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Review Article

Research progress on therapeutic effect and mechanism of hydrocortisone on sepsis

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ABSTRACT

Sepsis has remained a high mortality rate worldwide. Endothelial cell dysfunction is closely associated with the development of sepsis. Hydrocortisone has potent immunological and antitoxic effects, and thus it is frequently used in the treatment of septic shock. However, it can also cause respiratory damage and death by anaphylaxis. In recent years, the combination of hydrocortisone and other drugs such as vitamin C and thiamine has achieved promising outcomes in refractory septic shock. The present review focuses on the therapeutic effects of hydrocortisone in sepsis and summarizes the mechanisms by which hydrocortisone acted on the vascular endothelial cells. We highlighted the effect of hydrocortisone on anti-inflammation, anti-apoptosis, improvement of vascular functions, and anti-oxidative stress. We also pointed out that the mechanisms by which the combination therapy with other drugs enhances the effects of hydrocortisone are still unclear and need to be clarified to determine the benefit of the treatment of sepsis.

1. Introduction

Sepsis is a life-threatening organ dysfunction caused by a dysregulated host response to infection [1]. To date, the annual incidence of sepsis remains high worldwide. In 2017, there were approximately 48.9 million cases of sepsis worldwide, and approximately 11 million sepsis-related deaths, accounting for 19.7% of all deaths that year, with more than half of sepsis occurring in children, mainly newborns [2]. Although sepsis-related investigations in developing countries have progressed in recent years, morbidity and mortality rates remain generally higher than in developed countries due to technical limitations. In mainland China, sepsis is diagnosed in approximately 33.6 % of Intensive Care Unit (ICU) patients. The average 30-day mortality rate for sepsis is approximately 29.5 % and the overall mortality rate for septic shock is approximately 37.3 %, higher than in Europe, North America, and Australia [3]. Many sepsis survivors suffer from sequelae that severely reduce their quality of life [4]. The regulatory mechanism of inflammation caused by the infection is not fully understood, which remains the central issue of sepsis.

Septic shock is a subset of sepsis with potentially severe circulatory and cellular/metabolic abnormalities that can significantly increase mortality [1]. During septic shock, the host's immune system triggers an inflammatory cascade that damages the vascular endothelium, leading to microvascular damage and capillary leakage. This dysfunctional response can lead to an imbalance between pro- and anti-inflammatory mediators, further promoting the release of cytokines [5].

Hydrocortisone is a short-acting glucocorticoid synthesized by the fascicular zone of the adrenal cortex and is used to treat patients with septic shock. Hydrocortisone (10 mg/h) reduces the level of TNF-α in patients with septic shock [6]. Hydrocortisone

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(50 mg/6h) can consistently improve microcirculation and reduce mortality in patients with septic shock [7]. However, it has also been reported that the use of hydrocortisone alone in the treatment of septic shock may lead to aggravated symptoms [8]. The combination of hydrocortisone with other drugs such as hydrocortisone, vitamin C and thiamine (HAT) may eliminate the adverse effects of hydrocortisone, which may be related to the activation of the hypothalamic-pituitary-adrenal axis (HPA axis) [9].

The addition of mineralocorticoids to glucocorticoids may be beneficial in reducing mortality and improving hemodynamics, but the probability of hyperglycemia and viral infection was higher [10]. In the sepsis model induced by cecal ligation and puncture, HAT treatment reduced renal oxidative stress and injury in the P-Die group [11]. However, it has also been reported that intravenous injection of HAT did not improve the 90-day mortality compared to hydrocortisone alone [12].

Although hydrocortisone has been widely used to treat septic shock with other drugs, there are still conflicting viewpoints on the efficacy of combination therapy. This paper reviews the research progress on the therapeutic effect and mechanism of hydrocortisone (Table 1) in the treatment of sepsis by searching the papers in PubMed over the past two decades (Figure 1).

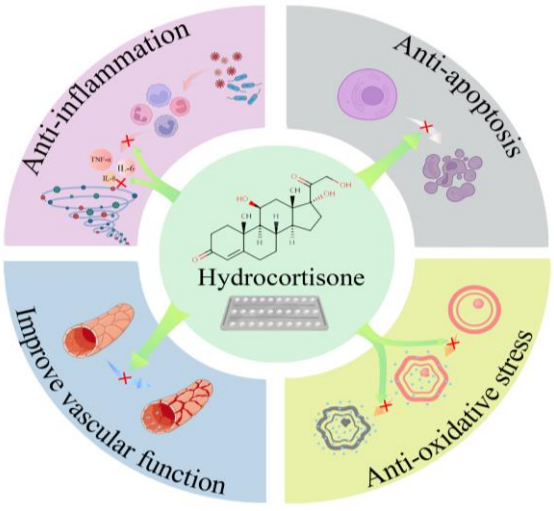

Fig. 1. The effect of hydrocortisone on vascular endothelial cells.

Table 1. Mechanism of hydrocortisone in the treatment of sepsis

Effect	Mechanism	Reference
Anti-inflammation	Inhibit the release of inflammatory cytokines	[10, 13]
	Inhibit lipoxins induced by inflammatory cytokines	[14, 15]
Anti-apoptosis	Inhibit apoptosis induced by TNF-α or LPS	[16]
	Promote apoptosis via bestrophin-3	[17]
Improve vascular function	Inhibit NO via suppressing the iNOS	[18]
	Reduce NO via suppressing the eNOS	[19, 20]
	Increase paracellular tightness	[21, 22]
	Increase/reduce vasoconstriction	[23, 24]
	Prevent the shedding of the glycocalyx	[25]
Anti-oxidative stress	Protects mitochondria from oxidative stress	[5, 26]

2. Anti-inflammation

Hydrocortisone inhibits the levels of eosinophils, phospholipase A, IL-6 and IL-8 in the blood of patients with sepsis, reduces the expression of monocyte human leukocyte antigen-DR (mHLA-DR) in monocytes, and enhances the phagocytosis by monocytes [13]. Also, hydrocortisone can inhibit the release of IL-6 induced by lipopolysaccharide (LPS) in human dermal microvascular endothelial cells (HDMEC) [27]. Hydrocortisone (100 μg/ml) can inhibit levels of IL-8 and CXCL1 induced by Adenosine-5'-triphosphate γS (ATPγS)[28].

Hydrocortisone inhibited the cyclooxygenase (COX) and production of lipoxins such as DiHOMEs and TriHOMEs induced by tumour necrosis factor-α (TNF-α) and IL-1β in EA.hy.926 vascular endothelial cells [14]. Hydrocortisone (300 ng/mL) inhibited the expression of ICAM-1 and VCAM-1 induced by interferon-γ (IFN-γ, 200 U/ml), IL-1β (1 ng/ml) or TNF-α (1 ng/ml) for 24 h in human umbilical vein endothelial cell (HUVECs) [15].

The combination of hydrocortisone and fludrocortisone attenuated inflammation in various organs by inhibiting nuclear factor-κB (NF-κB) activation and reducing the expression of TNF-α in endothelial aldosterone receptors [10]. The combination of vitamin C and hydrocortisone reduced the activation of NF-κB, enhanced the function of

adrenergic receptors and reduced the release of proinflammatory mediators [5].

Thus, hydrocortisone inhibits the recruitment of leukocytes, the production of inflammatory cytokines, the lipoxins induced by inflammatory cytokines. The combination therapy of hydrocortisone with vitamin C/fludrocortisone inhibits NF-κB activation, and thus reducing the release of proinflammatory mediators.

3. Anti-apoptosis

Hydrocortisone can inhibit TNF-α- or LPS-induced apoptosis in bovine glomerular endothelial cells [29]. Hydrocortisone inhibits the apoptosis induced by the anti-tumor drug Cytosine arabinoside in bovine pulmonary artery endothelial cells (BPAECs)[16].

However, in human microvascular endothelial cells (HMECs), hydrocortisone can inhibit the expression of bestrophin-3 and promote cell apoptosis, which was weakened by vitamin C via upregulation of vitelliform macular protein 3 [17].

The reported effect of hydrocortisone on apoptosis is inconsistent, but evidence supports that vitamin C could aid in preventing apoptosis.

3. Improve vascular function

3.1. Nitric oxide (NO)

Hydrocortisone can inhibit the LPS-induced overproduction of NO in porcine aortic endothelial cells by suppressing the inducible nitric oxide synthase (iNOS) activity, which may alleviate the hypotension after shock via inhibiting the pathological vasodilatation[18].

Hydrocortisone (1 nM-10 μM) inhibited ATP-induced Ca^{2+} mobilization in bovine coronary artery endothelial cells (BCAECs) in a concentration-dependent manner and reduced NO release via inhibition of endothelial nitric oxide synthase (eNOS) expression [19, 20]. Hydrocortisone (2 mM) could also inhibit the increase of eNOS and the production of NO induced by Estradiol (0.1 nM) for 24 h in HUVECs [30].

Thus, hydrocortisone could inhibit both eNOS and iNOS in endothelial cells, which might cause organ damage.

3.2. Cell junction

Hydrocortisone can increase paracellular tightness via inhibition of MMP-9 and elevation of claudin-5, protecting brain injury [21, 22]. The barrier properties of brain microvascular endothelial cells could be further enhanced by the addition of puromycin [31]. Also, hydrocortisone can increase VE-cadherin and thus reduces vascular permeability in endothelial cells [32].

Hydrocortisone may also maintain vascular permeability via vascular smooth muscle tension [23]. Aldosterone receptors play a critical role in regulating vascular tone. Hydrocortisone alleviates phenylephrine (PE)-induced vasoconstriction via inhibiting aldosterone receptors in septic rats [24].

However, it was demonstrated that low-dose hydrocortisone (3×10(-10) to 3×10(-9) mol/L) aggravates the deleterious effect on vascular permeability and disruption of adherens and tight junctions in HUVECs [33].

3.3. Vascular endothelial glycocalyx

Endothelial glycocalyx maintains the normal structure and function of endothelial cells [34]. In rats after cardiac arrest-cardiopulmonary resuscitation for 8 minutes, the blood-brain barrier was destroyed and the glycocalyx was damaged, which was inhibited by hydrocortisone [21]. Also, hydrocortisone maintains coronary permeability at physiological levels by protecting the endothelial glycocalyx [35].

Moreover, hydrocortisone prevents mast cell activation and release of inflammatory mediators such as histamine during cardiac ischemia-reperfusion injury and may protect vascular endothelial glycocalyx [36]. Hydrocortisone (10 μg/ml) can prevent the shedding of endothelial glycocalyx induced by TNF-α [25]. The level of TNF-α in the plasma of patients with sepsis is negatively correlated with miR-150 [37]. Hydrocortisone may protect endothelial cells by inhibiting TNF-α and increasing miR-150.

4. Anti-oxidative stress

It was suggested a synergistic effect of hydrocortisone and vitamin C in the treatment of sepsis [5, 26]. Vitamin C and HAT scavenge superoxide radicals (O^{2-}) and inhibit the activation of xanthine oxidase and NADPH oxidase. Vitamin C protects mitochondria from oxidative stress, and restores the eNOS activity and improves the eNOS bioavailability. Vitamin C clears peroxynitrite ($ONOO^{-}$), preventing endothelial tight junction loosening [5, 26].

5. Discussion

Hydrocortisone is used in combination with other drugs to prevent septic shock. Fludrocortisone has a direct rather than an adjuvant effect on the vasculature [24]. The combination of HAT and hydrocortisone improvise anti-inflammatory, anti-apoptosis and anti-mitochondrial injury in patients with septic shock. However, the mechanism by which the addition of fludrocortisone or HAT improves the treatment by hydrocortisone and the effectiveness of the combination therapy is challenged. The combination of hydrocortisone and fludrocortisone reduced the mortality of septic shock patients, but hyperglycemia was more common [10]. How to maximize the auxiliary effect of these drugs in septic shock remains unresolved.

During sepsis, the vascular tone was reduced and hemodynamics was changed [38]. Fluid shear stress (10 dyn/cm^2) can activate glucocorticoid receptor (GR) in vascular endothelial cells, make GR translocate into the nucleus and activate the GR transcription signaling pathway [39]. Our previous study also showed that fluid shear stress (15 dyn/cm2) promotes NO release from vascular endothelial cells, which is mediated by glycocalyx [40]. However, long-term high-dose (> 50 mg) use of hydrocortisone can lead to glucocorticoid-induced diabetes mellitus (GI-DM) and glucocorticoid resistance syndrome, resulting in impaired NO production. Attention should be paid to the role of fluid shear stress in sepsis and related signaling pathways such as GR and endothelial glycocalyx.

6. Conclusion

Studies have shown that hydrocortisone functions on an anti-inflammatory for sepsis. Conflicting effects of hydrocortisone in anti-apoptosis and protection of vascular functions were present, which was improved by the combination therapy with other drugs such as vitamin C and thiamine. Oxidative stress was also ameliorated by combination therapy. The adverse effect of combination therapy was also presented. The mechanisms underlying the combination therapy need to be further clarified. An appropriate combination of drugs might be sought to ameliorate the vascular endothelium damage.

Abbreviations

COX: Cyclooxygenase
eNOS: Endothelial Nitric Oxide Synthase
HDMEC: Human Dermal Microvascular Endothelial Cells
HMECs: Human Microvascular Endothelial Cells
HUVECs: Human Umbilical Vein Endothelial Cell
ICU: Intensive Care Unit
iNOS: Inducible Nitric Oxide Synthase
LPS: Lipopolysaccharide
mHLA-DR: Monocyte Human Leukocyte Antigen-DR
NF-κB: Nuclear Factor-κB
TNF-α: Tumour Necrosis Factor-α

Conflict of Interest

The authors declare that they have no conflict of interest.

Consent for publications

All authors have read and approved the final manuscript for publication.

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The authors did not use human or animals in the research.

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Author's contribution

All authors had equal role in study design, work, statistical analysis and manuscript writing.

Reference

1. Singer M, Deutschman CS, Seymour CW, Shankar-Hari M, Annane D, Bauer M, Bellomo R, Bernard GR, Chiche J-D, Coopersmith CM (2016) The third international consensus definitions for sepsis and septic shock (Sepsis-3). Jama 315 (8): 801-810. doi: https://doi.org/10.1001/jama.2016.0287
2. Rudd KE, Johnson SC, Agesa KM, Shackelford KA, Tsoi D, Kievlan DR, Colombara DV, Ikuta KS, Kissoon N, Finfer S (2020) Global, regional, and national sepsis incidence and mortality, 1990–2017: analysis for the Global Burden of Disease Study. The Lancet 395 (10219): 200-211. doi: https://doi.org/10.1016/S0140-6736(19)32989-7
3. Liu Y-C, Yao Y, Yu M-M, Gao Y-L, Qi A-L, Jiang T-Y, Chen Z-S, Shou S-T, Chai Y-F (2022) Frequency and mortality of sepsis and septic shock in China: a systematic review and meta-analysis. BMC Infectious Diseases 22 (1): 1-12. doi: https://doi.org/10.1186/s12879-022-07543-8
4. Annane D, Sharshar T (2015) Cognitive decline after sepsis. The Lancet Respiratory Medicine 3 (1): 61-69. doi: https://doi.org/10.1016/S2213-2600(14)70246-2
5. Marik PE (2018) Hydrocortisone, ascorbic acid and thiamine (HAT therapy) for the treatment of sepsis. Focus on ascorbic acid. Nutrients 10 (11): 1762. doi: https://www.mdpi.com/2072-6643/10/11/1762#
6. Katsenos CS, Antonopoulou AN, Apostolidou EN, Ioakeimidou A, Kalpakou GT, Papanikolaou MN, Pistiki AC, Mpalla MC, Paraschos MD, Patrani MA (2014) Early administration of hydrocortisone replacement after the advent of septic shock: impact on survival and immune response. Critical care medicine 42 (7): 1651-1657. doi: http://doi.org/10.1097/ccm.0000000000000318
7. Büchele GL, Silva E, Ospina-Tascón GA, Vincent J-L, De Backer D (2009) Effects of hydrocortisone on microcirculatory alterations in patients with septic shock. Critical care medicine 37 (4): 1341-1347. doi: https://doi.org/10.1097/ccm.0b013e3181986647
8. Sacha GL, Chen AY, Palm NM, Wang X, Li M, Duggal A (2022) Clinical Utilization of Stress Dose Hydrocortisone in Adult Patients With Septic Shock: A Retrospective Observational Study at a Large Academic Medical Center. Journal of Pharmacy Practice 2022: 1-15. doi: https://doi.org/10.1177/08971900211037589
9. Annane D (2016) The role of ACTH and corticosteroids for sepsis and septic shock: an update. Front Endocrinol (Lausanne) 7: 70. doi: https://doi.org/10.3389/fendo.2016.00070
10. Annane D, Renault A, Brun-Buisson C, Megarbane B, Quenot J-P, Siami S, Cariou A, Forceville X, Schwebel C, Martin C (2018) Hydrocortisone plus fludrocortisone for adults with septic shock. New England Journal of Medicine 378 (9): 809-818. doi: https://doi.org/10.1056/NEJMoa1705716
11. Kim J, Stolarski A, Zhang Q, Wee K, Remick D (2022) hydrocortisone, ascorbic acid, and thiamine therapy decrease renal oxidative stress and acute kidney injury in murine sepsis. Shock: Injury, Inflammation, and Sepsis: Laboratory and Clinical Approaches 58 (5): 426-433. doi: https://doi.org/10.1097/SHK.0000000000001995
12. Lyu Q-Q, Zheng R-Q, Chen Q-H, Yu J-Q, Shao J, Gu X-H (2022) Early administration of hydrocortisone, vitamin C, and thiamine in adult patients with septic shock: a randomized controlled clinical trial. Critical Care 26 (1): 295. doi:

https://doi.org/10.1186/s13054-022-04175-x
13. Heming N, Sivanandamoorthy S, Meng P, Bounab R, Annane D (2018) Immune effects of corticosteroids in sepsis. Frontiers in Immunology 9: 1736. doi: https://doi.org/10.3389/fimmu.2018.01736
14. Motta A, Strassburg K, Oranje P, Vreeken R, Jacobs D (2019) Oxylipin profiling in endothelial cells in vitro–Effects of DHA and hydrocortisone upon an inflammatory challenge. Prostaglandins & Other Lipid Mediators 144: 106352. doi: https://doi.org/10.1016/j.prostaglandins.2019.106352
15. Ihm CG, Hong SP, Park JK, Lee TW, Cho BS, Yang MH, Kim MJ (1996) Effects of mixed leukocyte reaction, hydrocortisone and cyclosporine on expression of leukocyte adhesion molecules by endothelial and mesangial cells. Journal of Korean Medical Science 11 (6): 495-500. doi: https://doi.org/10.3346/jkms.1996.11.6.495
16. Moore IM, Merkle CJ, Miketova P, Salyer RK, Torres BJ, Schaeffer Jr RC, Montgomery DW (2006) Cytosine arabinoside induces programmed endothelial cell death through the caspase-3 pathway. Biological Research for Nursing 7 (4): 289-296. doi: https://doi.org/10.1177/1099800405286138
17. Wang X, Zhang G, Zhu C, Lin L, Zhao Z, Yu X, Liu G, Zhang H, Li Q, Dong W (2019) Vitamin C Prevents Hydrocortisone-Induced Injury in HMEC-1 through Promoting Bestrophin-3 Expression. Nutrition and cancer 71 (5): 852-860. doi: https://doi.org/10.1080/01635581.2018.1539184
18. Radomski M, Palmer R, Moncada S (1990) Glucocorticoids inhibit the expression of an inducible, but not the constitutive, nitric oxide synthase in vascular endothelial cells. Proceedings of the National Academy of Sciences 87 (24): 10043-10047. doi: https://doi.org/10.1073/pnas.87.24.10043
19. Yang S, Zhang L (2004) Glucocorticoids and vascular reactivity. Current vascular pharmacology 2 (1): 1-12. doi: https://doi.org/10.2174/1570161043476483
20. Rogers KM, Bonar CA, Estrella JL, Yang S (2002) Inhibitory effect of glucocorticoid on coronary artery endothelial function. American Journal of Physiology-Heart and Circulatory Physiology 283 (5): H1922-H1928. doi: https://doi.org/10.1152/ajpheart.00364.2002
21. Zhu J, Li X, Yin J, Hu Y, Gu Y, Pan S (2018) Glycocalyx degradation leads to blood–brain barrier dysfunction and brain edema after asphyxia cardiac arrest in rats. Journal of Cerebral Blood Flow & Metabolism 38 (11): 1979-1992. doi: https://doi.org/10.1177/0271678X17726062
22. Gerhartl A, Pracser N, Vladetic A, Hendrikx S, Friedl H-P, Neuhaus W (2020) The pivotal role of micro-environmental cells in a human blood–brain barrier in vitro model of cerebral ischemia: functional and transcriptomic analysis. Fluids and Barriers of the CNS 17: 1-17. doi: https://doi.org/10.1186/s12987-020-00179-3
23. Haines L, Villalba N, Sackheim AM, Collier DM, Freeman K (2019) Myogenic tone contributes to the regulation of permeability in mesenteric microvessels. Microvascular research 125: 103873. doi: https://doi.org/10.1016/j.mvr.2019.04.003
24. Fadel F, André-Grégoire G, Gravez B, Bauvois B, Bouchet S, Sierra-Ramos C, Polito A, Mansart A, Alvarez de la Rosa D, Annane D (2017) Aldosterone and vascular mineralocorticoid receptors in murine endotoxic and human septic shock. Critical Care Medicine 45 (9): e954-e962. doi: https://doi.org/10.1097/CCM.0000000000002462
25. Chappell D, Hofmann-Kiefer K, Jacob M, Rehm M, Briegel J, Welsch U, Conzen P, Becker BF (2009) TNF-α induced shedding of the endothelial glycocalyx is prevented by hydrocortisone and antithrombin. Basic research in cardiology 104: 78-89. doi: https://doi.org/10.1007/s00395-008-0749-5
26. Ammar MA, Ammar AA, Condeni MS, Bell CM (2021) Vitamin C for Sepsis and Septic Shock. American Journal of Therapeutics 28 (6): e649-e679. doi:

https://doi.org/10.1097/MJT.0000000000001423
27. Hettmannsperger U, Detmar M, Owsianowski M, Tenorio S, Kammler H-J, Orfanos CB (1992) Cytokine-stimulated human dermal microvascular endothelial cells produce interleukin 6--inhibition by hydrocortisone, dexamethasone, and calcitriol. Journal of investigative dermatology 99 (5): 531-536. doi: https://doi.org/10.1111/1523-1747.ep12667288
28. Bender A, Zapolanski T, Watkins S, Khosraviani A, Seiffert K, Ding W, Wagner JA, Granstein RD (2008) Tetracycline suppresses ATPγS-induced CXCL8 and CXCL1 production by the human dermal microvascular endothelial cell-1 (HMEC-1) cell line and primary human dermal microvascular endothelial cells. Experimental dermatology 17 (9): 752-760. doi: https://doi.org/10.1111/j.1600-0625.2008.00716.x
29. Meßmer UK, Winkel G, Briner VA, Pfeilschifter J (1999) Glucocorticoids potently block tumour necrosis factor-α-and lipopolysaccharide-induced apoptotic cell death in bovine glomerular endothelial cells upstream of caspase 3 activation. British journal of pharmacology 127 (7): 1633-1640. doi: https://doi.org/10.1038/sj.bjp.0702726
30. Xu R, Sowers JR, Skafar DF, Ram JL (2001) Hydrocortisone modulates the effect of estradiol on endothelial nitric oxide synthase expression in human endothelial cells. Life Sciences 69 (23): 2811-2817. doi: https://doi.org/10.1016/S0024-3205(01)01356-X
31. Calabria AR, Weidenfeller C, Jones AR, De Vries HE, Shusta EV (2006) Puromycin-purified rat brain microvascular endothelial cell cultures exhibit improved barrier properties in response to glucocorticoid induction. Journal of neurochemistry 97 (4): 922-933. doi: https://doi.org/10.1111/j.1471-4159.2006.03793.x
32. Lee S-W, Won J-Y, Lee H-Y, Lee H-J, Youn S-W, Lee J-Y, Cho C-H, Cho H-J, Oh S, Chae I-H (2011) Angiopoietin-1 protects heart against ischemia/reperfusion injury through VE-cadherin dephosphorylation and myocardiac integrin-β1/ERK/caspase-9 phosphorylation cascade. Molecular Medicine 17: 1095-1106. doi: https://doi.org/10.2119/molmed.2011.00106
33. Kirsch T, Beese M, Wyss K, Klinge U, Haller H, Haubitz M, Fiebeler A (2013) Aldosterone modulates endothelial permeability and endothelial nitric oxide synthase activity by rearrangement of the actin cytoskeleton. Hypertension 61 (2): 501-508. doi: https://doi.org/10.1161/HYPERTENSIONAHA.111.196832
34. Zeng Y, Zhang XF, Fu BM, Tarbell JM (2018) The Role of Endothelial Surface Glycocalyx in Mechanosensing and Transduction. In: Fu BM, Wright NT (eds) Molecular, Cellular, and Tissue Engineering of the Vascular System. Springer International Publishing, Cham, pp 1-27. doi:https://doi.org/10.1007/978-3-319-96445-4_1
35. Vickers NJ (2017) Animal communication: when i'm calling you, will you answer too? Current biology 27 (14): R713-R715. doi: https://doi.org/10.1016/j.cub.2017.05.064
36. Müller AM, Gruhn KM, Herwig MC, Tsokos M (2008) VE-cadherin and ACE: Markers for sepsis in post mortem examination? Legal Medicine 10 (5): 257-263. doi: https://doi.org/10.1016/j.legalmed.2008.02.003
37. Ma Y, Liu Y, Hou H, Yao Y, Meng H (2018) MiR-150 predicts survival in patients with sepsis and inhibits LPS-induced inflammatory factors and apoptosis by targeting NF-κB1 in human umbilical vein endothelial cells. Biochemical and biophysical research communications 500 (3): 828-837. doi: https://doi.org/10.1016/j.bbrc.2018.04.168
38. Morelli A, Passariello M (2016) Hemodynamic coherence in sepsis. Best Practice & Research Clinical Anaesthesiology 30 (4): 453-463. doi: https://doi.org/10.1016/j.bpa.2016.10.009
39. Nayebosadri A, Christopher L, Ji JY (2012) Bayesian image analysis of dexamethasone and shear stress-induced glucocorticoid receptor intracellular movement. Annals of biomedical engineering 40: 1508-1519.

doi: https://doi.org/10.1007/s10439-011-0499-7

40. Zeng Y, Liu J (2016) Role of glypican-1 in endothelial NOS activation under various steady shear stress magnitudes. Experimental Cell Research 348 (2): 184-189. doi: https://doi.org/10.1016/j.yexcr.2016.09.017

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