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Ronald Jenner, Gregor Anderluh, Agostinho Antunes, Figen Caliskan, Maik Damm, Christian W Gruber, Benjamin-Florian Hempel, Mande Holford, Maria Ikonomopoulou, Meral Kekeçoğlu, et al.

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Syllabus for a Master's-level course on Animal Venomics

Created by Working Group 5 (Training) of the European Venom Network (EUVEN)
(completed in April 2025)

<https://euven-network.eu/>

Authors

Ronald Jenner, Natural History Museum, London, UK
Gregor Anderluh, National Institute of Chemistry, Ljubljana, Slovenia
Agostinho Antunes, University of Porto, Portugal
Figen Caliskan, Eskişehir Osmangazi University, Turkey
Maik Damm, Fraunhofer Institute for Molecular Biology and Applied Ecology IME, Schmallenberg, Germany
Christian W. Gruber, Medical University of Vienna, Austria
Benjamin-Florian Hempel, Free University of Berlin, Germany
Mande Holford, City University of New York, USA
Maria Ikonopoulou, IMDEA Food Institute, Madrid, Spain
Meral Kekeçoğlu, Düzce University, Turkey
Kim Kirchhoff, City University of New York, USA
Jeroen Kool, Vrije Universiteit Amsterdam, The Netherlands
Margareta Lakušić, University of Porto, Portugal
Riadh Ben Mansour, Faculty of Sciences of Sfax, Tunisia
Pascale Marchot, Centre National de la Recherche Scientifique/Aix-Marseille Université, Marseille, France
Maria Vittoria Modica, Zoological Station Anton Dohrn, Naples, Italy
Ayse Nalbantsoy, Ege University, Bornova – Izmir, Turkey
Naoual Oukkache, Pasteur Institute of Morocco, Casablanca, Morocco
Kity Požek, Jožef Stefan Institute and University of Ljubljana, Slovenia
Björn M. von Reumont, Staatliches Museum für Naturkunde Karlsruhe, Germany
Yiannis Sarigiannis, University of Nicosia, Cyprus
Andrea Tarallo, Istituto di Ricerca sugli Ecosistemi Terrestri, Porano, Italy
Fiorella Tonello, University of Padova, Italy
Rui Vitorino, University of Aveiro, Portugal
Blerina Vrenozi, University of Tirana, Albania
Mark L. Zammit, University of Malta, Msida, Malta

About this syllabus

The aim of this syllabus is to aid people who wish to design a Master's-level course on animal venomology. It provides a list of topics that together comprise a comprehensive introduction into the study of animal venoms, and it offers a selection of suggested literature and online resources that can function as a foundation for the development of teaching materials. To get access to the YouTube links, please email Ronald Jenner (r.jenner@nhm.ac.uk).

COURSE OUTLINE

- 1. The diversity of animal venoms**
 - 1.1. Current definitions of venom
 - 1.2. Phylogenetic, functional, and ecological diversity of venoms
 - 1.3. The functional morphology of venom systems
- 2. The ecology and evolution of animal venoms**
 - 2.1. Venom variation within taxa
 - 2.2. Drivers of venom evolution
 - 2.3. Evolutionary sources of venom toxins
 - 2.4. Molecular mechanisms of venom evolution
- 3. Collecting animal venoms**
 - 3.1. Ethics and legal aspects of collecting specimens in the field
 - 3.2. Collecting specimens in the field
 - 3.3. Collecting and storing venoms
- 4. The composition and bioactivities of animal venoms**
 - 4.1. Common components of venom
 - 4.2. Physiological targets of venom toxins
 - 4.3. Mechanisms of venom toxin action
- 5. Profiling venom composition**
 - 5.1. Genomic methods
 - 5.2. Transcriptomic methods
 - 5.3. Proteomic methods
 - 5.4. Metabolomic methods
 - 5.5. Multiomics integration and web resources
- 6. Biotechnological and pharmacological applications of animal venoms**
 - 6.1. Production, isolation, and purification of toxins
 - 6.2. Bioassays of venom toxins
 - 6.3. Applications of venom toxins in research, biotechnology, etc.
- 7. Clinical and epidemiological aspects of animal venoms**
 - 7.1. Medically relevant animal venoms
 - 7.2. Epidemiology of snakebite, spider bite, and scorpion stings
 - 7.3. Clinical treatment of envenomations

CONTENT SUMMARIES AND SELECTED RESOURCES

1. The diversity of animal venoms

Aim: gain an appreciation of the diversity of venomous animals, their venoms, and their venom systems

1.1. Current definitions of venom

Objectives:

- Present current definitions of venom and discuss how and why they differ
- Discuss how venoms are distinguished from toxins, poisons and toxungens
- Introduce the main types of venoms based on their physiological targets

Suggested reading:

- Arbuckle, K. 2017. Evolutionary context of venom in animals. In: *Evolution of venomous animals and their toxins* (Malhotra, A. & Gopalakrishnakone, P., eds.), Springer: 1-23
- Fry, B.G. et al. 2009. The toxicogenomic multiverse: convergent recruitment of proteins into animal venoms. *Annu. Rev. Genomics Hum. Genet.* 10: 483-511
- Jenner, R. and Undheim, E. 2024. *Venom. The secrets of nature's deadliest weapon.* Natural History Museum.
- Modica, M.V. et al. 2020. Diversity and evolution of animal venoms: neglected targets, ecological interactions, future perspectives. *Front. Ecol. Evol.* 8: 65
- Nelsen, D. R. et al. 2013. Poisons, toxungens, and venoms: redefining and classifying toxic biological secretions and the organisms that employ them. *Biol. Rev.* 89: 450-465

Online resources:

- Lecture by Maria Vittoria Modica on day one of the 2022 online EUVEN Introductory Venomics Training School
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvsyoIkploC1iDR>)

1.2. Phylogenetic, functional, and ecological diversity of venoms

Objectives:

- Present an overview of the convergently evolved diversity of venomous animal taxa and lineages (point out that venoms occur outside Metazoa too)
- Present the functional and ecological diversity of venoms (e.g. the use of venoms in predation, defense, competition, parasitism, etc.)

Suggested reading:

- Fry, B.G. et al. 2015. The origin and evolution of the Toxicofera reptile venom system. In: *Venomous reptiles and their toxins* (Fry, B.G., ed.), Oxford University Press: 1-31

- Hayes, W.K. et al. 2025. It's a small world after all: the remarkable but overlooked diversity of venomous organisms, with candidates among plants, fungi, protists, bacteria, and viruses. *Toxins* 17: 99
- Jenner, R. and Undheim, E. 2024. *Venom. The secrets of nature's deadliest weapon*. Natural History Museum
- Modica, M.V. and Holford, M. 2010. The Neogastropoda: evolutionary innovations of predatory marine snails with remarkable pharmacological potential. In: *Evolutionary Biology – Concepts, Molecular and Morphological Evolution* (Pontarotti, P., ed.), Springer: 249–270.
- Schendel, V. et al. 2019. The diversity of venom: the importance of behavior and venom system morphology in understanding its ecology and evolution. *Toxins* 11: 666

Online resources:

- Lectures by Aida Verdes and Eivind Undheim on day one of the 2022 online EUVEN Introductory Venomics Training School
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvvsyoIkploC1iDR>)

1.3. The functional morphology of venom systems

Objectives:

- Discuss the phenotypic diversity of animal venom systems
- Show how different venom systems produce, store, deliver, and replenish venoms

Suggested reading:

- Jenner, R. and Undheim, E. 2024. *Venom. The secrets of nature's deadliest weapon*. Natural History Museum
- Modica, M.V. et al. 2019. Macroevolutionary analyses suggest environmental factors, not venom apparatus, play key role in Terebridae marine snail diversification. *Syst. Biol.* 69: 413–430
- Morgenstern, D. and King, G.F. 2013. The venom optimization hypothesis revisited. *Toxicon* 63: 120-128
- Schendel, V. et al. 2019. The diversity of venom: the importance of behavior and venom system morphology in understanding its ecology and evolution. *Toxins* 11: 666

Online resources:

- Lecture by Michel Dugon on day one of the 2022 online EUVEN Introductory Venomics Training School
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvvsyoIkploC1iDR>)

2. The ecology and evolution of animal venoms

Aim: gain an appreciation of the factors that underpin venom variation within and between taxa and the drivers of venom evolution

2.1. Venom variation within taxa

Objectives:

- Discuss ontogeny, sex, geography, season, and other factors that underpin intraspecific venom variation

Suggested reading:

- Aydeniz-Güneşer, B. et al. 2025. Characterization of the volatile profile of bee venom from different regions in Türkiye using gas chromatography-mass spectrometry. *J. Agricult. Sci.* 31: 22-32
- Casewell, N.R. et al. 2020. Causes and consequences of snake venom variation. *Trends Pharmacol. Sci.* 41: 570-581
- Sachkova, M.Y. et al., 2020. Some like it hot: population-specific adaptations in venom production to abiotic stressors in a widely distributed cnidarian. *BMC Biology* 18: 121
- Schonour, R.B. et al. 2020. Gradual and discrete ontogenetic shifts in rattlesnake venom composition and assessment of hormonal and ecological correlates. *Toxins* 12: 10
- Sunagar, K. et al. 2016. Ecological venomics: How genomics, transcriptomics and proteomics can shed new light on the ecology and evolution of venom. *J. Proteomics* 135: 62-72

2.2. Drivers of venom evolution

Objectives:

- Discuss the biotic and abiotic drivers of venom evolution, including loss of venom
- Discuss venom evolution in context of coevolutionary arms races (e.g. between predator and prey)
- Discuss use of comparative methods to study venom evolution

Suggested reading:

- Arbuckle, K., 2018. Phylogenetic comparative methods can provide important insights into the evolution of toxic weaponry. *Toxins* 10: 518
- Gorson, J. et al. 2021. Diet diversity in carnivorous terebrid snails is tied to the presence and absence of a venom gland. *Toxins* 13: 108. PMID: 33540609.
- Holding, M.L. et al. 2016. Venom resistance as a model for understanding the molecular basis of complex coevolutionary adaptations. *Integr. Comp. Biol.* 56: 1032-1043
- Sunagar, K. and Moran, Y. 2015. The rise and fall of an evolutionary innovation: contrasting strategies of venom evolution in ancient and young animals. *PLoS Genet.* 11: e1005596

- Zancolli, G. et al. 2019. When one phenotype is not enough: divergent evolutionary trajectories govern venom variation in a widespread rattlesnake species. *Proc. R. Soc. B.* 286: 20182735

Online resources:

- Lecture by Kevin Arbuckle on day one of the 2022 online EUVEN Introductory Venomics Training School and Wolfgang Wüster and Anna Nekaris on day five (<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvsyoIkploC1iDR>)

2.3. Evolutionary sources of venom toxins

Objectives:

- Discuss examples of venom toxins evolving from non-toxin ancestors
- Present examples of diversification within single toxin families to form new (sub)classes

Suggested reading:

- Selected chapters on reptile venom toxins in Fry, B.G. 2015. *Venomous reptiles and their toxins. Evolution, pathophysiology and biodiscovery.* Oxford University Press
- Barua, A. et al. 2021. Co-option of the same ancestral gene family gave rise to mammalian and reptilian toxins. *BMC Biol.* 19: 268
- Giorgianni, M.W. et al. 2020. The origin and diversification of a novel protein family in venomous snakes. *Proc. Natl. Acad. Sci. USA* 117: 10911-10920
- Jackson, T.N.W, and Koludarov, I. 2020. How the toxin got its toxicity. *Front. Pharmacol.* 11: 574925
- Koludarov, I. et al. 2023. Domain loss enabled evolution of novel functions in the snake three-finger toxin gene superfamily. *Nat. Commun.* 14: 4861
- Undheim, E.A.B. et al. 2015. Weaponization of a hormone: convergent recruitment of hyperglycemic hormone into the venom of arthropod predators. *Structure* 23: 1283-1292

2.4. Molecular mechanisms of venom evolution

Objectives:

- Discuss genomic mechanisms of venom evolution (e.g. recruitment of housekeeping genes, gene and genome duplication, horizontal gene transfer)

Suggested reading:

- Casewell, N.R. et al. 2013. Complex cocktails: the evolutionary novelty of venoms. *Trends Ecol. Evol.* 28: 219-229
- Drukewitz, S.H. and von Reumont, B.M. 2019. The significance of comparative genomics in modern evolutionary venomics. *Front. Ecol. Evol.* 7:163.

- Drukewitz, S.H. et al. 2019. Toxins from scratch? Diverse, multimodal gene origins in the predatory robber fly *Dasypogon diadema* indicate a dynamic venom gene evolution in dipteran insects. *Gigascience* 8, 1-13.
- Martinson, E.O. et al. 2016. Laterally transferred gene recruited as a venom in parasitoid wasps. *Mol. Biol. Evol.* 33: 1042-1052
- Undheim, E.A.B. et al. 2016. Toxin structures as evolutionary tools: using conserved 3D folds to study the evolution of rapidly evolving peptides. *Bioessays* 38: 539-548

Online resources:

- Lecture by Nick Casewell in the 2022 online EUVEN Introductory Venomics Training School (<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7Xuw7wvsyoIkploC1iDR>)

3. Collecting animal venoms

Aim: gain an understanding of ethical, legal, and practical aspects of collecting venoms, as well as handling venomous species and methods for extracting and storing venoms

3.1. Ethics and legal aspects of collecting specimens in the field

Objectives:

- Discuss ethical guidelines for working with venomous animals (general examples and country-specific variations)
- Provide an overview of international wildlife laws (CITES, IUCN guidelines) and the Nagoya Protocol on Access and Benefit-sharing
- Outline procedures and documentation required to obtain permits for animal, organ/gland and venom collection and transport, including CITES permits, research permissions, export/import licenses, and compliance with the Nagoya Protocol and highlight the importance (long term consequences)

Suggested reading:

- Dodd, C. K. 2016. Planning and setting objectives in field studies. In: *Reptile Ecology and Conservation: A Handbook of Techniques*. Oxford Academic.
- Reumont, B.M. von et al. 2022. Modern venomics—Current insights, novel methods, and future perspectives in biological and applied animal venom research. *Gigascience* 11: giac048
- Example of national Nagoya information hub: <https://www.nagoyaprotocol-hub.de/>

Online resources:

- CITES Species Database: <https://checklist.cites.org/#/en>
- IUCN Red List of Threatened Species: <https://www.iucnredlist.org/>
- Nagoya Map: <https://absch.cbd.int/en/countries?status=All>

3.2. Collecting specimens in the field

Objectives:

- Discuss protective equipment, handling tools and safety procedures required for interacting with different venomous species
- Discuss how to securely capture, restrain and release animals (use of traps, hooks, tongs, tubes, etc.), highlighting species-specific techniques and common mistakes to avoid
- Explain fieldwork organisation, including pre-expedition planning, species identification, habitat selection, team coordination, risk assessment, biosecurity measures, and sample/data management

Suggested reading:

- Chapter five in Fry, B.G. 2015. *Venomous reptiles and their toxins. Evolution, pathophysiology and biodiscovery*. Oxford University Press
- Fonseca, A. et al., 2028. Protocol to obtain targeted transcript sequence data from snake venom samples collected in the Colombian field. *Toxicon* 148: 1-6
- Guidelines for collecting and working with live reptiles and amphibians: <https://ssarherps.org/wp-content/uploads/2014/07/guidelinesherpsresearch2004.pdf>

3.3. Collecting and storing venoms

Objectives:

- Discuss venom extraction techniques (voluntary venom secretion, mechanical and chemical stimulation, electrostimulation, cell lysis for non-gland venom systems, density-based cell separation for e.g. cnidae collection)
- Discuss methods to prevent sample contamination
- Discuss protocols for short-term and long-term venom storage (e.g., freeze-drying, liquid nitrogen, protease inhibitors)

Suggested reading:

- Chapter five in Fry, B.G. 2015. *Venomous reptiles and their toxins. Evolution, pathophysiology and biodiscovery*. Oxford University Press
- Jesupret, C. et al. 2014. Vintage venoms: proteomic and pharmacological stability of snake venoms stored for up to eight decades. *J. Proteomics*. 105: 285-294
- Kekeçoğlu, M. et al. 2022. Factors affecting the quality of honey bee venom. *J. Apic. Sci.* 66: 5-14
- Mackessy, S.P. 2021. Venom handling and storage. In: *Handbook of Venoms and Toxins of Reptiles* (Mackessy, S.P. ed.). CRC Press
- Santos, L. et al., 2021. Good management practices of venomous snakes in captivity to produce biological venom-based medicines: achieving replicability and contributing to pharmaceutical industry. *J. Toxicol. Environ. Health B Crit. Rev.* 24: 30-50

Online resources:

- Lectures by Eivind Undheim (“Specimen handling and venom collection”), Figen Caliskan (“Scorpion venom collection”) and Paul Rowley (“Collecting venom from reptiles”) on day two of the 2022 online EUVEN Introductory Venomics Training School (<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvsvy0kpl0C1iDR>)

4. The composition and bioactivities of animal venoms

Aim: gain an appreciation of the composition and diverse bioactivities of animal venoms

4.1. Common components of venoms

Objectives:

- Describe the common components of venoms (e.g. inorganic molecules, peptides, proteins, non-proteinaceous organic molecules)
- Discuss what features make peptides and proteins suitable as venom components (e.g. solubility, stability)
- Describe the protein families commonly found in venoms

Suggested reading:

- Dresler, J. et al. 2024 A roadmap to the enzymes from spider venom: biochemical ecology, molecular diversity, and value for the bioeconomy. *Front. Arach. Sci.* 3: 1445500
- Fry, B.G. et al. 2009 The toxicogenomic multiverse: convergent recruitment of proteins into animal venoms. *Annu. Rev. Genomics Hum. Genet.* 10: 483-511
- Mackessy, S.P. 2021. *Handbook of Venoms and Toxins of Reptiles* (2nd ed.). CRC Press
- Villar-Briones, A. and Aird, S.D. 2018. Organic and peptidyl constituents of snake venoms: the picture is vastly more complex than we imagined. *Toxins* 10: 392

4.2. Physiological targets of venom toxins

Objectives:

- Discuss the different types of venoms (e.g. neurotoxic, cytolytic, hemotoxic, immunomodulating) in different taxa
- Discuss what targets the toxins in these venoms have evolved to act on (e.g. nervous system, cardiovascular system, pain receptors, microbes, cancer)

Suggested reading:

- Fry, B.G. et al. 2009 The toxicogenomic multiverse: convergent recruitment of proteins into animal venoms. *Annu. Rev. Genomics Hum. Genet.* 10: 483-511
- Op den Brouw, B. et al. 2023. Malaysian and Chinese king cobra venom cytotoxicity in melanoma (MM96L) and neonatal foreskin fibroblasts (NFF) show broad-spectrum potency that differs by age and location. *Toxins* 15: 549

- Op den Brouw, B. et al. 2022. Pharmacological characterisation of *Pseudocerastes* and *Eristicophis* viper venoms reveal anticancer (melanoma) properties and a potentially novel mode of fibrinogenolysis. *Int. J. Mol. Sci.* 22: 6896
- Pineda, S.S. et al. 2014. Spider venomics: implications for drug discovery. *Future Med. Chem.* 6: 1-16
- Ryan, R.Y.M. et al., 2021. Immunological responses to envenomation. *Front. Immunol.* 12: 1-20

4.3. Mechanisms of venom toxin action

Objectives:

- Discuss how neurotoxins act on their targets
- Discuss how cytotoxins act on their targets
- Discuss how hemotoxins act on their targets

Suggested reading:

- Selected chapters on reptile venom toxins in Fry, B.G. 2015. *Venomous reptiles and their toxins. Evolution, pathophysiology and biodiscovery.* Oxford University Press
- Garb, J.E. and Hayashi, C.Y. 2013. Molecular evolution of α -latrotoxin, the exceptionally potent vertebrate neurotoxin in black widow spider venom. *Mol. Biol. Evol.* 30: 999-1014
- Slagboom, J. et al. 2017. Haemotoxic snake venoms: their functional activity, impact on snakebite victims and pharmaceutical promise. *Br. J. Haematol.* 177: 947–959
- Sams, H.H. et al. 2001. Necrotic arachnidism. *J. Am. Acad. Dermatol.* 44: 561-576
- Ushkaryov, Y.A. et al. 2008. α -Latrotoxin and its receptors. In: *Pharmacology of Neurotransmitter Release* (Südhof, T.C., Starke, K., eds.), Springer: 171-206
- van Thiel, J. et al. 2020. Convergent evolution of toxin resistance in animals. *Biol. Rev.* 97: 1823-1843
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Online resources:

- Lecture by Kartik Sunagar on day two of the 2022 online EUVEN Introductory Venomics Training School
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7Xuw7wvsvyIkploC1iDR>)

5. Profiling venom composition

Aim: gain an understanding of the methods and techniques used to profile the composition of venoms, including modern -omics technologies

5.1. Genomic methods

Objectives:

- Learn about current short and long read DNA sequencing techniques (Illumina, ONT, PacBio, Hi-C)

- Understand how genome assembly and mapping/aligning of long and short reads works and what the advantages and disadvantages of both are
- Understand how RNA-seq and proteomics data can be mapped to the final genome assembly (gff file format etc.)
- Learn about additional tools/techniques in genomics and their challenges such as gene annotation, chromosome-level assembly and difficult identification of multi-gene families
- Brief introduction to new methods such as deep learning that are currently being developed on many levels for gene/genome analyses
- Use real data to get hands-on experience in the workflow from generated genome sequence data to polishing, assembly and first annotations. (Note: data sets prepared in advance are probably necessary for practicality)

Online resources:

- Lecture by Björn M von Reumont on day two of the online EUVEN Introductory Venomics Training School - DNA/genomics parts
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7Xuw7wvsyoIkploC1iDR>)

Suggested reading:

- Espinosa, E. et al. 2024. Advancements in long-read genome sequencing technologies and algorithms. *Genomics* 116: 3
- Giani, E.M. et al. 2020. Long walk to genomics: history and current approaches to genome sequencing and assembly. *Comput. Struct. Biotechnol. J.* 18: 9-19
- Drukewitz, S.H. et al. 2019. Toxins from scratch? Diverse, multimodal gene origins in the predatory robber fly *Dasypogon diadema* indicate a dynamic venom gene evolution in dipteran insects. *Gigascience* 8: 1-13
- Koludarov, I. et al. 2023. Prevalent bee venom genes evolved before the aculeate stinger and eusociality. *BMC Biology* 21: 229
- Rao, W.-Q. et al. 2022. The rise of genomics in snake venom research: recent advances and future perspectives. *Gigascience* 1: giac024
- Touchard, A. et al. 2024. The genome of the ant *Tetramorium bicarinatum* reveals a tandem organization of venom peptides genes allowing the prediction of their regulatory and evolutionary profiles. *BMC Genomics* 25: 84
- von Reumont, B. M. et al. 2022. Modern venomics-current insights, novel methods, and future perspectives in biological and applied animal venom research. *Gigascience* 11: giac048
-

5.2. Transcriptomic methods

Objectives:

- Learn about RNA sequencing (RNA-seq) and its application to study venom gland transcriptomes
- Understand the process of gene expression profiling and how it identifies toxin-encoding transcripts
- Explore bioinformatics tools and pipelines used for transcriptome assembly and analysis
- Compare transcriptomics with genomic and proteomic approaches to venom research - Understand benefits and limitations of transcriptomics in describing the venom composition
- Use data that allow for the combination of proteomics, transcriptomics and genomics and understand the benefit and advantages to combine these three approaches (see also genomics). For RNA-seq: Genome-guided RNA-seq assembly, identification and elimination of chimeric or artificial transcript predictions
- Discuss the challenges and considerations in analyzing venom gland transcriptomes, such as tissue-specific expression, differential expression analysis, and post-transcriptional modifications
- The promise of spatial transcriptomics to map differential gene expression to specific locations of venom glands
- Investigate applications in venomomics, including discovering novel toxins, studying venom evolution, and identifying regulatory pathways involved in venom production
- Practical exercise: analyze transcriptomic data using RNA-seq results to identify venom-related genes

Suggested reading:

- Achrak, E. et al., 2022. VenomFlow: an automated bioinformatic pipeline for identification of disulfide-rich peptides from venom arsenals. *Methods Mol. Biol.* 2498: 89-97
- Verdes, A. et al. 2016. From mollusks to medicine: a venomomics approach for the discovery and characterization of therapeutics from Terebridae peptide toxins. *Toxins* 19: 117
- von Reumont, B.M. 2018. Studying smaller and neglected organisms in modern evolutionary venomomics implementing RNASeq (transcriptomics)—A critical guide. *Toxins* 10: 292
- von Reumont, B.M. et al. 2022. Modern venomomics-current insights, novel methods, and future perspectives in biological and applied animal venom research. *Gigascience* 11: giac048
-

Online resources:

- Lecture by Björn M von Reumont on day two of the 2022 online EUVEN Introductory Venomics Training School (<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7Xuw7wvsyoIkploC1iDR>)

5.3. Proteomic methods

Objectives:

- Gain an understanding of mass spectrometry and protein analysis methods
- Overview of proteomic methods
 - Introduction to proteomics: definition and importance in venomics
 - Comparison with genomics and transcriptomics
- Applications in venomics
 - Venom gland proteomics: species-specific profiles, venom composition analysis
 - Functional proteomics: identifying toxin families, understanding toxin variability
 - Comparative proteomics: venom evolution and adaptation studies
- Proteomic workflows
 - Bottom-up proteomics: peptide mass fingerprinting and tandem MS
 - Top-down proteomics: intact protein analysis
- Mass spectrometry (MS) basics
 - Principles of mass spectrometry
 - Types of mass spectrometers: MALDI-TOF, ESI, Orbitrap, Q-TOF
 - Sample preparation: protein extraction, purification, and digestion
- Data acquisition and analysis
 - Data-dependent acquisition (DDA) vs. data-independent acquisition (DIA)
 - Identifying and quantifying proteins: peptide-spectrum matches, database searches, and quantitative approaches (label-free, SILAC, TMT)
- Practical considerations and challenges
 - Sensitivity and specificity issues
 - Handling complex venom samples
 - Overcoming dynamic range limitations
- Hands-on practical exercise
 - Analyzing venom proteomics data using a public database (e.g., UniProt)
 - Performing a simple proteomics experiment: protein extraction, digestion, and MS analysis (virtual or lab-based)

Suggested reading:

- Anand, P. et al. 2014. Sample limited characterization of a novel disulfide-rich venom peptide toxin from terebrid marine snail *Terebra variegata*. *PLoS ONE*, 9: e94122
- Calvete, J.J. (2013). Proteomic tools against the neglected pathology of snake bite envenoming. *Expert Rev. Proteomics* 10: 195-197
- Damm, M. et al. 2025. Mapping the architecture of animal toxin systems by mass spectrometry imaging. *Biotechnol. Adv.* 81: 108548
- El-Aziz, T.M.A. et al. 2020. Advances in venomics: Modern separation techniques and mass spectrometry. *J. Chromatogr. B* 1160: 122352
- Hellinger, R. et al. 2023. Peptidomics. *Nat. Rev. Methods Primers* 3: 25

- Shuken, S.R. 2023 An introduction to mass spectrometry-based proteomics. *J. Proteome Res.* 22: 2151-2171
- Savas, J.N. et al. 2011. Mass spectrometry accelerates membrane protein analysis. *Trends Biochem. Sci.* 36: 388-396
- Smith, R.D. and Kelleher, N.L. 2013. Proteoform: a single term describing protein complexity. *Nat. Methods* 10: 186-187
- Walker, A.A. et al. 2020. Deadly proteomes: a practical guide to proteotranscriptomics of animal venoms. *Proteomics* 20: 1900324
- Wu, C. C., & Yates, J. R. (2003). The application of mass spectrometry to membrane proteomics. *Nat. Biotechnol.* 21: 262-267

Online resources:

- Lectures by Sebastien Dutertre on day two of the 2022 online EUVEN Introductory Venomics Training School and Daniel Petras on day three (<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvsyoIkploC1iDR>)

5.4. Metabolomic methods

Objectives:

- Gain an understanding of metabolite profiling techniques
- Introduction to metabolomics and its importance in studying venom composition
- Applications in venomics
 - Characterizing venom metabolomes: identifying small molecules, toxins, and non-proteinaceous components
 - Linking metabolomic data with proteomic and transcriptomic data for comprehensive venom studies
- Metabolomic workflows
 - Overview of metabolomic studies: design, sample preparation, and analytical techniques
 - Metabolite extraction methods: solvent extraction, solid-phase extraction
- Analytical techniques in metabolomics
 - Mass spectrometry-based and nuclear magnetic resonance spectroscopy-based metabolomics and comparison of their sensitivity, throughput and data richness
- Data processing and analysis
 - Preprocessing steps: peak detection, alignment, normalization
 - Statistical analysis: multivariate analysis (PCA, PLS-DA), univariate analysis
 - Identification and quantification of metabolites: databases (e.g., HMDB, METLIN), software tools (e.g., MetaboAnalyst)
- Practical considerations and challenges
 - Sample complexity and matrix effects
 - Ensuring reproducibility and accuracy in metabolomic studies

- Integrating metabolomic data with other -omics data
- Hands-on practical exercise
 - Utilizing software tools like MetaboAnalyst for analyzing venom metabolomic data
 - Conducting a virtual metabolomics experiment: data acquisition, processing, and interpretation

Suggested reading:

- Alonso, A. et al. 2015. Analytical methods in untargeted metabolomics: state of the art in 2015. *Front. Bioeng. Biotechnol.* 3: 23
- Fiehn, O. 2002. Metabolomics—the link between genotypes and phenotypes. *Plant Mol. Biol.* 48: 155-171
- Johnson, C. et al. 2016. Metabolomics: beyond biomarkers and towards mechanisms. *Nat. Rev. Mol. Cell Biol.* 17: 451–459
- Tanugur-Samancı, A.E. and Kekeçoglu, M. 2021. An evaluation of the chemical content and microbiological contamination of Anatolian bee venom. *PLoS ONE* 16: 1-14
- Wishart, D.S. 2008. Applications of metabolomics in drug discovery and development. *Drugs in R&D* 9: 307-322
- Wishart, D.S. 2019. Metabolomics for investigating physiological and pathophysiological processes. *Physiol. Rev.* 99: 1819-1875

Online resources:

- Lecture by Daniel Petras on day three of the 2022 online EUVEN Introductory Venomics Training School
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7XuW7wvsyoIkploC1iDR>)

5.5. Multiomics integration and web resources

Objectives:

- Obtain the skills to effectively progress from available web resources (largely downstream analyses) to more advanced computing and command-line oriented path for integrative multiomics data analyses
- Advance from descriptive comparative findings to the multilayers of omics datasets
- Application of elaborated computational approaches (e.g. machine learning) for assisting the interpretation of diverse omics data types
- Machine learning training with omics data for predictive assessments to better disentangle the complexity of biological systems and their innovative mechanisms

Suggested reading:

- Zancolli, G. et al. 2024. Web of venom: exploration of big data resources in animal toxin research. *GigaScience* 13: giae054

- Emam, M. et al. 2024. Comparative evaluation of multiomics integration tools for the study of prediabetes: insights into the earliest stages of type 2 diabetes mellitus. *Netw. Model. Anal. Health Inform. Bioinform.* 13: 8
- Zheng, H. et al. 2023. Comparative venom multiomics reveal the molecular mechanisms driving adaptation to diverse predator–prey ecosystems in closely related sea snakes. *Mol. Biol. Evol.*40: msad125

Online resources:

- Comprehensive compilation of web resources, databases, and tools commonly used in venom and toxin-related research (supplementary table of Zancolli et al., 2024): <https://venomzone.expasy.org/10897>

6. Biotechnological and pharmacological applications of animal venoms

Aim: gain an understanding of the translational potential of venoms and their toxins

6.1. Production, isolation, and purification of toxins

Objectives:

- Discuss isolation of bioactive compounds from venoms and toxins derived from various venomous organisms via advanced chromatographic and electrophoretic techniques to achieve high-purity fractions of these compounds
- Discuss characterisation of primary and 3D structure, biochemical properties and functions of purified peptide toxins using instrumental analysis methods

Suggested reading:

- Caliskan, F. et al. 2012. Turkish scorpion *Buthacus macrocentrus*: general characterization of the venom and description of Bu1, a potent mammalian Na⁺-channel α -toxin. *Toxicon* 59: 408-415
- Kim, W. 2021. Bee venom and its sub-components: characterization, pharmacology, and therapeutics. *Toxins* 13: 191
- Lay, M. and Hodgson, W.C. 2024. Isolation and pharmacological characterisation of pre-synaptic neurotoxins from Thai and Javanese Russell's viper (*Daboia siamensis*) venoms. *Toxins* 16: 405
- Möller, C. et al. 2017. Isolation and characterization of Conohyal-P1, a hyaluronidase from the injected venom of *Conus purpurascens*. *J. Proteomics* 164: 73-84
- Tibery, D.V. et al. 2021. Purification and characterization of peptides Ap2, Ap3 and Ap5 (ω -toxins) from the venom of the Brazilian tarantula *Acanthoscurria paulensis*. *Peptides* 145: 170622

Online resources:

- Resource of purified protein sequence and functional information: <https://www.uniprot.org/>
- Database of purified and characterized venom-derived polypeptide ligands shown to be active on the potassium channel: <https://kaliumdb.org/>

6.2. Bioassays of venom toxins

Objectives:

- Introduction to bioassays of crude venom, purified, recombinantly produced, and chemically synthesised venom toxins, and their importance in venom research
- Types of bioassays:
 - *In vitro* bioassays (e.g., cell-based assays, enzyme assays)
 - *In vivo* bioassays (e.g., animal models, behavioral studies)
 - *Ex vivo* bioassays (e.g. venom gland or tissue explants)
 - Direct ligand-receptor binding assays
- Electrophysiology
- Detailed molecular pharmacology readouts (efficacy, potency, affinity etc.)
- High-throughput screening (HTS) assays
 - FRET/BRET (Fluorescence Resonance Energy Transfer/Bioluminescence Resonance Energy Transfer), HTRF (Homogeneous Time-Resolved Fluorescence)
 - Calcium-imaging (FLIPR)
- Bioassays for specific venom toxin activities:
 - Cytotoxicity assays (e.g., cell viability, apoptosis)
 - Neurotoxicity assays (e.g., neuronal cell cultures, FLIPR assays, electrophysiology, behavioral studies)
 - Hemotoxicity assays (e.g., blood coagulation, hemolysis)
- Structure-activity relationships (SAR) of venom toxins
- Data analysis and interpretation
- Statistical analysis of bioassay data

Suggested reading:

- Brusés, J.L. et al. 1993. Specific *in vitro* biological activity of snake venom myotoxins. *J. Neurochem.* 60: 1030-1042
- Palermo, G. et al. 2023. Acetylcholine-binding protein affinity profiling of neurotoxins in snake venoms with parallel toxin identification. *Int. J. Mol. Sci.* 24: 16769
- Patel, R.N. et al. 2023. An *in vitro* assay to investigate venom neurotoxin activity on muscle-type nicotinic acetylcholine receptor activation and for the discovery of toxin-inhibitory molecules. *Biochem Pharmacol.* 216: 115758

Online resources:

- Lecture by Izhar Karbat on day three of the 2022 online EUVEN Introductory Venomics Training School
(<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7Xuw7wvsyoIkploC1iDR>)

6.3. Applications of venom toxins in research, biotechnology, etc.

Objectives:

- Overview of the therapeutic and diagnostic potential of venom toxins
- Venom toxins as research tools for studying biological processes
- Potential of venom toxins for pharmaceutical development
- Applications in:
 - Pain management (e.g., analgesic peptides, venom-derived painkillers)
 - Cardiovascular diseases (e.g., antihypertensive peptides, cardiovascular toxins)
 - Cancer research (e.g., venom-derived compounds with anticancer activity)
 - Neurological disorders (e.g., neuroprotective peptides, neurotoxins for neurological disorders)
 - Skeletal muscle regeneration research (e.g. *Naja mossambica* cardiotoxin, *Notechis scutatus scutatus* notexin)
 - Fight against bacterial resistant strains (e.g. antimicrobial peptides - broad-spectrum activity, low risk, and additional bioactivities, including immunomodulatory, anticancer, etc.
 - Broad applications in human health, agriculture (e.g. biopesticides), aquaculture, etc.
- Case studies:
 - Outline of the GLP1-analog success story; from venom discovery (exendin-4) to blockbuster drugs
 - Approved venom-derived drugs (e.g., exenatide, ziconotide)
 - Venom-derived compounds in clinical trials
 - Research on venom toxins as lead compounds for drug development
- Future directions:
 - Emerging areas of research (e.g., venom toxins for regenerative medicine, venom-derived biomaterials)
 - Challenges and opportunities in translating venom toxin research into clinical applications

Suggested readings:

- Special Issue of *Molecules* on *Bioassay-Guided Isolation of Natural Products*:
https://www.mdpi.com/journal/molecules/special_issues/bioassay-isolation
- Achimba, F. et al. 2023. Targeting dysregulated ion channels in liver tumors with venom peptides. *Mol. Cancer Ther.* 23: 139-147

- El-Aziz, T.M.A. et al. 2020. Advances in venomics: Modern separation techniques and mass spectrometry. *J. Chromatogr. B* 1160: 122352
- Freuville, L. et al. 2024. Venom-derived peptides for breaking through the glass ceiling of drug development. *Front. Chem.* 12: 1465459
- Holford, M. et al. 2018. Venoms to the rescue. *Science* 361: 842-844
- Lewis, R. and Garcia, M. 2003. Therapeutic potential of venom peptides. *Nat. Rev. Drug Discov.* 2: 790–802
- Muttenthaler, M. et al. 2021. Trends in peptide drug discovery. *Nat. Rev. Drug Discov.* 20: 309–325
- Nothias, L.-F. et al. 2018. Bioactivity-based molecular networking for the discovery of drug leads in natural product bioassay-guided fractionation. *J. Nat. Prod.* 81: 758-767
- Oliveira, A.L. et al. 2022. The chemistry of snake venom and its medicinal potential. *Nat. Rev. Chem.* 6: 451–469
- Pineda, S.S. et al. 2014. Spider venomics: implications for drug discovery. *Future Med. Chem.* 6: 1-16
- Smallwood, T.B. and Clark, R.J. 2021. Advances in venom peptide drug discovery: where are we at and where are we heading? *Expert Opin. Drug Discov.* 16: 1163–1173
- Smith, J.J. et al. 2014. Therapeutic applications of spider-venom peptides. In: *Venoms to Drugs: Venom as a Source for the Development of Human Therapeutics* (King, G.F., ed.), Royal Society of Chemistry: 221-244
- Suhas, R. 2022. Structure, function and mechanistic aspects of scorpion venom peptides - A boon for the development of novel therapeutics. *Eur. J. Med. Chem. Rep.* 6: 100068
- Trim, C.M. et al. 2021. Utilisation of compounds from venoms in drug discovery. *Prog. Med. Chem.* 60: 1-66

Online resources:

- Lectures by Maria Ikonomopoulou, Helena Safavi-Hemami, and Gregor Anderluh on day four of the 2022 online EUVEN Introductory Venomics Training School (<https://youtube.com/playlist?list=PLJX3NTqgvWF4x7Xuw7wvsyoIkploC1iDR>)

7. Clinical and epidemiological aspects of animal venoms

Aim: gain an understanding of prevention of envenomations caused by animals that pose a public health risk, improving the diagnosis and treatment of envenomation cases, developing new public health policies, focusing on medically relevant species and producing effective antivenoms

7.1. Medically relevant animal venoms

Objectives:

- Overview of venomous species with significant epidemiological and clinical relevance, including terrestrial snakes, scorpions, spiders, honeybee and marine animals

- Identify key animal species whose venoms present significant medical risks to humans
- Discuss the clinical effects of envenomation, emphasizing symptoms and severity in medically important cases
- Discuss the health risks of venomous species in relation to the effectiveness and availability of antivenoms
- Discuss the alternative treatments used when antivenom is not available
- Highlight regional differences in medically significant venomous species (e.g., Australian marine venoms, South American snakes, African scorpions)
- Address the impact of climate change and ecological and anthropogenic disturbances in altering the geographical distribution of medically significant venomous species
- Highlight the factors influencing the severity of the animal bites (e.g. high temperatures, body size, venom dose, season, age, other diseases, etc.)

Suggested reading:

- Bittenbinder, M.A. et al. 2024. Tissue damaging toxins in snake venoms: mechanisms of action, pathophysiology and treatment strategies. *Commun. Biol.* 7: 358
- Casewell, N.R. et al. 2020. Causes and consequences of snake venom variation. *Trends Pharmacol. Sci.*, 41: 570-581
- Chippaux, J.P. 2017. Incidence and mortality due to snakebite in the Americas. *PLoS Negl. Trop. Dis.* 11: e0005662
- Ericsson, C.D. et al. 2006. Medically important venomous animals: biology, prevention, first Aid, and clinical management. *Clin. Infect. Dis.* 43: 1309–1317
- Hoxha, R. 2006. Two Albanians die from black widow spider bites. *Br. Med. J.* 333: 278
- Mebs, D. 2002. *Venomous and poisonous animals - A handbook for biologists, toxicologists, physicians and pharmacists.* CRC Press
- Santos, M.S.V. et al 2016. Clinical and epidemiological aspects of scorpionism in the world: a systematic review. *Wilderness Environ. Med.* 27: 504-518
- Schaper, A. et al. 2019. Poisoning by exotic pets. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* 62: 1332-1335
- Shackelford, R. et al. 2015. The black widow spider bite: differential diagnosis, clinical manifestations, and treatment options. *J. La. State Med. Soc.* 167: 74-8
- Valverde, F. et al. 2001. Fatal latrodectism in an elderly man. *Med. Clin.* 117: 319-319
- Vetter, R.S. and Isbister, G.K. 2008. Medical aspects of spider bites. *Annu. Rev. Entomol.* 53: 409-429
- Vrenozi, B. 2022. Venomous spiders of Albania—does an increase of temperature influence the toxicity of spider venom? *Toxicon: X* 15: 100135
- Vrenozi, B. and Lugaj, A. 2025. Medically significant spiders (Arachnida: Araneae) and hymenopterans (Insecta: Hymenoptera) of Albania: a comprehensive review of ecology and venom toxicity. *Pol. J. Entomol.* 94: 13-35

- Wigger, E. et al. 2002. The venom optimisation hypothesis: a spider injects large venom quantities only into difficult prey types. *Toxicon* 40: 749-752
- Williams, H.F. et al. 2019. The urgent need for a global snakebite strategy: recommendations for an improved international response. *Lancet Glob. Health* 7: e837–e838
- Yılmaz, M. et al. 2022. Coexistence of rhabdomyolysis, myocarditis and arrhythmia after spider bite: a case report. *J. Trop. Pediatr.* 68: fmac027

Online resources:

- World Health Organisation [Annex 5](#) on snake antivenom immunoglobulins
- Lists of antivenom resources in Germany: <https://www.antivenoms.toxinfo.med.tum.de/>
- Database for clinical treatment of poisoning victims (subscription needed): <https://www.toxinz.com>

7.2. Epidemiology of snakebite, spider bite, and scorpion stings

Objectives:

- Introduction to the One Health concept
- Epidemiological burden of envenomations (emphasis on their prevalence in rural and tropical regions)
- Demographic groups most affected by envenomation (with focus on factors such as age, gender, and occupation)
- Healthcare challenges related to snakebite, spider bite and scorpion stings and their impact on morbidity and mortality rates (disparities in healthcare and antivenom access in remote and underserved areas)
- The importance and development of public/private health initiatives to reduce the burden of envenomation
- The importance of precautions to avoid contact with venomous animals and of first aid in case of being bitten
- Emphasize global disparities in epidemiological reporting and the significance of comprehensive epidemiological databases and registries
- Highlight the importance of community engagement and public education in surveillance and prevention campaigns

Suggested reading:

- Alkahlout, B.H. et al. 2023. Global epidemiology and public health strategies for snakebite envenoming: an updated review. *Front. Public Health* 11: 1158274
- Bettini, S. 1964. Epidemiology of latrodectism. *Toxicon* 2: 93-102
- Chippaux, J.P. 2015. Epidemiology of envenomations by terrestrial venomous animals in Brazil based on case reporting: from obvious facts to contingencies. *J. Venom. Anim. Toxins Incl. Trop. Dis.* 13: 13

- Chippaux, J.P. 2012. Epidemiology of snakebites in Europe: a systematic review of the literature. *Toxicon* 59: 86–99
- Chippaux, J.P. and Goyffon, M. 2008. Epidemiology of scorpionism: A global appraisal. *Acta Trop.* 107: 71–79
- Clark, R.F. et al. 1992. Clinical presentation and treatment of black widow spider envenomation: a review of 163 cases. *Ann. Emerg. Med.* 21: 782-787
- Dzelalija, B. and Medic, A. 2003. *Latrodectus* bites in northern Dalmatia, Croatia: clinical, laboratory, epidemiological, and therapeutical aspects. *Croat. Med. J.* 44: 135-138
- Le Roux, G. et al., Richard, V., Larcher, G., French Poison Control Centers Research Group, Sinno-Tellier, S., Labadie, M., De Haro, L. & Descatha, A. 2021. Spider bites in France: epidaemiology of cases occurring in 10 years in metropolitan France. *Med. Vet. Entomol.* 36: 159-167
- Longbottom, J. et al. 2018. Vulnerability to snakebite envenoming: a global mapping of hotspots. *Lancet* 392: 673-684
- Monte, A.A. et al. 2011. A US perspective of symptomatic *Latrodectus* spp. envenomation and treatment: a National Poison Data System review. *Ann. Pharmacother.* 45: 1491-1498
- Müller, G. 1993. Black and brown widow spider bites in South Africa: a series of 45 cases. *S. Afr. Med. J.* 83: 399-405
- Vrenozi, B. 2022. Venomous spiders of Albania—does an increase of temperature influence the toxicity of spider venom? *Toxicon: X* 15: 100135

Online resources:

- One Health Commission: <https://www.onehealthcommission.org/>
- World Health Organization One Health initiative: <https://www.who.int/news-room/questions-and-answers/item/one-health>
- International Snakebite Awareness Day Website: <https://snakebiteawareness.org/>
- WHO guide to preventing and controlling snakebite envenoming: <https://iris.who.int/bitstream/handle/10665/324838/9789241515641-eng.pdf?sequence=1>

7.3. Clinical treatment of envenomations

Objectives:

- Overview of current international protocols and standardization for the clinical management of snakebites, spider bites, scorpion stings, and other animal-related envenomations
- First aid of snakebites and other envenomations
- Antivenom therapy and its importance in envenomations, including challenges in production, use, distribution, and accessibility with an emphasis on barriers to early antivenom access

- Discuss the emergency interventions required to prevent complications such as acute heart failure, acute myocarditis, kidney failure, bleeding disorders, or muscle damage following envenomation
- Discuss the psychological effects during and after the patient's treatment process, such as pain, fear, and post-injury/disability trauma, including stress
- Emphasize the importance of phobia toward venomous animals, alongside the venom symptoms
- Healthcare challenges in recognizing animal bites and envenomations and administering the proper treatment
- Address the critical need for specialized training of healthcare providers in rural and resource-limited settings
- Introduce the concept and potential of drug repurposing to identify novel envenomation treatments using already marketed drugs
- To explore and apply relevant engineering and design methodologies for the development of next-generation antivenoms

Suggested reading:

- Albulescu, L.O. et al. 2020. Repurposing approved drugs to treat snakebite envenoming: a review. *Toxins* 12: 448
- Borak, D. et al. 2023. Viper envenomation in Central and Southeastern Europe: a multicentre study. *Clin. Toxicol.* 61: 656–64
- Gerardo, C.J. et al. 2019. Does this patient have a severe snake envenomation? The rational clinical examination systematic review. *JAMA Surg.* 154: 346-354
- Gerdes, A.B. et al. 2009. Spiders are special: fear and disgust evoked by pictures of arthropods. *Evol. Hum. Behav.* 30: 66-73
- Gutiérrez, J.M. et al. 2017. Snakebite envenoming. *Nat. Rev. Dis. Primers* 3: 17063
- Gutiérrez, J.M. and Calvete, J.J. 2023. Next-generation antivenoms: translating research into treatments. *Nat. Rev. Drug Discov.* 22: 265-279
- Hornbeak, K.B. and Auerbach, P.S. 2017. Marine envenomation. *Emerg. Med. Clin. North Am.* 35: 321-337
- Knudsen, C. and Laustsen, A.H. 2018. Recent advances in next generation snakebite antivenoms. *Trop. Med. Infect. Dis.* 3: 42
- Lewin, M.R. et al. 2018. Drug repurposing for snakebite treatment: new uses for old drugs. *PLOS Negl. Trop. Dis.* 12: e0006396
- Lopes, P.H. et al. 2020. Clinical aspects, diagnosis and management of *Loxosceles* spider envenomation: literature and case review. *Arch. Toxicol.* 94: 1461-147
- Mammola, S. et al. 2020. Media framing of spiders may exacerbate arachnophobic sentiments. *People nat.* 2: 1145-1157
- Paolino, G. et al. 2021. Key to medically relevant Italian spider bites: a practical quick recognition tool for clinicians. *Clin. Ter.* 172: 336-346

- Pneumatikos, I.A. et al. 2003. Acute fatal toxic myocarditis after black widow spider envenomation. *Ann. Emerg. Med.* 41: 158
- Vrenozi, B. and Lugaj, A. 2025. Medically significant spiders (Arachnida: Araneae) and hymenopterans (Insecta: Hymenoptera) of Albania: a comprehensive review of ecology and venom toxicity. *Pol. J. Entomol.* 94: 13-35
- Wagler, A. and Wagler, R. 2014. Arthropods and the current great mass extinction: effective themes to decrease arthropod fear and disgust and increase positive environmental beliefs in Children? *Int. J. Environ. Sci. Educ.* 9: 197-214
- Warrell, D.A. and Williams, D.J. 2023. Clinical aspects of snakebite envenoming and its treatment in low-resource settings. *Lancet* 401: 1382 - 1398
- Warrell, D.A. 2025. What is new in the treatment of snakebite envenoming? Opportunities and challenges. *Trans. R. Soc. Trop. Med. Hyg.* trae145

Online resources:

- WHO advice on snakebite treatment: <https://www.who.int/teams/control-of-neglected-tropical-diseases/snakebite-envenoming/treatment>
- Video about snakebite prevention and treatment: <https://www.who.int/podcasts/episode/science-in-5/episode--125---snakebites--life-saving-facts#>
- Royal Children's Hospital Melbourne guide for snakebite treatment: https://www.rch.org.au/clinicalguide/guideline_index/Snakebite/
- New South Wales governmental advice on spider and snakebite treatment: <https://aci.health.nsw.gov.au/networks/eci/clinical/tools/snake-spider-bite>
- West Australia governmental advice on snakebite treatment: <https://pch.health.wa.gov.au/for-health-professionals/emergency-department-guidelines/snake-bite>
- Target product profiles for antivenoms in sub-Saharan Africa: https://cdn.who.int/media/docs/default-source/ntds/snakebite-envenoming/sub-saharan-african-antivenom-tpps.pdf?sfvrsn=ab4b74f_9
- WHO recommendation of EchiTABG antivenom for use in sub-Saharan Africa: <https://www.who.int/news/item/19-08-2018-who-issues-new-recommendation-on-antivenom-for-snakebites>