathovagal imbalances, which further elevate renal arterial pressure and worsen kidney damage[13]. These findings highlight the critical role of dysregulation of ANS in the pathogenesis of SAH-associated renal complications.Although the effects of SAH on kidney function have been well documented, the mechanisms through which acidotic blood contributes to renal injury remain insufficiently explored. Acidosis is a common consequence of SAH and has been implicated in systemic hypoxia, carotid chemoreceptor activation, and increased sympathetic drive, all of which contribute to the development, and exacerbation of renal hypertension. However, direct effects of acidic blood on renal epithelial cells and glomerular anatomy have yet to be fully elucidated. Previous studies have primarily focused on sympathetic overactivation and electrolyte disturbances as key contributors to SAH-induced renal dysfunction, often overlooking the potential role of acidosis played in the pathogenesis renal pathologies. This study aims to bridge this gap by investigating the mechanisms through which acidic blood contributes to the development of renal epithelial cell degeneration and glomerular atrophy following SAH. While existing research has predominantly attributed SAH-related renal damage to excessive sympathetic activation and electrolyte imbalances, the specific effects of acidosis on renal structure and function remain largely undefined. By building on current knowledge of SAH-associated renal complications, this study seeks to provide novel insights into the pathophysiology of SAH-induced kidney injury and identify potential therapeutic targets for mitigating renal damage.

MATERIALS and METHODS

The animals used in this experimental study were owned and managed by our institution. Ethical approval for the study was obtained from the Institutional Review Board of Animal Experiments Local Ethics Committee of Atatürk University (approval number: E-2200369130, dated: 29.06.2022). The study was conducted on 26 rabbits; five of which were used to analyze the normal structures of the carotid bodies and kidneys. Twenty-one rabbits consisted of both sham surgery group (n=5) that received an injection of 0.5 cc saline solution, and study (n=16) group received an injection of 0.5 cc of autologous-auricular arterial blood into cisterna magna following surgical preparation of suboccipital-cervival region under general anesthesia. SHAM and study group animals received these injections once a day for three-day period. Before surgery, the SHAM and study group animals were anesthetized with an injection of 1 mg/kg acepromazine, 25 mg/kg ketamine hydrochloride, and 15 mg/kg lidocaine hydrochloride combination. After a followed-up of two weeks, all animals were sacrificed under general anesthesia before surgery. Their carotid bodies and kidneys were removed and fixed in a 10% formalin solution for one week. Then, these samples were embedded in paraffin blocks, and 20 consecutive 5 µm sections were taken from these paraffin blocks for the stereological analysis. Specimens were stained with hematoxylin and eosin method. Histopathologically, condensed cytoplasm, shrinking nuclei, angulated cells, and pericytoplasmic halo formation around cytoplasm due to cytoplasmic regression were accepted as epithelial degeneration criteria for carotid body neurons and kidneys. The physical dissector method was used to evaluate the number of atrophic glomeruli by refereces to glomerular cells like our previous studies. Stereological methods were used to estimate the number of atrophic glomeruli; and the corelation between the pH values and the number of atrophic glomeruli was analyzed using IBM SPSS 20.0 (SPSS Inc., Chicago, Illinois, USA) software. Shapiro-Wilk tests were used to evaluate variabilities in distribution for normalizing descriptive data expression of mean ± standard deviation. Variabilities in distributed

data were analyzed by Analysis of Variance test. Kruskal-Wallis test was also used when the results were considered statistically significant at $p<0.05$.

RESULTS

Two out of 16 rabbits died within the second week, likely due to cardiorespiratory disorders, and replaced by additional new animals for restudy. The mean blood pH values were: 7.346±0.032 in the control (n=5), 7.315±0.062 in the sham (n=5), and 7.20±0.014 in the study groups (n=16) (Figure 1). Circulatory and respiratory changes were detected in the study groups. Systolic blood pressure was measured as 99±7/mmHg in normotensive, 106±8/mmHg in sham, and 117±13/mmHg in the study rabbits.

The mean density of atrophic glomeruli of the control, sham, and study groups were estimated as 13±3/mm^3, 24±5/mm^3, and 67±11/mm^3, respectively (Figure 2). The levels of significance noted in statistical analyses performed between pH values and number of atrophic glomeruli were: $p<0.005$ in control vs sham; $p<0.0005$ in sham vs study; $p<0.00001$ in control vs study groups.

Number of degenerated carotid body neurons and pH changes were comparable to those found in our previous relevant studies[13,14].

Histopathological Results

Hilar renal artery vasospasm, vagal nerve axonal injury with degeneration of perirenal ganglia, atrophic glomeruli, degenerated perirenal ganglia, inflamed degenerated vagal plexus around renal artery and kidney, stenotic renal artery, degenerated perirenal ganglia, intrarenal artery covered with lymphoid tissue, slightly edematous glomeruli, and atrophic glomeruli, hemorrhagic parenchymal edema with ghost degenerated glomeruli and atrophic glomeruli were detected in SAH created rabbits.

Figure 3 shows the binuclear neurons of carotid bodies in control (A), moderately deformed neurons in sham (B), and severely deformed neurons in study (C) groups. Figure 4 shows cross-sectional view of the renal artery on computed tomography (RA) in a normal rabbit (A). Moreover, histopathological appearances of control (B), moderately stenotic renal artery in a sham (C), and severely stenotic renal artery in a study animal (D) are shown in Figure 4. The method of estimating number of glomeruli is demonstrated in Figure 5: In order to predict the number of glomeruli stereologically, the cross-sectional region (A) of the kidney was taken into consideration, n pairs of physical dissectors designed in a 3-dimensional form consisting of consecutive sections taken at 100-micron intervals in the glomeruli thickness and the method for estimating the number of glomeruli (G) in two consecutive pairs at 100 microns apart were used. Figure 6 shows normal glomerulus in the control (A), moderately deformed glomerulus in the sham (B), and severely deformed glomerulus in the study (C) groups.

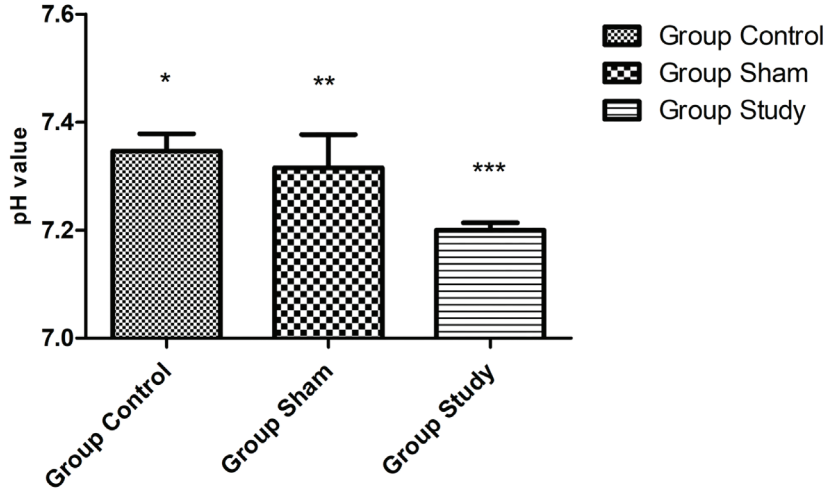

Figure 1. pH Value of the groups. *p<0.005 in control/SHAM; **p<0.0005 in SHAM/study; ***p<0.00001 in control/study
SHAM: Sham-operated group

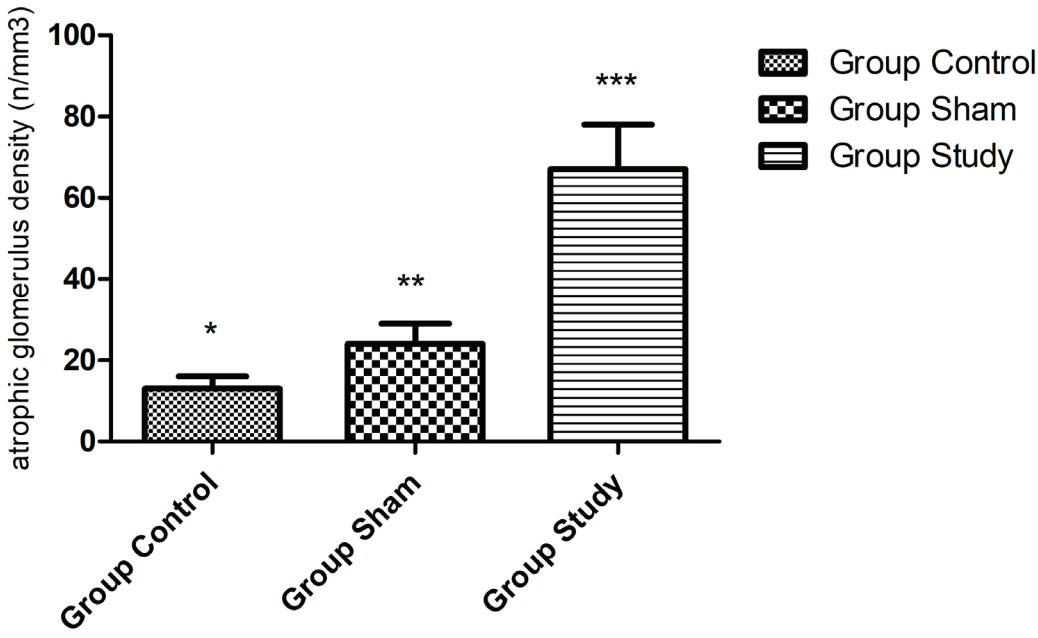

Figure 2. The mean atrophic glomerulus density (n/mm^3) of the groups. *p<0.005 in control/SHAM; **p<0.0005 in SHAM/study; ***p<0.00001 in control/study

SHAM: Sham-operated group

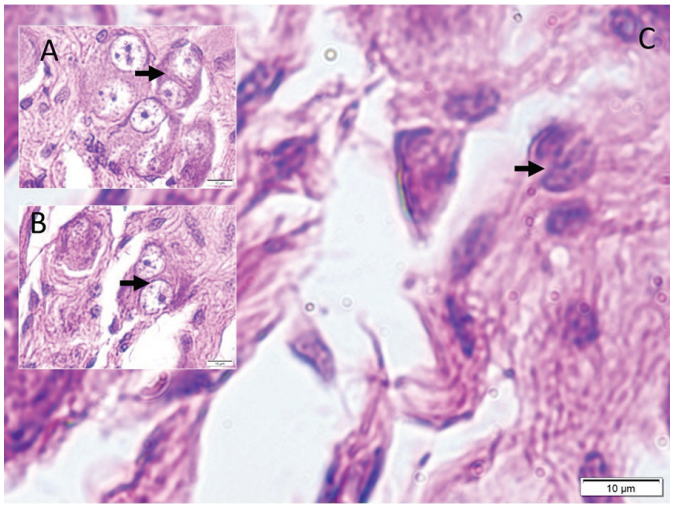

Figure 3. Carotid body's binuclear neurons in control (A), moderately deformed neurons in SHAM (B) and severely deformed neurons in study (C) groups (arrow-LM, HE, x100/A,B,C)

SHAM: Sham-operated group, LM: Light microscopy, HE: Hematoxylin and eosin staining

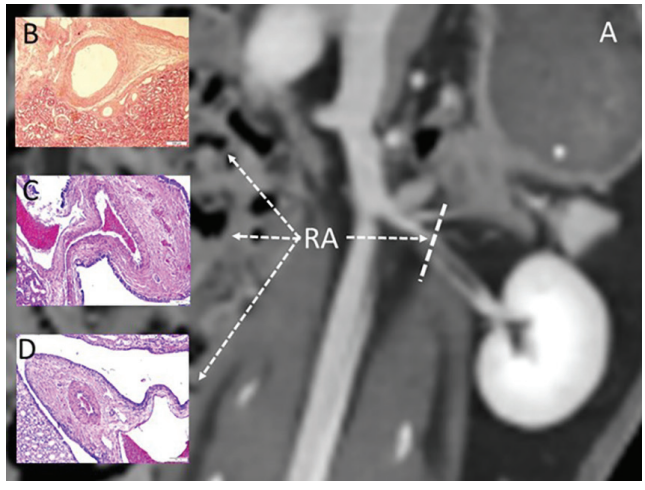

Figure 4. Tomographycal appearances of a renal artery with the section level (RA) in a normal rabbit (A). And histopatholgical appearances of a control (B), moderately constructed renal artery in a SHAM (C) and severely constructed renal artery in a study animal (D) (LM, HE, x10/A, B, C)

RA: Renal artery, SHAM: Sham-operated group, LM: Light microscopy, HE: Hematoxylin and eosin staining

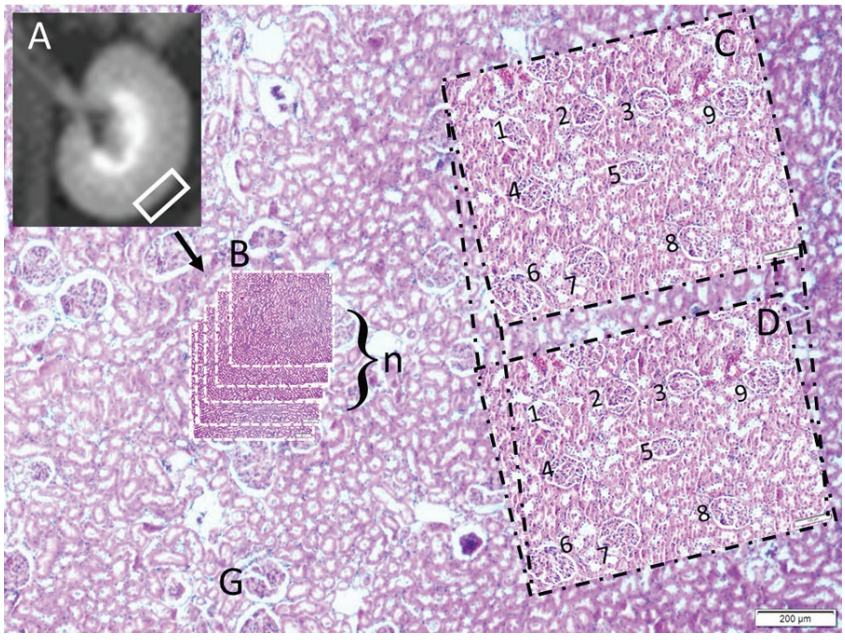

Figure 5. Glomerulus numbers estimation method is seen (LM, HE, x4). In order to predict the glomerulus number stereologically, the cross-sectional region (A) taken from the kidney, a series of n consecutive 1-mm sections (B) were obtained from this section, n pairs of physical dissectors designed in 3-dimensional form consisting of consecutive sections taken at 100 micron intervals in the glomeruli thickness and the method for estimating the glomeruli (G) number in two consecutive pairs 100 microns apart are followed. Sections C and D are consecutive sections. If a glomerulus present in section C is not found in section D, it is considered a disappearing glomerulus pair and included in the count. If no corresponding glomerulus is identified, it is excluded from the analysis

LM: Light microscopy, HE: Hematoxylin and eosin staining

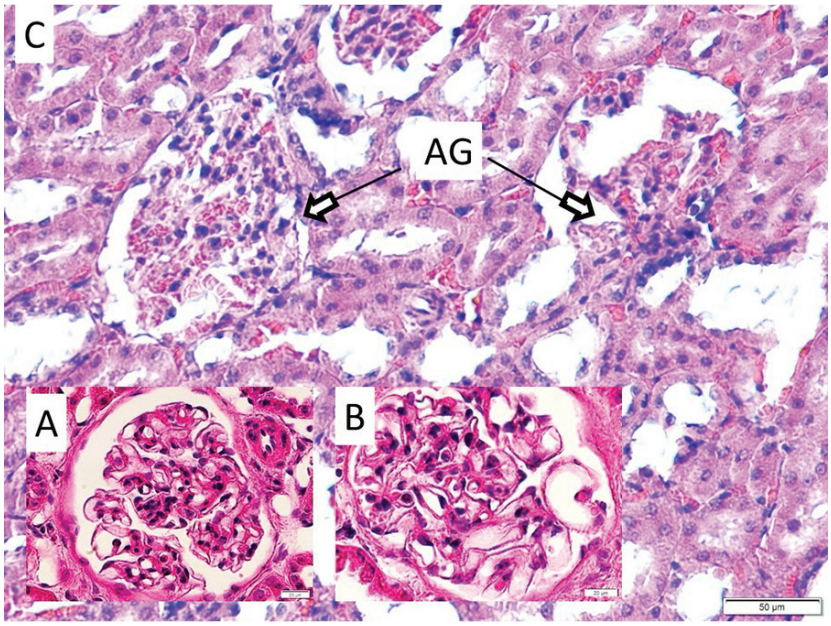

Figure 6. Normal glomeruls in control (A), moderately deformed glomerulus in SHAM (B) and and severely deformed glomerulus study (C) group (LM, HE, x40/ B, C, D)

SHAM: Sham-operated group, LM: Light microscopy, HE: Hematoxylin and eosin staining

DISCUSSION

SAH is a neurovascular emergency that can lead to severe complications affecting renal function. This study investigates the underlying mechanisms of histopathological changes in the kidneys following SAH, with a particular focus on the role of ANS dysfunction in renal impairment and hypertension. The findings provide valuable insights into the pathophysiology of renal complications following SAH, contributing to a deeper understanding of this complex interaction.

Renal Autonomic Innervation and Its Relationship with SAH

The kidneys receive innervation from somatosensory, sympathetic, and vagal nerves[15]. The sympathetic nervous system plays a crucial role in regulating renal function and arterial blood pressure, whereas vagal nerves exert antihypertensive and homeostatic effects via parasympathetic activity[16,17] In conditions such as SAH, vagal ischemia or dysfunction may be a key factor in the pathogenesis of neurogenic renal hypertension[18].

Parasympathetic preganglionic neurons in the renal hilus and around the suprarenal glands modulate parasympathetic functions[19]. Vagal efferent fibers are distributed among microganglia, including the periarterial plexuses surrounding renal arteries[7]. Vagal afferents contribute to regulation of blood volume, homeostasis and can modulate activity of the renal nerve following SAH[20]. Studies have shown that interventions such as bilateral vagotomy[21], vagal blockage[22], vagal efferent dysfunction[23], an increase in hypertensive molecules in the solitary nucleus-vagal ganglion[24], and metabolic conditions like diabetes[25] can all lead to heightened renal sympathetic activity and renal hypertension[26]. These findings underscore the critical role of sympathovagal balance in maintaining renal function.

Chronic Kidney Disease (CKD) and Sympathovagal Balance

CKD is associated with increased central sympathetic activity and reduced cardiac vagal tone[9]. Metabolic disorders such as diabetes may exacerbate this process due to an impaired anti-inflammatory role of the vagus nerve[8]. Acute hypothermia has been suggested as a potential approach to suppress renal sympathetic nerve activity[27]. Prolonged renal ischemia has also been linked to both vagal and sympathetic afferent activation during reperfusion[28]. Experimental models, including cervical vagotomy, disruption of vagal impulses, and increased renal sympathetic activity in vagotomized rats further support the role of ANS dysfunction in renal hypertension[10-12]. These observations highlight the significance of ANS imbalance in the pathogenesis of CKD.

Renal Innervation and Vagotomy

Renal sympathetic neurons increase renal blood flow in hypotensive subjects[29]. Since baroreceptors and chemoreceptors in the carotid sinus modulate blood pH and blood pressure[30], SAH-induced ischemia of glossopharyngeal nerve-carotid body chemoreceptor network can lead to development of dangerous acidosis and hypertension[14] and renal insufficiency[31]. As a result, excess renal sodium retention leads to nephrotic syndrome-like disorders[32]. Decreased vagal inputs related to baroreceptor reflex[33] disorders lead to renal vascular hypertension[34]. Systemic hypoxia markedly potentiates the renal constriction caused by the baroreflex, caused by the carotid chemoreceptor afferent input[35].

Subarachnoid Hemorrhage and Renal Disease

SAH can impair renal function, leading to serious complications such as AKI and renal failure. Moreover, kidney disease is a recognized risk factor for stroke, and stroke itself may exacerbate renal dysfunction[36,37]. In this study, post-SAH metabolic acidosis was found to contribute to vascular and structural damage in the kidneys, including renal artery vasospasm and glomerular atrophy. Notably, our findings suggest a previously undescribed mechanism in the literature, in which SAH-induced acidosis directly contributes to renal epithelial cell degeneration and vascular dysfunction.

SAH, Acidosis, and Multiorgan Dysfunction

The effects of SAH-induced acidosis are not confined to the kidneys but extend to other organ systems, potentially leading to widespread tissue damage. Conditions such as degeneration of the chemoreceptor network, consisting of the glossopharyngeal nerve and carotid body (GPN-CB) carotid body-glossopharyngeal[14] and cervical trauma[13] can result in severe acidosis in both blood and cerebrospinal fluid. This process has been implicated in pathological changes such as "burned-out" spinal cord lesions[38], degeneration of choroid plexus[39] and intestinal injury[40]. These findings suggest that post-SAH acidosis may be a critical driver of multiorgan failure, underscoring the need for further investigation into its systemic effects.

Study Limitations

One of the primary limitations of this study is the absence of biochemical data, which could have provided further insights into the observed findings. Future research incorporating biochemical analyses or novel biomarkers will be essential to strengthen and validate the results of our research study. Another limitation of this study is the relatively small sample size. We, the authors, acknowledge that sample size is a critical component of any study, as an insufficient number of subjects may lead to the oversight of significant differences within the population. However, increasing the number of experimental animals beyond what is necessary could result in unnecessary sacrifice of greater number of animals. Based on our experiences derived from our previous eresearch studies, this study was therefore conducted using twenty-six adult rabbits, ensuring a balance between scientific rigor and ethical considerations.

CONCLUSION

This study sheds light on the mechanisms underlying renal pathology following SAH, particularly the disruption of sympathovagal balance and the impact of acidosis on renal dysfunction. Moving forward, recognizing acidosis as a key contributor to multiorgan failure may help to initiate the development of targeted therapeutic strategies. Additionally, our findings offer new perspectives for preventing and managing renal complications following SAH.

Ethics

Ethics Committee Approval: Ethical approval for the study was obtained from the Institutional Review Board of Animal Experiments Local Ethics Committee of Atatürk University (approval number: E-2200369130, dated: 29.06.2022).

Informed Consent: Not applicable.

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Footnotes

Author Contributions

Surgical and Medical Practices: B.F., M.D.A, Concept: B.F., M.D.A, Design: B.F., M.D.A, Data Collection or Processing: B.F., M.D.A, Analysis or Interpretation: B.F., M.D.A, Literature Search: B.F., M.D.A, Writing: B.F., M.D.A.

Conflict of Interest: The authors have no conflict of interest to declare.

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REFERENCES

1. Kepoglu U, Kanat A, Dumlu Aydin M, Akca N, Kazdal H, Zeynal M, et al. New histopathologic evidence for the parasympathetic innervation of the kidney and the mechanism of hypertension following subarachnoid hemorrhage. J Craniofac Surg. 2020;31(3):865-70. doi: 10.1097/SCS.0000000000006041
2. Kieninger M, Unbekannt D, Schneiker A, Sinner B, Bele S, Prasser C. Effect of hydroxyethyl starch solution on incidence of acute kidney injury in patients suffering from cerebral vasospasm following aneurysmal subarachnoid hemorrhage. Neurocrit Care. 2017;26(1):34-40. doi: 10.1007/s12028-016-0265-7
3. Tujjar O, Belloni I, Hougardy JM, Scolletta S, Vincent JL, Creteur J, et al. Acute kidney injury after subarachnoid hemorrhage. J Neurosurg Anesthesiol. 2017;29(2):140-9. doi:10.1097/ANA.0000000000000270
4. King AE, Szarlej DK, Rincon F. Dabigatran-associated intracranial hemorrhage: literature review and institutional experience. Neurohospitalist. 2015;5(4):234-44. doi: 10.1177/1941874415569069
5. Kubo Y, Ogasawara K, Kakino S, Kashimura H, Yoshida K, Ogawa A. Cerebrospinal fluid adrenomedullin concentration correlates with hyponatremia and delayed ischemic neurological deficits after subarachnoid hemorrhage. Cerebrovasc Dis. 2008;25(1-2):164-9. doi: 10.1159/000113734
6. Ybanez N, Agrawal V, Tranmer BI, Gennari FJ. Severe hypokalemia in a patient with subarachnoid hemorrhage. Am J Kidney Dis. 2014;63(3):530-5. doi: 10.1053/j.ajkd.2013.07.005
7. Berthoud HR, Powley TL. Characterization of vagal innervation to the rat celiac, suprarenal and mesenteric ganglia. J Auton Nerv Syst. 1993;42(2):153-69. doi: 10.1016/0165-1838(93)90046-w
8. Caligiorne SM, Silva AQ, Fontes MA, Silva JR, Baltatu O, Bader M, et al. Baroreflex control of heart rate and renal sympathetic nerve activity in rats with low brain angiotensinogen. Neuropeptides. 2008;42(2):159-68. doi:10.1016/j.npep.2007.12.003
9. How JM, Pumpa TJ, Sartor DM. The circulatory and renal sympathoinhibitory effects of gastric leptin are altered by a high fat diet and obesity. Auton Neurosci. 2013;177(2):95-100. doi: 10.1016/j.autneu.2013.02.018
10. Nakayama T, Suzuki A, Ito R. The articulo-cardiac sympathetic reflex in spinalized, anesthetized rats. J Physiol Sci. 2006;56(2):137-43. doi: 10.2170/physiolsci.RP000705
11. Hiatt N, Hiatt JR. Vagal modulation of the insulin secretory response to KCl loading in nephrectomized dogs. Horm Metab Res. 1995;27(2):67-9. doi: 10.1055/s-2007-979910
12. DiBona GF, Sawin LL. Reflex regulation of renal nerve activity in cardiac failure. Am J Physiol. 1994;266(1 Pt 2):R27-39. doi: 10.1152/ajpregu.1994.266.1.R27
13. Çakır T, Kayacı S, Aydın MD, Özöner B, Çalık İ, Altınkaynak K. A new neuropathologic mechanism of blood ph irregularities after neck trauma: importance of carotid body-glossopharyngeal nerve network degeneration. World Neurosurg. 2019;125:e972-7. doi: 10.1016/j.wneu.2019.01.218
14. Ozmen S, Altinkaynak K, Aydin MD, Ahiskalioglu A, Demirci T, Özlü C, et al. Toward understanding the causes of blood

pH irregularities and the roles of newly described binuclear neurons of carotid bodies on blood pH regulation during subarachnoid hemorrhage: Experimental study. Neuropathology. 2019;39(4):259-67. doi: 10.1111/neup.12552

15. Onen MR, Yilmaz I, Ramazanoglu L, Tanrıverdi O, Aydin MD, Kanat A, et al. rational roots of sympathetic overactivity by neurogenic pulmonary edema modeling arising from sympathyco-vagal imbalance in subarachnoid hemorrhage: an experimental study. World Neurosurg. 2016;92:463-70. doi: 10.1016/j.wneu.2016.04.067
16. Weaver LC, Fry HK, Meckler RL. Differential renal and splenic nerve responses to vagal and spinal afferent inputs. Am J Physiol. 1984;246(1 Pt 2):R78-87. doi: 10.1152/ajpregu.1984.246.1.R78
17. Thames MD, Ballon BJ. Occlusive summation of carotid and aortic baroreflexes in control of renal nerve activity. Am J Physiol. 1984;246(6 Pt 2):H851-7. doi: 10.1152/ajpheart.1984.246.6.H851
18. Araz O, Aydin MD, Gundogdu B, Altas E, Cakir M, Calikoglu C, et al. Preventive role of hilar parasympathetic ganglia on pulmonary artery vasospasm in subarachnoid hemorrhage: an experimental study. Turk Neurosurg. 2015;25(4):519-25. doi: 10.5137/1019-5149.JTN.8754-13.3
19. Berthoud HR, Powley TL. Interaction between parasympathetic and sympathetic nerves in prevertebral ganglia: morphological evidence for vagal efferent innervation of ganglion cells in the rat. Microsc Res Tech. 1996;35(1):80-6. doi: 10.1002/(SICI)1097-0029(19960901)35:1<80:AID-JEMT7>3.0.CO;2-W
20. Veelken R, Leonard M, Stetter A, Hilgers KF, Mann JF, Reeh PW, et al. Pulmonary serotonin 5-HT3-sensitive afferent fibers modulate renal sympathetic nerve activity in rats. Am J Physiol. 1997;272(2 Pt 2):H979-86. doi: 10.1152/ajpheart.1997.272.2.H979
21. Morgunov N, Baines AD. Vagal afferent activity and renal nerve release of dopamine. Can J Physiol Pharmacol. 1985;63(6):636-41. doi: 10.1139/y85-106
22. Imaizumi T, Brunk SD, Gupta BN, Thames MD. Central effect of intravenous phenylephrine on baroreflex control of renal nerves. Hypertension. 1984;6(6 Pt 1):906-14. doi: 10.1161/01.hyp.6.6.906
23. Salman IM, Phillips JK, Ameer OZ, Hildreth CM. Abnormal central control underlies impaired baroreflex control of heart rate and sympathetic nerve activity in female Lewis polycystic kidney rats. J Hypertens. 2015;33(7):1418-28. doi: 10.1097/HJH.0000000000000572
24. Blanch GT, Freiria-Oliveira AH, Speretta GF, Carrera EJ, Li H, Speth RC, et al. Increased expression of angiotensin II type 2 receptors in the solitary-vagal complex blunts renovascular hypertension. Hypertension. 2014;64(4):777-83. doi: 10.1161/HYPERTENSIONAHA.114.03188
25. Millar PJ, Floras JS. Statins and the autonomic nervous system. Clin Sci (Lond). 2014;126(6):401-15. doi: 10.1042/CS20130332
26. Zucker IH, Panzenbeck MJ, Barker S, Tan W, Hajdu MA. PGI2 attenuates baroreflex control of renal nerve activity by a vagal mechanism. Am J Physiol. 1988;254(3 Pt 2):R424-30. doi: 10.1152/ajpregu.1988.254.3.R424
27. Sabharwal R, Coote JH, Johns EJ, Egginton S. Effect of hypothermia on baroreflex control of heart rate and renal sympathetic nerve activity in anaesthetized rats. J Physiol. 2004;557(Pt 1):247-59. doi: 10.1113/jphysiol.2003.059444
28. Ustinova EE, Schultz HD. Renal sympathetic nerve activity during cardiac ischemia and reperfusion in rats. Am J Physiol. 1996;271(4 Pt 2):R1033-40. doi: 10.1152/ajpregu.1996.271.4.R1033
29. Lupa K, Wójcik G, Kruk A, Tarnecki R, Niechaj A. Pattern of ongoing discharge of single renal sympathetic neurons in the rabbit. Arch Physiol Biochem. 1997;105(5):456-66. doi: 10.1076/apab.105.5.456.3297
30. Ohta H, Talman WT. Baroreceptors in the carotid sinus contribute to arterial baroreceptor reflexes in normotensive rats. Clin Exp Pharmacol Physiol Suppl. 1995;22(1):S62-3. doi: 10.1111/j.1440-1681.1995.tb02971.x
31. Soyalp C, Kocak MN, Ahiskalioglu A, Aksoy M, Atalay C, Aydin MD, et al. New determinants for casual peripheral mechanism of neurogenic lung edema in subarachnoid hemorrhage due to ischemic degeneration of vagal nerve, kidney and lung circuitry. Experimental study1. Acta Cir Bras. 2019;34(3):e201900303. doi: 10.1590/s0102-865020190030000003
32. Hinojosa-Laborde C, Jones SY, DiBona GF. Hemodynamics and baroreflex function in rats with nephrotic syndrome. Am J Physiol. 1994;267(4 Pt 2):R953-64. doi: 10.1152/ajpregu.1994.267.4.R953
33. Dong XH, Pan JY, Zhan CY. [Different changes in renal sympathetic nerve activity and adrenal sympathetic nerve activity produced by hemorrhage]. Sheng Li Xue Bao. 1992;44(5):478-86. https://pubmed.ncbi.nlm.nih.gov/1293764/
34. Mitani Y, Hosomi H, Tateishi J, Iwasaki T. Flow-dependence of vasodilatory response in renal vascular bed to hemorrhage in dogs. Biomed Biochim Acta. 1987;46(6):487-98. https://pubmed.ncbi.nlm.nih.gov/3675566/
35. Pelletier CL, Shepherd JT. Effect of hypoxia on vascular responses to the carotid baroreflex. Am J Physiol. 1975;228(1):331-6. doi: 10.1152/ajplegacy.1975.228.1.331
36. Kudo K, Konta T, Degawa N, Saito S, Kondo R, Kayama T, et al. Relationship between kidney damage and stroke types in Japanese patients. Clin Exp Nephrol. 2012;16(4):564-9. doi:10.1007/s10157-012-0594-6
37. Ovbiagele B. Chronic kidney disease and risk of death during hospitalization for stroke. J Neurol Sci. 2011;301(1-2):46-50. doi: 10.1016/j.jns.2010.11.002
38. Kanat A, Aydin MD, Bayram E, Kazdal H, Aydin N, Omeroglu M, et al. A New Determinant of Poor Outcome After Spontaneous Subarachnoid Hemorrhage: Blood pH and the Disruption of Glossopharyngeal Nerve-Carotid Body Network: First Experimental Study. World Neurosurg. 2017;104:330-8. doi: 10.1016/j.wneu.2017.04.105
39. Demirci T, Aydin MD, Caglar O, Aydin N, Ozmen S, Nalci KA, et al. First definition of burned choroid plexus in acidic cerebrospinal fluid-filled brain ventricles during subarachnoid hemorrhage: Experimental study. Neuropathology. 2020;40(3):251-60. doi: 10.1111/neup.12645
40. Caglar O, Karadeniz E, Firinci B, Aydin ME, Ceylan O, Aydin MD, et al. Destructive effects of acidic blood on the intestines: experimental study. Eurasian J Med. 2021;53(1):22-7. doi: 10.5152/eurasianjmed.2021.20035