This is an open-access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

P-ISSN: 2304-3075; E-ISSN: 2305-4360
International Journal of Veterinary Science
www.ijvets.com; editor@ijvets.com

Review Article https://doi.org/10.47278/journal.ijvs/2025.044

Applications and Advancements of Animal Cell Cultures in Virology: Insights from Lumpy Skin Disease Virus Research

Raikhan Nissanova [1], Wassie Molla [2], Mukhit Orynbayev [3], Maksat Serikov [1], Vladimir Kirpichenko [1], Ainur Ragatova [4], Markhabat Kassenov [1], Alim Bizhanov [1], Leila Kassymbekova [5], Assylbek Zhanabayev [6], Gulnara Baikadamova [6,*], Aspen Abutalip [1], Assiya Mussayeva [1], Urzhan Omarbekova [1], Yerzhan Ospanov [1], Zhuldus Tlegenova [1], Assiya Borsynbayeva [1], Kairat Turgenbayev [7], Assylbek Mussoyev [8], Maxsat Berdikulov [9], Buerliesi Aheti [6] and Issatay Alymov [6*]

[1]Department of Bacteriology, Kazakh Research Veterinary Institute, Almaty, 050016, Kazakhstan
[2]College of Veterinary Medicine and Animals Sciences, University of Gondar, Gondar 196, Ethiopia
[3]Research Institute for Biological Safety Problems, 080409, Kazakhstan
[4]Department of Veterinary Medicine, A. Baitursynov Kostanay Regional University, 110000, Kazakhstan
[5]Department of Veterinary Medicine and Industrial Technologies, Innovative University of Eurasia, 140000, Pavlodar
[6]Department of Veterinary Medicine, Saken Seifullin Kazakh Agrotechnical University, Astana, 010000, Kazakhstan
[7]Department of Biology, K. Zhubanov Aktobe Regional University, 030000, Kazakhstan
[8]Kazakh National Agrarian Research University, 050008, Almaty, Kazakhstan
[9]National Reference Center for Veterinary Medicine, Astana, 010000, Kazakhstan

***Corresponding author:** gulnar.baykadamova@mail.ru (G.B.); issimovarman@gmail.com (I.A.)

Article History: 25-025 Received: 29-Jan-25 Revised: 16-Mar-25 Accepted: 17-Mar-25 Online First: 29-Apr-2025

ABSTRACT

The article provides a comprehensive review of the current state and future directions for the use of animal cell cultures in virological research. The review critically evaluates the use of animal cell cultures to enhance understanding of viral pathogenesis and improve vaccine development strategies, highlighting promising technologies in this field. It discusses technologies and tools for virus and cell visualization, bioinformatics approaches to data analysis, and the challenges and potential for future research. The review emphasizes the importance of animal cell cultures in studying viruses and developing vaccines, noting the advent of 3D cell culture technologies that enhance the translational significance of *in vitro* models. The adaptation of new culture media mimicking human blood plasma is expected to improve understanding of viral pathogenesis and virus propagation efficiency. The use of animal cell cultures is illustrated through the study of the lumpy skin disease virus. The application of artificial intelligence in cell and tissue cultivation research opens possibilities for modeling and analyzing viral pathogenesis. The article calls for further development in this area, emphasizing the need to establish a National Collection of Cell Cultures.

Key words: Animal cell cultures; Virology; Vaccine development; Lumpy skin disease virus

INTRODUCTION

Animal cell culture is a cornerstone of virological research, offering unparalleled opportunities for the isolation, propagation, and study of viruses under controlled conditions. The adaptability of cell culture systems enables researchers to model viral infections, test antiviral compounds, and develop vaccines with precision (Alomari et al. 2023; Rehman et al. 2024). With the advent of advanced cell culture techniques, including organoids and 3D cultures, researchers have broadened the scope of applications, making it possible to simulate in vivo-like environments (Ozawa et al. 2023).

Cite This Article as: Nissanova R, Molla W, Orynbayev M, Serikov M, Kirpichenko V, Ragatova A, Kassenov M, Bizhanov A, Kassymbekova L, Zhanabayev A, Baikadamova G, Abutalip A, Mussayeva A, Omarbekova U, Ospanov Y, Tlegenova Z, Borsynbayeva A, Turgenbayev K, Mussoyev A, Berdikulov M, Aheti B and Alymov I, 2025. Applications and advancements of animal cell cultures in virology: Insights from lumpy skin disease virus research. International Journal of Veterinary Science x(x): xxxx. https://doi.org/10.47278/journal.ijvs/2025.044

Virology research has increasingly relied on cell lines due to their reproducibility, scalability and compatibility with high-throughput screening (Luo et al. 2023; Rajaram et al. 2020). However, challenges remain in mimicking the complexities of *in vivo* systems, particularly for viruses with strict host-specific requirements (Cordeiro et al. 2024; Douglass et al. 2020). Recent advancements, such as microfluidic platforms and computational modeling, have further enhanced the fidelity of these systems (Kheiri et al. 2024; Keshavarz and Nasab 2023).

Despite their widespread use, cell cultures are not without limitations. Issues such as genetic drift, contamination and differences in cellular responses between *in vitro* and *in vivo* systems necessitate careful optimization and validation (Dolskiy et al. 2020; Urazayeva et al. 2024). As the field advances, the integration of artificial intelligence and multi-omics approaches holds promise for addressing these challenges and improving the predictive power of cell culture-based studies (Tzaferis et al. 2023).

This review aims to provide an overview of the critical role of animal cell cultures in virology, highlighting their applications, limitations and future potential. By synthesizing recent advances and practical insights, this work offers a valuable resource for researchers developing novel viral diagnostics, therapeutics, and vaccines.

The importance and timeliness of this research are underscored by the increasing emergence of novel viral threats and the rapid evolution of viral pathogens. In recent years, outbreaks of infectious diseases have underscored the urgent need for reliable in vitro models that can accurately recapitulate virus–host interactions (Khan et al. 2022; Zhugunissov et al. 2023; Eker et al. 2024; Begum et al. 2024; Ashraf et al. 2025). By refining cell culture techniques and incorporating cutting-edge technologies, such as microfluidics, high-resolution imaging, and single-cell analysis, this study addresses critical gaps in our current methodologies (Liu and Zheng 2024; Gupta et al. 2024). These innovations are essential for accelerating the development of effective vaccines and antiviral therapies, ensuring that research keeps pace with evolving global health challenges. As such, this investigation not only advances our understanding of viral pathogenesis but also provides a timely framework for future research endeavors aimed at protecting public health (Eze et al. 2024; Garg et al. 2024; Tursunov et al. 2024; Prajapati et al. 2024).

Historical development of cell culture

The historical development of cell culture began with the pioneering work of Ross G. Harrison in 1907, who first applied the *in vitro* cell culture method to study the origin of nerve fibers in frogs (Keshavarz and Nasab 2023). This foundational work laid the groundwork for the evolution of cell culture techniques, which have since undergone significant changes and improvements. The progression from embryological techniques to the establishment of tissue culture and the subsequent development of cell culture media further advanced the field (Rogo et al. 2023). The "hanging drop technique" by Harrison and subsequent advancements by Alexis Carel and Charles Lindbergh facilitated the transition from tissue to cell culture, enabling the growth of cells in a monolayer and the cultivation of viruses, which was instrumental in the development of the polio vaccine (Sahu et al. 2024).

In parallel, plant tissue culture emerged from the ideas of the German scientist Haberlandt in the early 20th century, leading to the development of various *in vitro* techniques and applications in plant biology and biotechnology (Husen and Pant 2024). The historical context of cell culture is also intertwined with the broader understanding of cellular systems biology and the protoplasm concept, which has influenced modern cell biology (Krasnova et al. 2023). The ability to grow and maintain individual cell types *in vitro* has allowed for mechanistic studies of whole-organism physiology and has applications in comparative physiology and conservation biology (Jiménez and Harper 2023).

The field of evolutionary cell biology, which examines the origins and functions of cellular features through an evolutionary lens, has also benefited from the tools and insights provided by cell culture, particularly through experimental laboratory evolution (Helsen et al. 2023; Nuraliyeva et al. 2023). Technological advancements, such as the development of the Advanced TC™ polymer modification, have further refined cell culture techniques, improving the propagation of fastidious cells and enhancing cell-based assays (Almeida-Pinto et al. 2023).

In general, the historical development of cell culture is marked by a series of innovations and refinements that have expanded its applications across various biological fields. As shown in Fig. 1, from its inception in the early 20th century to the present day, cell culture has become an indispensable tool in both basic and applied research, contributing to our understanding of cellular functions and the mechanisms of disease.

Animal cell cultivation in virology: methods and their application in virus research and vaccine development

The cultivation of animal cells plays a pivotal role in studying viral replication, pathogenesis, and vaccine development. This section explores the key aspects of animal cell cultures in virology, existing knowledge gaps, and current challenges. Animal cell cultures are broadly classified into primary cultures, cell lines and cell strains. Primary cultures originate directly from tissue explants or cell suspensions and have a limited proliferation capacity before growth ceases (Hasan et al. 2023). Cell lines are capable of continuous propagation through multiple passages, often due to transformation, but may exhibit genetic instability and aneuploidy (Piwocka et al. 2024). Cell strains are derived from primary cultures and, despite passaging, retain certain original cellular properties. Table 1 provides a comparative overview of these cell culture types, summarizing their advantages, disadvantages, and primary applications.

There are interesting contrasts between primary cultures and established cell lines. Primary cultures, such as BC160, are closer to the *in vivo* state but are more laborious to maintain, while established cell lines, like KG55T, offer ease of use but may not fully represent the original tissue's biology (Matsuura 1983; Honegger 1999). Additionally, the timing of subculturing can significantly affect the properties of cultured cells, as seen with neural stem cells, where day 7 was optimal for passaging to maintain cell vitality and differentiation potential (Xiong et al. 2011).

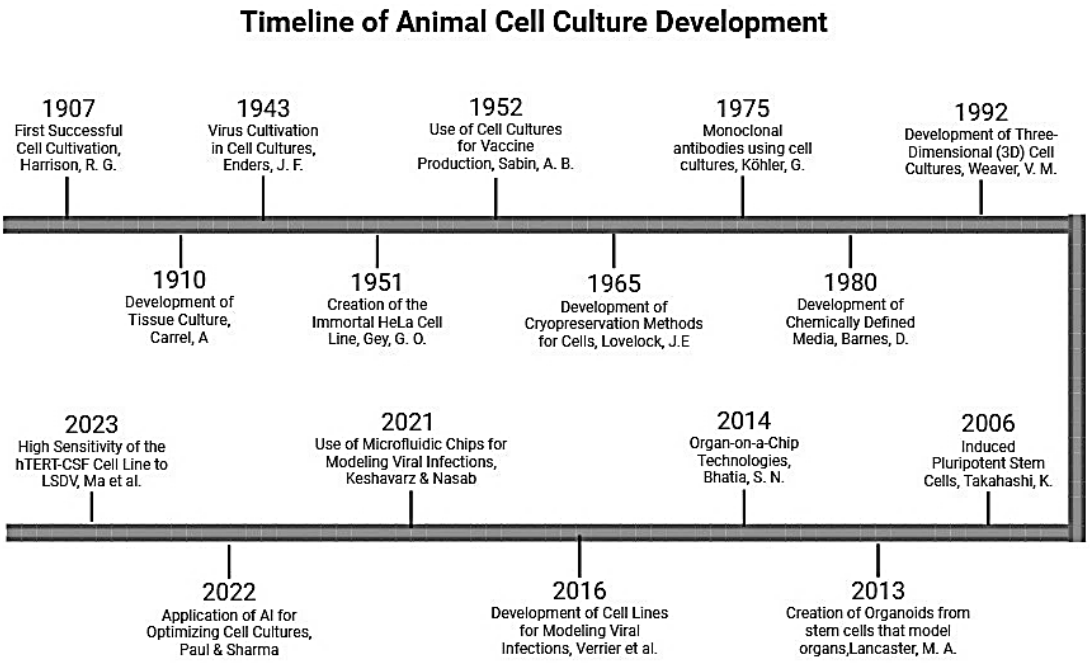

Fig. 1: Timeline of the most significant events in the development of cell cultures.

Table 1: Comparison of Cell Culture Types

No.	Type of cell culture	Advantages	Disadvantages	Area of application
1	Primary cell cultures	High physiological relevance	Limited proliferation, difficulty maintaining	Study of viral pathogenesis, toxicology
2	Cell lines	Easy to culture, reproducible	Risk of genetic instability	Vaccinology, drug testing
3	Cell strains	Resistance to passaging	Gradual loss of original properties	Long-term studies of viruses
4	3D cell culture	Close to *in vivo* simulation, high sensitivity	High costs, difficult to reproduce	Modeling of infectious processes

Table 2: Examples of Viruses and Suitable Cell Cultures for Their Study

Virus	Cell Culture Type	Application	References
Lumpy Skin Disease Virus (LSDV)	Vero, MDBK, hTERT-CSF, BHK-21	Replication study, vaccine production	Ma et al. 2023; Kumar et al. 2021; Wang et al. 2022
Influenza A Virus (IAV)	MDCK, Vero, HEK293	Replication optimization, vaccine production	Rüdiger et al. 2019
Hepatitis C Virus (HCV)	JFH-1 cell line	Life cycle study, antiviral strategies	Wakita 2016
Hepatitis B и D Virus (HBV, HDV)	NTCP-expressing cell lines	Infection modeling, therapeutic strategies	Verrier et al. 2016
Dengue Virus (DENV)	Primary cultures, mouse models, primate cell cultures	Vaccine evaluation, pathogenesis study	Kayesh et al. 2022; Zompi and Harris 2012
Crimean-Congo Hemorrhagic Fever Virus (CCHFV)	Primary cultures, mouse models	Immune response evaluation, vaccine development	He et al. 2016
Rift Valley Fever Virus (RVFV)	CelCradleTM-500A Bioreactors	Vaccine virus production	Rhazi et al. 2021
Hepatitis E Virus (HEV)	HepG2/C3A cells	Replication and pathogenesis study	Meister et al. 2019
SARS-CoV-2	Vero E6, Calu-3, Caco-2	Viral entry mechanism, antiviral testing	Smith et al. 2022
Foot-and-Mouth Disease Virus (FMDV)	BHK-21 cells	Vaccine testing, neutralizing antibody evaluation	Foglia et al. 2022

For a more detailed understanding of the cell cultures used for studying various viruses and their respective purposes, Table 2 presents examples of viruses, the corresponding types of cell cultures, and their key research applications.

As shown in Table 2, different viruses require specific cell cultures optimized for replication and pathogenesis studies. This information provides guidance on selecting appropriate cell cultures to achieve accurate and reproducible results in virological research.

Primary cell cultures are valued for their physiological relevance but are limited by short lifespans and labor-intensive maintenance. Subculturing, or passaging, allows continued cell growth but requires precise timing to preserve cell characteristics (Chalak et al. 2024). Established cell lines offer ease of maintenance and reproducibility but may develop genetic instability and aneuploidy over time (Piwocka et al. 2024). Cell strains balance these qualities, retaining original cellular properties after multiple passages.

Traditional methods, including primary culture establishment and subculturing techniques, laid the groundwork for modern cell culture technology and remain essential tools in viral research (Spier 1992; Zhong et al. 2009; Dirks 2021). These approaches continue to be relevant for applications such as viral pathogenesis studies, toxicology assessments, and vaccine development.

Advances in second- and third-generation sequencing technologies enable precise genomic analysis of cell

cultures (Kazim et al. 2024). New chemically defined and protein-free media formulations offer improved control over cell environments, enhancing growth and productivity (Park et al. 2023). Bioreactor technology has enabled better control over key parameters, such as oxygen supply and redox potential, which are vital for cell physiology and viral protein expression (Ge et al. 2023).

While traditional methods remain indispensable, modern technologies have revolutionized cell culture practices, improving precision, scalability and applicability across virology and biomedical research.

The application of animal cell cultures in the study of lumpy skin disease virus

Lumpy Skin Disease Virus (LSDV), which causes a contagious disease in cattle, belongs to the genus Capripoxvirus (Khalafalla 2022). Despite extensive research, significant gaps remain in understanding the mechanisms of LSDV transmission and the role of vectors, particularly given the virus's ability to adapt to diverse environments and the emergence of recombinant strains (Sprygin et al. 2020; Shumilova et al. 2022; Wilhelm and Ward 2023).

LSDV induces fever, nodular skin lesions, and significant economic losses, especially among susceptible herds (Akther et al. 2023). Interestingly, although the virus is transmitted by blood-feeding insects, studies suggest they act primarily as mechanical vectors, as the virus does not productively replicate in insect cell lines (Tuppurainen et al. 2011; Cook et al. 2019).

Cell cultures play a central role in studying LSDV, providing a controlled environment for investigating viral replication, pathogenesis, and the development of therapeutic interventions (Chervyakova et al. 2019; Orynbayev et al. 2021). For example, the use of MDBK (Madin-Darby Bovine Kidney) cells and chicken chorioallantoic membranes (CAM) enabled researchers to study the role of the viral superoxide dismutase (SOD) homolog in viral growth and histopathological changes (Douglass et al. 2020). In another study, complete inactivation of the Neethling vaccine strain was confirmed following treatment with binary ethylenimine (BEI), inducing a robust immune response in rabbits (Hamdi et al. 2020; Matsiela et al. 2022).

LSDV has also been successfully propagated in lamb testes cell cultures, where pronounced cytopathic effects (CPE) were observed (Khan et al. 2021). In India, the virus was isolated using primary goat cells and later adapted to Vero cells, although CPE was not consistently observed (Kumar et al. 2021). Similarly, successful virus isolation was reported using MDBK cell cultures in China (Wei et al. 2023). However, studies reveal inconsistencies regarding the suitability of Vero cells for primary LSDV isolation, potentially due to differences in viral strains or culture conditions (Kumar et al. 2021; Wang et al. 2022).

Vaccine development for LSDV relies on various cell cultures for virus propagation and the production of live attenuated vaccines. The hTERT-CSF cell line demonstrated the highest viral load, highlighting its potential for vaccine production (Ma et al. 2023). Similarly, the BHK-21 cell line has shown suitability for producing attenuated LSDV vaccines (van Diepen et al. 2021). However, challenges remain concerning genetic stability,

The integration of Process Analytical Technology (PAT) and Quality by Design (QbD) principles ensures reproducibility and product quality in cell-based biopharmaceutical production (Gibbons et al. 2023). Additionally, transient transfection assays have become more refined, streamlining the production of therapeutic proteins (Porosk et al. 2022).

safety and immunogenicity of vaccine strains (Haegeman et al. 2021; Chervyakova et al. 2022). The use of bioreactors has further improved the efficiency of vaccine production (Rhazi et al. 2021).

Serological diagnostic systems for LSDV require substantial viral biomass production. Cell lines such as hTERT-CSF and BHK-21 have shown high susceptibility to LSDV, making them suitable candidates for propagating the virus and producing recombinant proteins (van Diepen et al. 2021; Ma et al. 2023).

Cell cultures remain indispensable tools for studying molecular mechanisms of LSDV infection, evaluating vaccine candidates, and understanding virus-host interactions. These systems are critical for developing effective strategies to combat Lumpy Skin Disease.

Challenges and prospects for research development

The current landscape of cell culture research is marked by both challenges and promising prospects. A major challenge is the standardization of cell cultivation methods, which is crucial for reproducibility and scientific progress (Seisenov et al. 2023; Pamies et al. 2024; Kulpiisova et al. 2024). The lack of standardized protocols and documentation methods can reduce laboratory efficiency and jeopardize the reproducibility of results, a foundational requirement in scientific research (Batista Leite et al. 2024). Moreover, data reproducibility issues are particularly pertinent in certain fields, such as research involving variable genomic integrity (VGI), where the characteristics of the data itself pose difficulties. Another challenge is the need for cell cultivation methods that can accurately predict the biocompatibility of materials, which is essential for research and development in biomaterials (Yadav et al. 2024). Additionally, the development of *in vitro* models that accurately reflect physiological systems and organs remains an ongoing endeavor, as contemporary methods continue to strive to overcome the limitations of standard approaches (Bajek and Tylkowski 2021).

Despite these challenges, significant prospects exist for advancing research. Advances in the cultivation technologies of human pluripotent stem cells (hPSCs) address critical issues related to safety, quality control, and cost management, which are essential for the clinical translation of cell therapy products (Ozawa et al. 2023; Kulpiisova et al. 2024). The evolution of cell cultivation methods, including 3D organoid models, facilitates the development of personalized medicine and translational research (Preksha et al. 2021; Bulekov et al. 2023). Moreover, the validation of "in-field" cell cultivation protocols expands the capabilities of biobehavioral research in local and remote field conditions (McDade et al. 2021). Although this field faces challenges associated with standardization and reproducibility, the continual development of new cell cultivation methods and the integration of innovative technologies open exciting prospects for advancing research and clinical applications

(Kargaeyeva et al. 2023). The future of cell culture research promises more personalized and precise medical interventions, as well as broader accessibility to complex research methodologies beyond traditional laboratory settings (Waldstein et al. 2024). The development of cell lines resistant to common pollutants is a pertinent area of research. Studies have shown that environmental pollutants can induce neurotoxicity and developmental neural toxicity, and human-derived neural cell lines, such as the SH-SY5Y neuroblastoma cell line, are utilized to investigate these effects (Li et al. 2023) Additionally, primary cell lines, like the BC160 breast cancer culture, are valuable for cancer research, although they present challenges in isolation and maintenance, which can lead to a preference for established cell lines (Piwocka et al. 2024).

Among the promising directions for advancing cell cultures in virology is the adoption of three-dimensional (3D) models such as organoids, organ-on-a-chip systems, and spheroids (Li et al. 2023). Organoids mimic entire organs, providing more accurate *in vivo*-like conditions, while organ-on-a-chip devices simulate organ functions, facilitating targeted studies of viral effects. Spheroids offer improved 3D tissue organization, enhancing the understanding of viral growth and pathogenesis. These 3D models are essential complements to traditional approaches and could play a pivotal role in future virological research.

Conclusion

Animal cell cultures are crucial tools in virological research, offering a controlled environment to study virus growth, replication, and host-pathogen interactions. Advances in cell culture technologies, particularly the development of 3D cultures, have enhanced the relevance of *in vitro* models, making them more reflective of living organisms. This improvement is vital for understanding virus-host dynamics and developing effective therapies. However, challenges such as scalability, reproducibility, and standardization of 3D culture methods persist and require ongoing attention. The integration of AI into cell culture research offers promising avenues for innovation. AI can enhance data analysis, predictive modeling, and the optimization of culture conditions, potentially revolutionizing virological research, although challenges in data integration and model accuracy remain. Additionally, novel media formulations that closely mimic human blood plasma could significantly advance our understanding of viral pathogenesis and improve antiviral drug efficacy. However, these new media require careful validation to ensure they meet the diverse needs of different cell types and experimental setups.

Declarations

Funding: The research was carried out within the framework of the scientific and technical project "Improvement of measures to ensure biological safety in Kazakhstan: Counteraction to dangerous and especially dangerous infections" BR218004/0223 on the task: "Monitoring of epidemiological and epizootological situation, external and priority internal sources of threats to biological safety".

Acknowledgement: The authors sincerely acknowledge Peter White, University of Sydney, for revising the English text.

Conflict of Interest: The authors declare no conflicts of interest.

Author's Contribution: R.N., W.M., G.B.: supervision, writing—original draft, writing—review and editing. M.O., M.S., V.K., A.R., M.K., A.B., L.K., A.Zh., A.A., A.M., U.O., Y.O., Zh.T., A.B., K.T., A.M., M.B., B.A., I.A.: formal analysis, visualization, validation, resources, conceptualization, methodology, investigation.

Data Availability Statement: Data generated for this study is present in Tables/Figure form.

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

Publisher's Note: All claims stated in this article are exclusively those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated/assessed in this article or claimed by its manufacturer is not guaranteed or endorsed by the publisher/editors.

REFERENCES

Akther M, Akter SH, Sarker S, Aleri JW, Annandale H, Abraham S and Uddin JM, 2023. Global burden of lumpy skin disease, outbreaks, and future challenges. Viruses 15(9): 1861. https://doi.org/10.3390/v15091861

Almeida-Pinto J, Mano JF, Gaspar V M, Lagarto MR and Lavrador P, 2023. Cell surface engineering tools for programming living assemblies. Advanced Science 10(34): 2304040. https://doi.org/10.1002/advs.202304040

Alomari T, Al-Abdallat H, Hamamreh R, Alomari O, Hos BH, and Reiter RJ, 2023. Assessing the antiviral potential of melatonin: A comprehensive systematic review. Reviews in Medical Virology 34(1): p.e2499. https://doi.org/10.1002/rmv.2499

Ashraf MA, Raza MA, Imran A and Amjad MN, 2025. Next-generation vaccines for influenza B virus: advancements and challenges. Archives of Virology 170(2): p.25. https://doi.org/10.1007/s00705-024-06210-4

Bajek A and Tylkowski B, 2021. Medical Physics: Models and Technologies in Cancer Research. Walter de Gruyter GmbH and Co KG. https://doi.org/10.1515/9783110662306-202

Batista Leite S, Brooke MA, Carusi A, Collings A, Deceuninck P, Dechamp JF, Dekker B, De Ranieri E, Ganley E, Gastaldello A, He F, LaFlamme M, Langezaal I, Morris J, Pamies D, Piergiovanni M, Pulverer B, Sadler D, Shamu C, Siegel V, Straccia M and Weissgerber TL, 2024. Promoting reusable and open methods and protocols (PRO-MaP) can improve methodological reporting in the life sciences. PLoS Biology 22(9): e3002835. https://doi.org/10.1371/journal.pbio.3002835

Begum R, Uddin MB, Rahman MM, Roy M, Rahman A, Rafe-Ush-Shan SM, Chowdhury MSR, Hossain H, Alam J, Cho HS and Hossain MM, 2024. Lumpy skin disease in Bangladesh: seroprevalence and risk factors of LSD in cattle. International Journal of Veterinary Science 13(6): 896-902. https://doi.org/10.47278/journal.ijvs/2024.207

Bulekov TA, Limanskaya VB, Bulekova AA, Davletova AM and Kasimova GV, 2023, March. Agrotechnics of sorghum in

grass-field crop rotation for the conditions of the West Kazakhstan region. In IOP Conference Series: Earth and Environmental Science 1154 (1): p. 012053. https://doi.org/10.1088/1755-1315/1154/1/012053

Chalak M, Hesaraki M, Rajabi S, Abdi S, Hemmatzadeh F, Yeganeh M and Mirbahari SN, 2024. Cell Immortality: In vitro effective techniques to achieve and investigate its applications and challenges. Life 14(3): 417. https://doi.org/10.3390/life14030417

Chervyakova OV, Sultankulova K T, Nissanova RK and Orynbayev MB, 2019. Lumpy Skin Disease Virus: Approaches to attenuation for vaccine development. Eurasian Journal of Applied Biotechnology 1: 21-32. https://doi.org/10.11134/btp.1.2019.1

Chervyakova O, Issabek A, Sultankulova K, Bopi A, Kozhabergenov N, Omarova Z, Tulendibayev A, Aubakir N and Orynbayev M, 2022. Lumpy Skin Disease Virus with four knocked out genes was attenuated in vivo and protects cattle from infection. Vaccines 10 (10): 1705. https://doi.org/10.3390/vaccines10101705

Cook C, Dietrich I, Greaves D, Darpel K and Beard P, 2019. Lumpy Skin Disease Virus does not replicate productively in insect cell lines. Microbiology Society 1(10): 36-40. https://doi.org/10.1099/acmi.imav2019.po0025

Cordeiro S, Oliveira BB, Valente R, Ferreira D, Luz A, Baptista PV and Fernandes AR, 2024. Breaking the mold: 3D cell cultures reshaping the future of cancer research. Frontiers in Cell and Developmental Biology 12: 1507388. https://doi.org/10.3389/fcell.2024.1507388

van Diepen M, Chapman R, Douglass N, Whittle L, Chineka N, Galant S, Cotchobos C, Suzuki A and Williamson AL, 2021. Advancements in the growth and construction of recombinant Lumpy Skin Disease Virus (LSDV) for use as a vaccine vector. Vaccines 9 (10): 1131. https://doi.org/10.3390/vaccines9101131

Dirks WG, 2021. Ethical challenges using human tumor cell lines in cancer research. Springer: 39–46. https://doi.org/10.1007/978-3-030-63749-1_4

Dolskiy AA, Grishchenko IV and Yudkin DV, 2020. Cell cultures for virology: Usability, advantages, and prospects. International Journal of Molecular Sciences 21 (21): 7978. https://doi.org/10.3390/ijms21217978

Douglass N, Munyanduki H, Ruzaiq O, Gers S, Mutowembwa P, Heath L and Williamson AL, 2020. Influence of the viral superoxide dismutase (SOD) homologue on lumpy skin disease virus (LSDV) growth, histopathology and pathogenicity. Vaccines 8 (4): 664. https://doi.org/10.3390/vaccines8040664

Eker F, Duman H, Ertürk M and Karav S, 2024. The potential of lactoferrin as antiviral and immune-modulating agent in viral infectious diseases. Frontiers in Immunology 15: p.1402135. https://doi.org/10.3389/fimmu.2024.1402135

Eze C, Emeihe E, Nwankwo E and Igwama G, 2024. AI-driven health data analytics for early detection of infectious diseases: A conceptual exploration of U.S. public health strategies. Comprehensive Research and Reviews in Science and Technology 2(2): 074–082. https://doi.org/10.57219/crrst.2024.2.2.0038

Foglia EA, Chaligava T, Aliyeva T, Kharatyan S, Tranquillo V, Pötzsch C, van Maanen C, Rosso F, Grazioli S, & Brocchi E, 2024. Evaluation of Two Vaccines against Foot-and-Mouth Disease Used in Transcaucasian Countries by Small-Scale Immunogenicity Studies Conducted in Georgia, Azerbaijan and Armenia. Vaccines 12(3): 295. https://doi.org/10.3390/vaccines.12030295

Garg P, Pareek S, Kulkarni P, Horne D, Salgia R and Singhal SS, 2024. Next-Generation Immunotherapy: Advancing Clinical Applications in Cancer Treatment. Journal of Clinical Medicine 13(21): 6537. https://doi.org/10.3390/jcm13216537

Ge C, Geng F and Selvaganapathy PR, 2023. Advancing our understanding of bioreactors for industrial-sized cell culture: health care and cellular agriculture implications. American Journal of Physiology-Cell Physiology 325(3): C580–C591. https://doi.org/10.1152/ajpcell.00408.2022

Gibbons L, Magill A, Madden F, Le N, O'Mahony-Hartnett C, Hayes R, Rode C, Mclaughlin J, Rea R, O'Mahony J, Mccarthy B, Singh, P and Maslanka F, 2023. An assessment of the impact of Raman based glucose feedback control on CHO cell bioreactor process development. Biotechnology Progress 39(5): p.e3371. https://doi.org/10.1002/btpr.3371

Gupta P, Mohan A, Mishra A, Nair A, Chowdhury N, Balekai D, Rai K, Prabhakar A and Saiyed T, 2024. Multiplexed fluorescence and scatter detection with single cell resolution using on-chip fiber optics for droplet microfluidic applications. Microsystems and Nanoengineering 10(1): 35. https://doi.org/10.1038/s41378-024-00665-w

Haegeman A, De Leeuw I, Mostin L, Van Campe W, Aerts L, Venter E, Tuppurainen E, Saegerman C and De Clercq K, 2021.Comparative evaluation of Lumpy Skin Disease Virus-Based live attenuated vaccines. Vaccines 9 (5): 473. https://doi.org/10.3390/vaccines9050473

Hasan MM, Li T and Sekiya R, 2023. Ex vivo expansion of primary cells from limb tissue of Pleurodeles waltl. Development, growth and differentiation 65(5): 255–265. https://doi.org/10.1111/dgd.12866

Hamdi J, Boumart Z, Daouam S, El Arkam A, Bamouh Z, Jazouli M, Tadlaoui KO, Fihri OF, Gavrilov B and El Harrak M, 2020. Development and Evaluation of an Inactivated Lumpy Skin Disease Vaccine for Cattle. Veterinary Microbiology 245: 108689. https://doi.org/10.1016/j.vetmic.2020.108689

He B, Chen G and Zeng Y, 2016. Three-dimensional cell culture models for investigating human viruses. Virologica Sinica 31: 363–79. https://doi.org/10.1007/s12250-016-3889-z

Helsen J, Sherlock G and Dey G, 2023. Experimental evolution for cell biology. Trends in Cell Biology 33(11): 903-912. https://doi.org/10.1016/j.tcb.2023.04.006

Honegger P, 1999. Overview of cell and tissue culture techniques. Current Protocols in Pharmacology 4(1): 11–12. https://doi.org/10.1002/0471141755.ph1201s04

Husen A and Pant M, 2024. Tissue Culture Techniques and Medicinal Plants: Enhancing Propagation and Production. CRC Press 5(2): 1944-1978. https://doi.org/10.1002/0471141757.fr1201s74

Jiménez AG and Harper JM, 2023. Exploring the role of primary fibroblast cells in comparative physiology: A historical and contemporary overview. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 325 (1): 45–54. https://doi.org/10.1152/ajpregu.00025.2023

Kargaeyeva M, Aubakirov K, Mongush S, Sayana Iskhan K, Davletova A and Baimukanov A, 2023. OnLine Journal of Biological Sciences 23 (1): 81-86. https://doi.org/10.3844/ojbsci.2023.81.86

Kayesh MEH and Tsukiyama-Kohara K, 2022. Mammalian animal models for dengue virus infection: A recent overview. Archives of Virology 4(6): 1–14. https://doi.org/10.1007/s00705-021-05298-2

Kazim I, Verma S, Gyatsho K, Bhutia E and Reyher K, 2024. Advancements in sequencing technologies. Journal of Knowledge Learning and Science Technology 3(4): 108–124. https://doi.org/10.60087/jklst.v3.n4.p108

Keshavarz M and Nasab AN, 2023. Cell culture techniques in microfluidic chips. In principles of human organs-on-chips 11: 89–121. https://doi.org/10.1016/B978-0-12-823536-2.00008-0

Khalafalla A, 2022. Lumpy Skin Disease: An economically significant emerging disease. In Cattle Diseases-Molecular and Biochemical Approach. IntechOpen; 432-458. https://doi.org/10.5772/intechopen.108845

Khan A, Du XX, Hussain R and Kwon OD, 2022. Lumpy skin

disease: A threat to the livestock industry - A review. Agrobiological Records 9: 22-36. https://doi.org/10.47278/journal.abr/2022.015

Khan YR, Hussain AAK, Ijaz M, Rabbani AH, Khan RL, Abbas SN, Aziz MU, Ghaffar A and Sajid HA, 2021. A review: Surveillance of lumpy skin disease (LSD) a growing problem in Asia. Microbial Pathogenesis 158: 105050. https://doi.org/10.1016/j.micpath.2021.105050

Krasnova O, Kovaleva A, Saveleva A, Kulakova K, Bystrova O, Martynova M, Domnina A, Sopova J and Neganova I, 2023. Mesenchymal stem cells lose the senescent phenotype under 3D cultivation. Stem Cell Research andamp; Therapy 14(1): 373. https://doi.org/10.1186/s13287-023-03599-8"

Kumar N, Chander Y, Kumar R, Khandelwal N, Riyesh T, Chaudhary K, Shanmugasundaram K, Kumar S, Kumar A and Gupta MK, 2021. Isolation and characterization of lumpy skin disease virus from cattle in India. PLoS One 16 (1): e0241022. https://doi.org/10.1371/journal.pone.0241022

Kulpiisova A, Aitpayeva Z, Maimatayeva A, Ussenova, Paritova A, Zhanabayev A, Bakishev T, Tursunkulov S, Kitapbay T, Abutalip A. and Mussayeva A, Ospanov Y, Omarbekova U, Turalin B, Sapa V, Aisin M, Bizhanov A, Baikadamova G, Chylbak-ool S, Pakhomova E, Rametov N, Issimov A and Burambayeva N, 2024. Knowledge, attitude and practice related to anthrax among livestock farmers in West Kazakhstan. Veterinary Medicine and Science 10(5): e1553. https://doi.org/10.1002/vms3.1553

Kulpiisova A, Yessengaliyev K, Kassimova G, Kozhakhmetova A, Kadraliyeva B, Rustem A, Temirzhanova A, Burambayeva N, Chylbak-Ool S, Pakhomova E, Abekeshev N, Baikadamova G, Kemeshev Z, Tegza A, Issimov A and White P, 2024. Utilization of assisted reproductive technologies in breeding Auliekol Cattle: A Comparative Study. Life 14(9): p.1167. https://doi.org/10.3390/life14091167

Li J, Bai H, Wang Z, Xu B, Olson KNP, Liu C, Su Y, Hao J, Shen J and Xi X, 2023. Advancements in organs-on-chips technology for viral disease and anti-viral research. Organs-on-a-Chip 5: 100030. https://doi.org/10.1016/j.ooc.2023.100030

Li MR, Men SH, Wang ZY, Liu C, Zhou GR and Yan ZG, 2023. The application of human-derived cell lines in neurotoxicity studies of environmental pollutants. Science of the Total Environment 912: 168839. https://doi.org/10.1016/j.scitotenv.2023.168839

Liu X and Zheng X, 2024. Microfluidic-based electrical operation and measurement methods in single-cell analysis. Sensors (Basel, Switzerland) 24(19): 6359. https://doi.org/10.3390/s24196359

Luo X, Liu L, Ma B, Lin Q, Fu X, Niu Y, Li N, Liang H and Zhang M, 2023. Development of a new marine fish continuous cell line derived from brain of Red Sea Bream (Pagrosomus major) and its application to fish virology and heavy metal toxicology. Animals 13(22): 3524. https://doi.org/10.3390/ani13223524

Ma C, Ren S, Afera TB, Yang X, Lin Y, Gao X, Wang F, Qiu X, Wang X and Yin X, 2023. The comparative study revealed that the HTERT-CSF cell line was the most susceptible cell to the lumpy skin disease virus infection among eleven cells. Journal of Virological Methods 317: 114745. https://doi.org/10.1016/j.jviromet.2023.114745

Matsiela MS, Naicker L, Dibakwane VS, Ntombela N, Khoza T and Mokoena N, 2022. Improved safety profile of inactivated neethling strain of the lumpy skin disease vaccine. Vaccine*: X* 12: 100209. https://doi.org/10.1016/j.jvacx.2022.100209

Matsuura H, 1983. Primary cultured cells and an established cell line of human hepatocellular carcinomas. Acta Medica Okayama 37 (4): 341–52. https://doi.org/10.18926/AMO/32387

McDade TW, Aronoff JE, Leigh AK, Finegood ED, Weissman-Tsukamoto RM, Brody GH and Miller GE, 2021. Out of the laboratory and into the field: Validation of portable cell culture protocols. Psychosomatic Medicine 83 (3): 283–90. https://doi.org/10.1097/psy.0000000000000923

Meister TL, Bruening J, Todt D and Steinmann E, 2019. Cell culture systems for the study of hepatitis E virus. Antiviral Research 163: 34–49. https://doi.org/10.1016/j.antiviral.2019.01.007

Nuraliyeva U, Spatay N, Davletova A, Toishimanov M, Moldakhmetova G, Kussainova Z, Khudaiberdiev A, Khrapova S and Baimukanov D, 2023. OnLine Journal of Biological Sciences 23 (4): 520.527, https://doi.org/10.3844/ojbsci.2023.520.527

Orynbayev MB, Nissanova RK, Khairullin BM, Issimov A, Zakarya KD, Sultankulova KT, Kutumbetov LB, Tulendibayev AB, Myrzakhmetova BS and Burashev ED, 2021. Lumpy Skin Disease in Kazakhstan. Tropical Animal Health and Production 53: 1–7. https://doi.org/10.1007/s11250-021-02613-6

Ozawa H, Matsumoto T and Nakagawa M, 2023. Culturing human pluripotent stem cells for regenerative medicine. Expert Opinion on Biological Therapy 23 (6): 479–489. https://doi.org/10.1080/14712598.2023.2225701

Pamies D, Hartung T, Loskill P, Reyes DR, Suter-Dick L, Erfurth H, Werner S, Zurich MG, Pistollato F, Dehne EM, Coecke S, Stacey GN, Piergiovanni M, Wang S, Frey O, Candarlioglu P, Wagegg BA, Leist M, Freedman BS and Teo K, 2024. Recommendations on fit-for-purpose criteria to establish quality management for microphysiological systems and for monitoring their reproducibility. Stem Cell Reports 19(5): 604–617. https://doi.org/10.1016/j.stemcr.2024.03.009

Park S, Cho H, Hong BH, Lee D, Park U, Silberberg YR, Song J and Choi D, 2023. Debottlenecking and reformulating feed media for improved CHO cell growth and titer by data-driven and model-guided analyses. Biotechnology Journal 18(12): p.2300126. https://doi.org/10.1002/biot.202300126

Piwocka O, Musielak M, Ampuła K, Piotrowski I, Adamczyk B, Fundowicz M, Suchorska WM and Malicki J, 2024. Navigating challenges: Optimising methods for primary cell culture isolation. Cancer Cell International 24 (1): 28. https://doi.org/10.1186/s12935-023-03190-4

Porosk L, Nebogatova J, Härk HH, Vunk B, Arukuusk P, Toots U, Ustav M, Langel Ü and Kurrikoff K, 2022. Expressed therapeutic protein yields are predicted by transiently transfected mammalian cell population. BioRxiv: 2003–22. https://doi.org/10.1101/2022.03.15.484372

Prajapati RN, Bhushan B, Singh K, Chopra H, Kumar S, Agrawal M, Pathak D, Chanchal DK and Laxmikant L, 2024. Recent advances in pharmaceutical design: Unleashing the potential of novel therapeutics. Current Pharmaceutical Biotechnology 25(16): 2060–2077. https://doi.org/10.2174/0113892010275850240102105033

Preksha G, Rajendran Yesheswini R and Srikanth CV, 2021. Cell culture techniques in gastrointestinal research: Methods, possibilities and challenges. Indian Journal of Pathology and Microbiology 64 (Suppl 1): S52–57. doi: https://doi.org/10.4103/IJPM.IJPM_933_20

Rajaram S, Boikos C, Gelone DK and Gandhi A, 2020. Influenza Vaccines: The potential benefits of cell-culture isolation and manufacturing. Therapeutic Advances in Vaccines and Immunotherapy 8: 2515135520908121. https://doi.org/10.1177/2515135520908121

Rehman S, Abuzahra M, Wibisono FJ, Effendi MH, Khan MS, Ullah S, Abubakar AA, Zaman A, Shah MK, Malik MI, Rahman A, Abbas A and Nadeem M, 2024. Identification of risk factors and vaccine efficacy for lumpy skin disease in Sidoarjo and Bblitar districts of East Java, Indonesia.

International Journal of Veterinary Science 13(5): 574-579. https://doi.org/10.47278/journal.ijvs/2024.137

Rhazi H, Safini N, Mikou K, Alhyane M, Tadlaoui KO, Lin X, Venkatesan NP and Elharrak M, 2021. Production of small ruminant morbillivirus, rift valley fever virus and lumpy skin disease virus in CelCradle™-500A Bioreactors. BMC Veterinary Research 17:1–9. https://doi.org/10.1186/s12917-021-02801-4

Rogo U, Fambrini M and Pugliesi C, 2023. Embryo rescue in plant breeding. Plants 12(17): 3106. https://doi.org/10.3390/plants12173106; https://doi.org/10.3390/plants12173106

Rüdiger D, Kupke SY, Laske T, Zmora P and Reichl U, 2019. Multiscale modeling of influenza a virus replication in cell cultures predicts infection dynamics for highly different infection conditions. PLOS Computational Biology 15 (2): e1006819. https://doi.org/10.1371/journal.pcbi.1006819

Sahu H, Choudhari SG, Gaidhane A and Chakole S, 2024. Jonas Salk (1914-1995): Pioneering the fight against polio and beyond. Cureus 16 (9). https://doi.org/10.7759/cureus.69681

Seisenov B, Duimbayev D, Kazhgaliyev N, Abdrakhmanov T, Tegza A, Abeldinov R, Burambayeva N, Temirzhanova A, Tegza I, Kemeshev Z, Zhanabayev A, Akhmetbekov N, Aisin M, Zhugunissov K and Arman Issimov A, 2023. In vitro fertilization in Kazakh Whiteheaded cattle: A comparative study. Life 13(8): p.1632. https://doi.org/10.3390/life13081632

Shumilova I, Krotova A, Nesterov A, Byadovskaya O, van Schalkwyk A and Sprygin A, 2022. Overwintering of recombinant lumpy skin disease virus in northern latitudes, Russia. Transboundary and Emerging Diseases 69 (5): e3239–43. https://doi.org/10.1111/tbed.14521

Smith D, Price DR, Faber MN, Chapuis AF and McNeilly TN, 2022. Advancing animal health and disease research in the lab with three-dimensional cell culture systems. Veterinary Record 191 (1). https://doi.org/10.1002/vetr.1528

Spier RE, 1992. Animal cells in culture are microorganisms. Cytotechnology 8: 89–92 https://doi.org/10.1007/BF02525490

Sprygin A, Van Schalkwyk A, Shumilova I, Nesterov A, Kononova S, Prutnikov P, Byadovskaya O and Kononov A, 2020. Full-length genome characterization of a novel recombinant vaccine-like lumpy skin disease virus strain detected during the climatic winter in Russia, 2019. Archives of Virology 165 (11): 2675–77. https://doi.org/10.1007/s00705-020-04756-7

Tuppurainen ESM, Stoltsz WH, Troskie M, Wallace DB, Oura CAL, Mellor PS, Coetzer JAW and Venter EH, 2011. A potential role for ixodid (hard) tick vectors in the transmission of lumpy skin disease virus in cattle. Transboundary and Emerging Diseases 58 (2): 93–104. https://doi.org/10.1111/j.1865-1682.2010.01184.x

Tursunov K, Tokhtarova L, Kanayev D, Mustafina R, Tarlykov P and Mukantayev K, 2024. Evaluation of an in-house ELISA for detection of antibodies against the Lumpy Skin Disease virus in vaccinated cattle. International Journal of Veterinary Science 13(2): 248-253. https://doi.org/10.47278/journal.ijvs/2023.089

Tzaferis C, Karatzas E, Baltoumas FA, Pavlopoulos GA, Kollias G and Konstantopoulos D, 2023. SCALA: A complete solution for multimodal analysis of single-cell next generation sequencing data. Computational and Structural Biotechnology Journal 21: 5382–93. https://doi.org/10.1016/j.csbj.2023.10.032

Urazayeva ST, Kurmangaliyeva SS, Kaliyev AA, Tussupkaliyeva KS, Issimov A, Urazayeva, AB, Tashimova ZK, Mussin NM, Begalin T, Amanshiyeva AA and Nurmaganbetova GZ, 2024. Attitude toward vaccination against COVID-19 and acceptance of the national "QazVac" vaccine in the Aktobe city population, West Kazakhstan: A cross-sectional survey. Plos One 19(5): e0303854. https://doi.org/10.1371/journal.pone.0303854

Verrier ER, Colpitts CC, Schuster C, Zeisel MB and Baumert TF, 2016. Cell culture models for the investigation of hepatitis B and D virus infection. Viruses 8 (9): 261. https://doi.org/10.3390/v8090261

Wakita T, 2016. Cell Culture Systems for Propagation of HCV. In T. Miyamura, S. M. Lemon, C. M. Walker, and T. Wakita (Eds.), Hepatitis C Virus I: Cellular and Molecular Virology 67-80. Tokyo: Springer Japan

Waldstein KA, Issimov A, Ganama M, Jinge V, Tilley S and Hua X, 2024. Nasal virus infection induces asthma exacerbation through B-cell-dependent recruitment of inflammatory monocytes. In International Forum of Allergy and Rhinology 14(12): 1857-1868. https://doi.org/10.1002/alr.23426

Wang J, Xu Z, Wang Z, Li Q, Liang X, Ye S, Cheng K, Xu L, Mao J and Wang Z, 2022. Isolation, identification and phylogenetic analysis of lumpy skin disease virus strain of outbreak in Guangdong, China. Transboundary and Emerging Diseases 69 (5): e2291–2301. https://doi.org/10.1111/tbed.14570

Wei YR, Ma WG, Wang P, Wang W, Su XH, Yang XY, Mi XY, Wu JY and Huang J, 2023. Retrospective genomic analysis of the first lumpy skin disease virus outbreak in China (2019). Frontiers in Veterinary Science 9: 1073648. https://doi.org/10.3389/fvets.2022.1073648

Wilhelm L and Ward MP, 2023. The spread of lumpy skin disease virus across southeast asia: insights from surveillance. Transboundary and Emerging Diseases 2023(1): 3972359. https://doi.org/10.1155/2023/3972359

Xiong F, Gao H, Zhen Y, Chen X, Lin W, Shen J, Yan Y, Wang X, Liu M and Gao Y, 2011. Optimal time for passaging neurospheres based on primary neural stem cell cultures. Cytotechnology 63: 621–631. https://doi.org/10.1007/s10616-011-9379-0

Yadav A, Xuan Y, Sen CK and Ghatak S, 2024. Standardized reporting of research on exosomes to ensure rigor and reproducibility. Advances in Wound Care 13(11): 584–599. https://doi.org/10.1089/wound.2024.0093

Zhong JJ, Bai FW and Zhang W, 2009. Biotechnology in China I: from bioreaction to bioseparation and bioremediation. Springer Science and Business Media 1; 177–215. https://doi.org/10.1007/978-3-540-88415-6

Zhugunissov K, Mambetaliyev M, Sarsenkulova N, Tabys S, Kenzhebaeva M, Issimov A and Abduraimov Y, 2023. Development of an inactivated camelpox vaccine from attenuated camelpox virus strain: Safety and protection in camels. Animals 13(9): 1513. https://doi.org/10.3390/ani13091513

Zompi S and Harris E, 2012. Animal models of dengue virus infection. Viruses 4 (1): 62–82. https://doi.org/10.3390/v4010062

In Press