CHAPTER 3

ANEURYSMAL SUBARACHNOID HEMORRHAGE

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Introduction

Subarachnoid hemorrhage (SAH) refers to life-threatening bleeding in the subarachnoid space between the arachnoid mater and the pia mater. Although the incidence of SAH varies by region, the worldwide incidence is 9 per 100,000 person-years (1). SAH accounts for 5% of all strokes (2). The causes of SAH are summarized in Table 1. It can occur spontaneously or as a result of trauma. Approximately 85% of spontaneous SAH cases are attributed to aneurysms, while the remaining cases are associated with non-aneurysmal perimesencephalic bleeding, arteriovenous (AV) malformations, amyloid angiopathies, cerebral arterial vasculitis, tumors, anticoagulant use, and cocaine use (1).

Table 1: Causes of Subarachnoid Hemorrhage
Trauma
Spontaneous a) Aneurysmatic Subarachnoid hemorrhage b) Nonaneurysmal perimesencephalic hemorrhage c) Arteriovenous malformation d) Amyloid angiopathy e) Cerebral artery vasculitis f) Tumors g) Anticoagulant drugs h) Cocaine use

Aneurysmal subarachnoid hemorrhage (aSAH) is a fatal condition, with prehospital mortality rates ranging from 22% to 26%, and in-hospital mortality rates around 19% to 20% (3). Risk factors for the development of intracranial aneurysms include female gender, black race, smoking, chronic alcohol use, hypertension, family history, and inherited diseases such as autosomal dominant

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Acknowledgement

The radiological images were obtained from the Ankara Etlik City Hospital archive.

References

1. de Rooij NK, Linn FH, van der Plas JA, et al. Incidence of subarachnoid hemorrhage: a systematic review with emphasis on region, age, gender, and time trends. *Journal of Neurology, Neurosurgery, and Psychiatry.* 2007;78(12): 1365-1372. doi: 10.1136/jnnp.2007.117655.
2. Odili A, Reddy U. Management of Subarachnoid Hemorrhage. *Anaesthesia and Intensive Care Medicine*. 2023;24(6): 340-347.
3. Hoh BL, Ko NU, Amin-Hanjani S, et al. 2023 Guideline for the Management of Patients with Aneurysmal Subarachnoid Hemorrhage: A Guideline from the American Heart Association/American Stroke Association. *Stroke*. 2023;54(7): e314-e370. doi: 10.1161/STR.0000000000000436.
4. D'Souza S. Aneurysmal Subarachnoid Hemorrhage. *Journal of Neurosurgical Anesthesiology*. 2015;27(3): 222-240. doi: 10.1097/ANA.0000000000000130.
5. Shea AM, Reed SD, Curtis LH, et al. Characteristics of nontraumatic subarachnoid hemorrhage in the United States in 2003. *Neurosurgery*. 2007;61(6): 1131-1137.
6. Moore SA, Rabinstein AA, Stewart MW, et al. Recognizing the signs and symptoms of aneurysmal subarachnoid hemorrhage. *Expert Review of Neurotherapeutics*. 2014;14(7): 757-768. doi: 10.1586/14737175.2014.922414.
7. Ogunlaja OI, Cowan R. Subarachnoid Hemorrhage and Headache. Current Pain and Headache Reports. 2019 May 23;23(6):44. doi: 10.1007/s11916-019-0785-x.
8. Fontanarosa PB. Recognition of subarachnoid hemorrhage. *Annals of Emergency Medicine*. 1989;18(11): 1199-1205. doi: 10.1016/s0196-0644(89)80059-9.
9. Linn FH, Rinkel GJ, Algra A, et al. The notion of "warning leaks" in subarachnoid hemorrhage: are such patients in fact admitted with a rebleed? *Journal of Neurology, Neurosurgery, and Psychiatry*. 2000;68(3): 332-336. doi: 10.1136/jnnp.68.3.332.
10. Perry JJ, Stiell IG, Sivilotti ML, et al. Clinical decision rules to rule out subarachnoid hemorrhage for acute headache. *The Journal of the American Medical Association*. 2013;310: 1248–1255.
11. Perry JJ, Sivilotti MLA, Sutherland J, et al. Validation of the Ottawa Subarachnoid Hemorrhage Rule in patients with acute headache. *Canadian Medical Association Journal*. 2017;189(45): E1379-E1385. doi: 10.1503/cmaj.170072.
12. Dubosh NM, Bellolio MF, Rabinstein AA, et al. Sensitivity of early brain computed tomography to exclude aneurysmal subarachnoid hemorrhage: a systematic review and meta-analysis. *Stroke*. 2016;47(3): 750-755.
13. Walton M, Hodgson R, Eastwood A, et al. Management of patients presenting to the emergency department with sudden onset severe headache: systematic review of diagnostic accuracy studies. *Emergency Medicine Journal*. 2022;39: 818–825. doi: 10.1136/emermed-2021-211900.
14. Agid R, Andersson T, Almqvist H, et al. Negative CT angiography findings in patients with spontaneous subarachnoid hemorrhage: when is digital subtraction angiography still needed? *American Journal of Neuroradiology*. 2010;31(4): 696-705.

15. Hunt WE, Hess RM. Surgical risk as related to time of intervention in the repair of intracranial aneurysms. *Journal of Neurosurgery*. 1968;28(1): 14-20. doi: 10.3171/jns.1968.28.1.0014.
16. Teasdale GM, Drake CG, Hunt W, et al. Universal subarachnoid hemorrhage scale: report of a committee of the World Federation of Neurosurgical Societies. *Journal of Neurology, Neurosurgery, and Psychiatry*. 1988;51(11): 1457-1463. doi: 10.1136/jnnp.51.11.1457.
17. Yasargil MG. Microneurosurgery. *Verlag Stuttgart: Georg Thieme*; 1984;2: 7–12.
18. Tagaki K, Tamura A. How should a subarachnoid hemorrhage grading scale be determined? A combinatorial approach based solely on the Glasgow Coma Scale. *Journal of Neurosurgery*. 1999;90: 680–687.
19. Fisher CM, Kistler JP, Davis JM. Relation of cerebral vasospasm to subarachnoid hemorrhage visualized by CT scanning. *Neurosurgery*. 1980;6: 1–9.
20. Tawk RG, Hasan TF, D'Souza CE, et al. Diagnosis and Treatment of Unruptured Intracranial Aneurysms and Aneurysmal Subarachnoid Hemorrhage. *Mayo Clinic Proceedings*. 2021;96(7): 1970-2000. doi: 10.1016/j.mayocp.2021.01.005.
21. Larsen CC, Astrup J. Rebleeding after aneurysmal subarachnoid hemorrhage: a literature review. *World Neurosurgery*. 2013;79(2): 307-312. doi: 10.1016/j.wneu.2012.06.023.
22. van Donkelaar CE, Bakker NA, Veeger NJ, et al. Predictive Factors for Rebleeding After Aneurysmal Subarachnoid Hemorrhage: Rebleeding Aneurysmal Subarachnoid Hemorrhage Study. *Stroke*. 2015;46(8): 2100-2106. doi: 10.1161/STROKEAHA.115.010037.
23. Guo LM, Zhou HY, Xu JW, et al. Risk factors related to aneurysmal rebleeding. *World Neurosurgery*. 2011;76(3-4): 292-298. doi: 10.1016/j.wneu.2011.03.025.
24. Macdonald RL, Schweizer TA. Spontaneous subarachnoid hemorrhage. *The Lancet*. 2017;389(10069): 655-666. doi: 10.1016/S0140-6736(16)30668-7.
25. Anderson CS, Heeley E, Huang Y, et al. INTERACT2 Investigators. Rapid blood-pressure lowering in patients with acute intracerebral hemorrhage. *The New England Journal of Medicine*. 2013;368(25): 2355-2365. doi: 10.1056/NEJMoa1214609.
26. Qureshi AI, Palesch YY, Barsan WG, et al. ATACH-2 Trial and the Neurological Emergency Treatment Trials Network. Intensive blood-pressure lowering in patients with acute cerebral hemorrhage. *The New England Journal of Medicine*. 2016;375: 1033–1043. doi: 10.1056/NEJMoa1603460.
27. Greenberg SM, Ziai WC, Cordonnier C, et al. 2022 Guideline for the Management of Patients with Spontaneous Intracerebral Hemorrhage: A Guideline from the American Heart Association/American Stroke Association. *Stroke*. 2022;53(7): e282-e361. doi: 10.1161/STR.0000000000000407.
28. Minhas JS, Moullaali TJ, Rinkel GJE, et al. Blood Pressure Management After Intracerebral and Subarachnoid Hemorrhage: The Knowns and Known Unknowns. *Stroke*. 2022;53(4): 1065-1073. doi: 10.1161/STROKEAHA.121.036139.
29. Connolly ES Jr, Rabinstein AA, Carhuapoma JR, et al. Guidelines for the management of aneurysmal subarachnoid hemorrhage: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2012;43: 1711–1737.
30. Doherty JU, Gluckman TJ, Hucker WJ, et al. 2017 ACC Expert Consensus Decision Pathway for Periprocedural Management of Anticoagulation in Patients with

Nonvalvular Atrial Fibrillation: A Report of the American College of Cardiology Clinical Expert Consensus Document Task Force. *Journal of the American College of Cardiology*. 2017;69(7): 871-898. doi: 10.1016/j.jacc.2016.11.024.

31. Steiner T, Poli S, Griebe M, et al. Fresh frozen plasma versus prothrombin complex concentrate in patients with intracranial hemorrhage related to vitamin K antagonists (INCH): a randomised trial. *The Lancet Neurology*. 2016;15: 566–573. doi: 10.1016/S1474-4422(16)00110-1.
32. Sarode R, Milling TJ, Refaai MA, et al. Efficacy and safety of a 4-factor prothrombin complex concentrate in patients on vitamin K antagonists presenting with major bleeding: a randomized, plasma-controlled, phase IIIb study. *Circulation*. 2013;128: 1234–1243. doi: 10.1161/CIRCULATIONAHA.113.002283.
33. Baker RI, Coughlin PB, Gallus AS, et al. Warfarin Reversal Consensus Group. Warfarin reversal: consensus guidelines, on behalf of the Australasian Society of Thrombosis and Haemostasis. *The Medical Journal of Australia*. 2004;181(9): 492-497. doi: 10.5694/j.1326-5377.2004.tb06407.x.
34. Pollack CV, Reilly PA, Eikelboom J, et al. Idarucizumab for dabigatran reversal. *New England Journal of Medicine*. 2015;373(6): 511-520. doi: 10.1056/NEJMoa1502000
35. Shih AW, Crowther MA. Reversal of direct oral anticoagulants: a practical approach. *Hematology*, *The Journal of the American Society of Hematology.* 2016;2016(1): 612-619. doi: 10.1182/asheducation-2016.1.612.
36. Majeed A, Ågren A, Holmström M, et al. Management of rivaroxaban-or apixaban-associated major bleeding with prothrombin complex concentrates: a cohort study. *Blood, The Journal of the American Society of Hematology.* 2017;130(15): 1706-1712.
37. Lu G, DeGuzman FR, Hollenbach SJ, et al. A specific antidote for reversal of anticoagulation by direct and indirect inhibitors of coagulation factor Xa. *Nature Medicine*. 2013;19: 446–451.
38. Ammar AA, Ammar MA, Owusu KA, et al. Andexanet alfa versus 4-factor prothrombin complex concentrate for reversal of factor Xa inhibitors in intracranial hemorrhage. *Neurocritical Care*. 2021;35: 255–261. doi: 10.1007/s12028-020-01161-5.
39. Schulman S, Bijsterveld NR. Anticoagulants and their reversal. Transfusion Medicine Reviews. 2007;21(1): 37-48. doi: 10.1016/j.tmrv.2006.08.002.
40. Post R, Germans MR, Tjerkstra MA, et al. Ultra-early tranexamic acid after subarachnoid hemorrhage (ULTRA): a randomized controlled trial. *The Lancet*. 2021;397(10269): 112-118.
41. Spetzler RF, McDougall CG, Albuquerque FC, et al. The barrow ruptured aneurysm trial: 3-year results. *Journal of Neurosurgery*. 2013;119(1): 146-157.
42. Mitchell P, Kerr R, Mendelow AD, et al. Could late rebleeding overturn the superiority of cranial aneurysm coil embolization over clip ligation seen in the International Subarachnoid Aneurysm Trial? *Journal of Neurosurgery.* 2008;108(3): 437-442.
43. Lanzino G, Kongable GL, Kassell NF. Electrocardiographic abnormalities after nontraumatic subarachnoid hemorrhage. *Journal of Neurosurgical Anesthesiology*. 1994;6(3): 156-162. doi: 10.1097/00008506-199407000-00002.
44. Andreoli A, di Pasquale G, Pinelli G, et al. Subarachnoid hemorrhage: frequency and severity of cardiac arrhythmias. A survey of 70 cases studied in the acute phase. *Stroke*. 1987;18(3): 558-564. doi: 10.1161/01.str.18.3.558.

45. Capes SE, Hunt D, Malmberg K, et al. Stress hyperglycemia and prognosis of stroke in nondiabetic and diabetic patients: a systematic overview. *Stroke*. 2001;32: 2426–2432.
46. Frontera JA, Fernandez A, Claassen J, et al. Hyperglycemia after SAH: predictors, associated complications, and impact on outcome. *Stroke*. 2006 ;37(1): 199-203. doi: 10.1161/01.STR.0000194960.73883.0f.
47. Magee CA, Thompson Bastin ML, Graves K, et al. Fever Burden in Patients with Subarachnoid Hemorrhage and the Increased Use of Antibiotics. *Journal of Stroke and Cerebrovascular Diseases*. 2019;28(11): 104313. doi: 10.1016/j.jstrokecerebrovasdis.
48. Naidech AM, Kreiter KT, Janjua N, et al. Phenytoin exposure is associated with functional and cognitive disability after subarachnoid hemorrhage. *Stroke*. 2005;36(3): 583-587. doi: 10.1161/01.STR.0000141936.36596.1e.
49. Kshettry VR, Rosenbaum BP, Seicean A, et al. Incidence and risk factors associated with in-hospital venous thromboembolism after aneurysmal subarachnoid hemorrhage. *Journal of Clinical Neuroscience*. 2014;21(2): 282-286. doi: 10.1016/j.jocn.2013.07.003.
50. Pan X, Li J, Xu L, et al. Safety of prophylactic heparin in the prevention of venous thromboembolism after spontaneous intracerebral hemorrhage: a meta-analysis. *Journal of Neurological Surgery Part A: Central European Neurosurgery.* 2020;81(03): 253-260.
51. See AP, Wu KC, Lai PM, et al. Risk factors for hyponatremia in aneurysmal subarachnoid hemorrhage. *Journal of Clinical Neuroscience*. 2016;32: 115-118. doi: 10.1016/j.jocn.2016.04.006.
52. Harrigan MR: Cerebral salt wasting syndrome: a review. *Neurosurgery*. 1996;38: 152-160.
53. Lee KH, Lukovits T, Friedman JA. "Triple-H" therapy for cerebral vasospasm following subarachnoid hemorrhage. *Neurocritical Care*. 2006;4(1): 68-76. doi: 10.1385/NCC:4:1:068.
54. Hasan D, Lindsay KW, Wijdicks EF, et al. Effect of fludrocortisone acetate in patients with subarachnoid hemorrhage. *Stroke*. 1989;20(9): 1156-1161.
55. Roos YB, de Haan RJ, Beenen LF, et al. Complications and outcome in patients with aneurysmal subarachnoid hemorrhage: a prospective hospital-based cohort study in the Netherlands. *Journal of Neurology, Neurosurgery & Psychiatry*. 2000;68: 337–341.
56. Vergouwen MD, Vermeulen M, van Gijn J, et al. Definition of delayed cerebral ischemia after aneurysmal subarachnoid hemorrhage as an outcome event in clinical trials and observational studies: proposal of a multidisciplinary research group. *Stroke*. 2010;41(10): 2391-2395. doi: 10.1161/STROKEAHA.110.589275.
57. Allen GS, Ahn HS, Preziosi TJ, et al. Cerebral arterial spasm: a controlled trial of nimodipine in patients with subarachnoid hemorrhage. *New England Journal of Medicine*. 1983;308: 619–624. doi: 10.1056/NEJM198303173081103.
58. Muench E, Horn P, Bauhuf C, et al. Effects of hypervolemia and hypertension on regional cerebral blood flow, intracranial pressure, and brain tissue oxygenation after subarachnoid hemorrhage. *Critical Care Medicine*. 2007;35: 1844–1851.
59. Hoh BL, Ogilvy CS. Endovascular treatment of cerebral vasospasm: transluminal balloon angioplasty, intra-arterial papaverine and intra-arterial nicardipine. *Neurosurgery Clinics of North America*. 2005;16: 501–516.
60. Woods KS, Horvat CM, Kantawala S, et al. Intracranial and Cerebral Perfusion Pressure Thresholds Associated with Inhospital Mortality Across Pediatric

Neurocritical Care. *Pediatric Critical Care Medicine*. 2021;22(2): 135-146. doi: 10.1097/PCC.0000000000002618.
61. Freeman WD. Management of Intracranial Pressure. *Continuum*. 2015;21(5): 1299-1323. doi: 10.1212/CON.0000000000000235.
62. Desai P, Prasad K. Dexamethasone is not necessarily unsafe in primary supratentorial intracerebral hemorrhage. *Journal of Neurology, Neurosurgery & Psychiatry*. 1998;65(5): 799-801.
63. Claassen J, Peery S, Kreiter KT, et al. Predictors and clinical impact of epilepsy after subarachnoid hemorrhage. *Neurology*. 2003;60(2): 208-14.
64. Naidech AM, Kreiter KT, Janjua N, et al. Phenytoin exposure is associated with functional and cognitive disability after subarachnoid hemorrhage. *Stroke*. 2005;36(3): 583-587. doi: 10.1161/01.STR.0000141936.36596.1e.
65. Kodankandath TV, Farooq S, Wazni W, et al. Seizure Prophylaxis in the Immediate Post-Hemorrhagic Period in Patients with Aneurysmal Subarachnoid Hemorrhage. *Journal of Vascular and Interventional Neurology*. 2017;9(6): 1-4.