Journal of Drug Delivery and Therapeutics

Open Access to Pharmaceutical and Medical Research

Open Access Full Text Article

Review Article

Role of animal models in advancing Biomedical Research and Therapeutic Innovation

Nimisha Sunil Solas, Vaishnavi Govind Tirthe, Shaista Fatema Sadeq Shaikh, Snehal A Gojare *

Department of Pharmacology, PES's Modern College of Pharmacy, Nigdi, Pune 411044

Article Info:

Article History:

Received 13 Nov 2025
Reviewed 07 Jan 2026
Accepted 28 Jan 2026
Published 15 Feb 2026

Cite this article as:

Solas NS, Tirthe VG, Shaikh SFS, Gojare SA, Role of animal models in advancing Biomedical Research and Therapeutic Innovation, Journal of Drug Delivery and Therapeutics. 2026; 16(2):41-49 *DOI: http://dx.doi.org/10.22270/jddt.v16i2.7569*

For Correspondence:

Ms. Snehal A Gojare, Department of Pharmacology, PES's Modern college of Pharmacy, Nigdi, Pune

Abstract

A living organism functions as an animal model when it enables research into standard biological and behavioural operation or spontaneous and generated disease processes or identical biological events between species or human samples. Needless to say, research using non-human animal's dates back in time to understand human biology and improve human health. Scientists utilize the animal model with non-human subjects because it reproduces conditions that match human disease progression and detection methods and therapeutic approaches. To select the optimal animal model researchers, need extensive expertise in particular species and breeds for evaluating how well the model represents clinical conditions and the selected measures. The study of the 2019 Coronavirus disease pathogenesis relies on primate and rodent and porcine models to monitor infection pathways and therapeutic method development. Research in different animal species is necessary before human testing takes place for worldwide medical issues including diabetes, obesity, neurological disorders, pain management, rehabilitation medicine and surgical techniques. Research utilizing animal models helps identify pathogenic forces of intervertebral disc diseases together with cancer diseases alongside genetic disorders and EC therefore requiring specific animal models as research tools in order to better grasp the defect processes of each condition while evaluating new therapeutic effectiveness. The review investigates important aspects of animal model utilization under optimal conditions to direct upcoming research endeavors.

Keywords: Animal models, Biomedical research, Preclinical studies, Disease modelling, Therapeutic development, genetically modified animals, Ethical guidelines, Translational research.

Introduction

Animal models are used to study various human diseases, including autoimmune disorders, arthritis, epilepsy, Alzheimer's, cardiovascular diseases, and diabetes. They also play a key role in medical device development, tissue engineering, bone and cartilage regeneration, wound healing, and vascular surgeries. These models allow research that would be ethically impossible in humans. [1]

Data Sources and Study Selection:

Relevant literature was retrieved from PubMed, ScienceDirect, SpringerLink, Google Scholar, and Frontiers Journals, focusing mainly on publications from 2019–2025. Studies were selected based on relevance to animal models in biomedical research, therapeutic evaluation, and ethical guidelines, while non-peer-reviewed or unrelated articles were excluded after title, abstract, and full-text screening.

Ethical Guidelines

Animal research must follow strict ethical and legal guidelines. In India, the CCSEA regulates animal use in experiments under the Ministry of Fisheries, ensuring compliance with the Prevention of Cruelty to Animals Act, 1960.

CCSEA Guidelines for Use of Animals in Research -

CCSEA issues regulations through the Breeding of and Experiments on Animals (Control and Supervision) Rules, 1998 (amended in 2001, 2006, and 2018). The key guidelines include:

1. Registration Requirement	5. Experimental Procedures and Welfare
2. Institutional Animal Ethics Committee	6. Humane Endpoints and Euthanasia
3. Application for Experimentation Approval	7. Record Keeping and Compliance
4. Species-Specific Housing and Care	8. Prohibited Practices

Type of Animal Models

Natural models	Most natural models use mice and rats. Athymic nude mice (foxn1 mutation) are key in research; mottled mice model Menkes disease. [5]
Induced models	Induced disease models are created in healthy animals through genetic, surgical, chemical, or dietary modifications to replicate pathological processes. [2, 3]
Knock-out models	Genetically modified models have inserted genes (transgenic) or gene knockouts via homologous recombination. [3, 5]
Transgenic animals	Transgenic animals are made by genome integration of foreign DNA, mainly using CRISPR/Cas9. [2, 3]
Surgical induced models	The OVX rats serve as one example of surgically induced models while another example comes from the use of murine models of ischaemic stroke. [2, 6]
Chemically induced models	The Rasergine-induced model serves as an effective method to study PD. [2, 7]

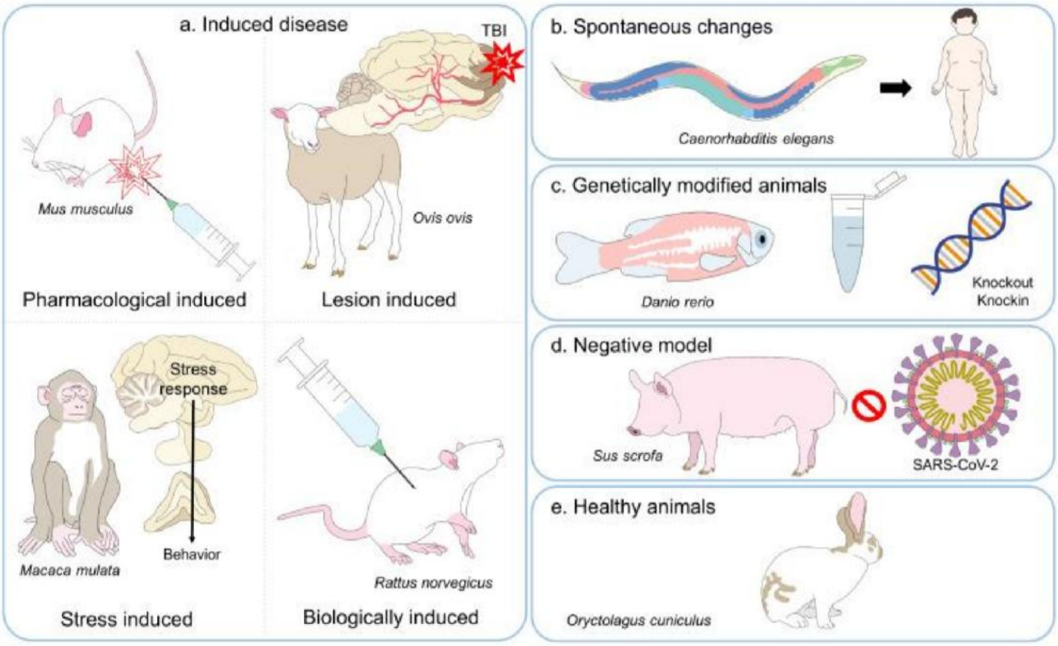

Figure 1: Classification of animal models based on use in science. [3]

Table 1: Animal models and their application in distinct fields of current biomedical science

Research Area	**Animal Models Used**	**Purpose / Key Features**
Emerging Infectious Diseases	Primates, ferrets, rodents, minks, cats, camelids, zebrafish	Used in SARS-CoV-2 research due to lung injury susceptibility to study infection pathways, disease progression, and therapeutic development. [7, 8, 9]
Surgical and Musculoskeletal Disease Models	Rabbits, rodents	Rabbits were used in early microsurgery experiments, while rodents are widely used to study extremity reimplantation, vascularization, and degenerative disc disorders, including lumbar spinal stenosis modeled by silicone-induced spinal canal narrowing. [10, 11, 12,13,15]

Table 2: The significance and challenges of animals in biomedical research

a. Small animal models Significance and limitations –

Sr no.	Small animal models	Significance and limitations
1	Rats, Mice	Inbred rats are easy to breed and handle but lack genetic diversity, limiting their use in inflammation research. [1]
2	Guinea pig	Outbred models aid studies on various diseases, but guinea pigs show limited use in Ebola research due to low infectivity. [23]
3	Golden hamster	Ideal for reproductive, cancer, and infection studies due to progesterone control and short gestation. [24]
5	Rabbit	Good model for osteoarthritis, wound healing, drug testing, asthma, cardiovascular, and Alzheimer's research.[25]
6	Ferret	Similar respiratory tracts and vomiting ability make them useful for teratogenicity research despite limited availability and cost. [25]

b. Large animal models Advantages and disadvantages –

Animal	Advantages	Disadvantages
Horse	Supports testing critical defects with serial sampling and human-like knee cartilage aging.	High costs and ethical concerns stem from specialized facilities, limited care, and scarce equine research tools.[26]
Sheeps	Supports multiple large defects, human-like knee cartilage, easy handling, and societal acceptance as a research animal.	Requires special facilities and skills; non-weight-bearing post-op is limited; has a different stomach system than humans.[27]
Dogs	Dogs allow multiple measurements, mirror human diseases functionally, and show breed genetic diversity like humans.	Ethical concerns, breed-specific drug intolerances, and costs are key issues in companion animal research. [29]
Pigs	Pigs enable multiple measurements, model human diseases, and show breed genetic diversity.	Ethical concerns are lower than for pets; non-weight-bearing post-surgery is not possible; costs remain high. [28]

Animal models in Gynaecological disease studies

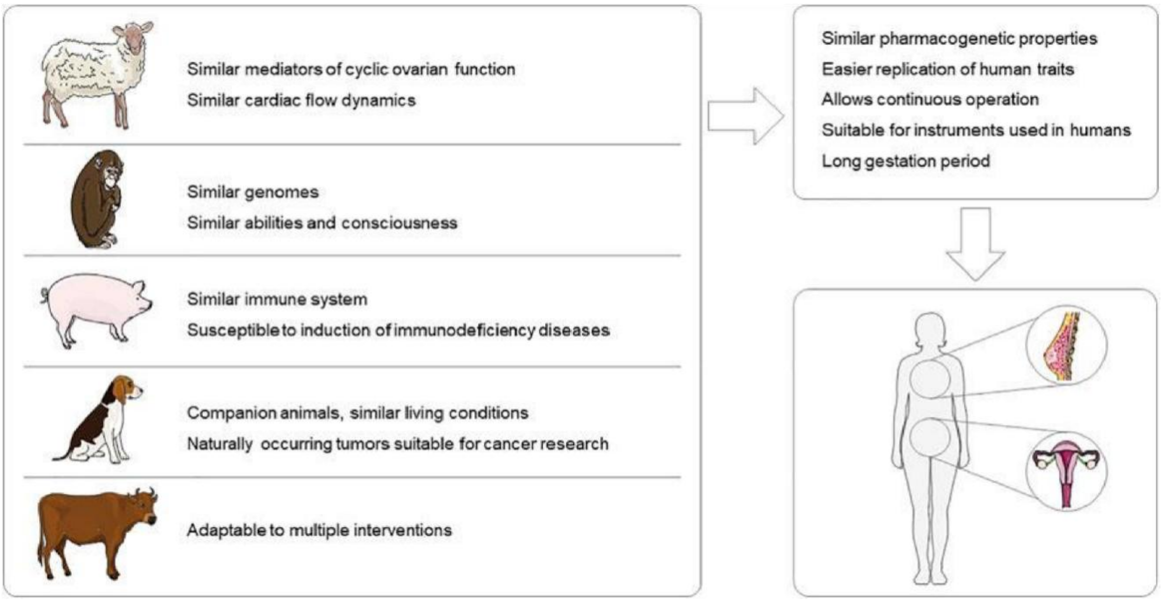

Figure 2: Advantages of large animal models for gynaecological disease research [6]

Table 3: Preclinical research models for endometrial cancer: development and selection of animal models

Animal models	Pros	Cons	Research directions
1) Spontaneous	Affordable, low-maintenance model that mimics full cancer development.	Long culture cycle, Low incidence and unstable.	Used to study risk factors, disease progression, therapy, toxicology, and hormone-related cancer. [18, 19]
2) Chemically induced	Similar histopathology, High incidence, Simple operation.	Unclear genetic background, Long time to induce.	Studies chemical-induced carcinogenesis and estrogen-related molecular pathways. [19]
3) Genetically engineered	Immune system existence. Specific gene mutation.	Difficult operation, expensive, Low tumor mutation load	Molecular pathway mechanism. New molecular therapeutic targets. [18, 19]
4) Xenograft	Low cost, short cycle, predictable growth, easy observation.	Immune deficiency, Limited similarity to human.	Drug efficacy, immunotherapy, cancer biology, biomarkers. (18, 19)
5) Humanized	Human-like immunity; useful for immunotherapy.	Technically difficult, High cost.	Tumor - immune system interaction; Immunotherapy. [19]

Table 4: Animal models in gene therapy [17, 18]

Sr no.	Model type	Animals used	Diseases
1	Genetically engineered	Mice, Rat, Monkey	Huntington's disease
2	Xenograft	Mice, Monkey	Glioblastoma
3	Disease induction	Monkey, Rat, Mice, rabbit	Duchenne muscular dystrophy
4	Spontaneous	Dog, Cat, mice	X linked hydrocephalus

Table 5: Animal models for Type 1 and Type 2 Diabetes

1) Type 1 diabetic animal models [21]

1. Chemically Induced T1DM Animal Models

Animal	Chemical	Advantages	Limitations
Rat	Alloxan (150 mg/kg)	Cost effective. Easy of handling. Shares similar numerous pathophysiology and pathological features with humans.	Densely haired skin heals by contraction, making partial wounds difficult. Chemicals can cause toxicity, and hyperglycemia mainly stems from beta-cell damage and insulin deficiency, not resistance. [21]
Mouse	Streptozotocin (60 mg/kg)		
1.Rabbit,	Alloxan,	1. Mimics human burn wound metabolism and pathology.	1. Higher infection risk and morbidity than mice and rats.
2.dog,	STZ ,	2. Replicates thermal burn symptoms and effects.	2. Loose skin makes irreversible diabetes hard to induce.
3.primate,	MLD-STZ	3. Low-dose STZ primate model benefits T1DM research.	3. Drug administration needs skilled handlers.
4.pig		4. Diabetes physiology similar to humans.	4. Requires higher doses to induce diabetes; irreversible diabetes is difficult.[1, 21]

2. Genetically/ spontaneously induced T1D animal models

Animal	Genes	Advantages	Limitations
NOD mouse (nonobese Diabetes)	Polygenic model showing hyper-glycemia and leukocyte	Widely used to study T1DM. Exploring genetics of T1DM	Expensive. Difficult to handle (21)

	infiltration of pancreatic β-cells.		
KDP rat	Formed from a nonsense mutation in the Cbl-b.	Rapid diabetes onset without T-lymphopenia; ~70% in both sexes.	Expensive; few studies, mainly genotype-focused.
LETL rat **(Left evans tokushima lean)**	It mimics human Type 1 diabetes with sudden polyphagia, and hyperglycemia.	First rat model with spontaneous autoimmune islet B cell destruction and diabetes without lymphopenia.	Develops diabetes at 20%, costly, and partially replicates human T1DM.
LEWIDDM rat	Spontaneously develops autoimmune T1DM through β-cell apoptosis.	Creates T1DM equally in both sexes; used to test treatments preventing B cell destruction.	Expensive. May not completely mimic the T1DM condition seen in humans
BB rat (bio breeder)	Exhibits hyper-glycemia and ketoacidosis typical of T1DM onset.	BB rats, showing hypoinsulinemia, ketonuria, and weight loss, are used to study islet transplant tolerance.	Diabetes is associated with T- cell lymphopenia. Expensive.
Akita mouse	Diabetes caused by mutation, leading to insulin deficiency.	Single insulin 2 mutation offers clearer genetic study of diabetes than polygenic models.	Akita mice have higher B cell regeneration than humans, affecting T1DM study translation.
3. Virally induced T1DM animal models			
Animal	Virus type	Advantages	Limitations
Monkey	EMC virus , Coxsackie virus	Diabetes follows pancreatic B cell destruction by EMC virus; Coxsackie B infects first.	Unclear diabetes mechanism; nonspecific effects; safety and ethical concerns.
Mouse	EMC virus Coxsackie virus, LCMV	EMC virus causes T1DM via B cell destruction; Coxsackie B infects B cells first.	Diabetes mechanism unclear; low specificity; safety and ethical concerns.
Hamster	EMC virus , Coxsackie virus LCMV	EMC, Coxsackie B infect B cells; LCMV triggers immune T1DM.	Diabetes mechanism unclear; low specificity; safety and ethical issues.
Rat	RCMV (rat cytomegalovirus), KRV (kilham rat virus)	RCMV and KRV models study how viral infections trigger or worsen T1DM.	Diabetes mechanism unknown; nonspecific effects; safety and ethics concerns.
4. Surgical T1D animal models			
Animal	Surgery type	Advantages	Limitations
Rat, mouse	Pancreatomy	Reflects effects of reduced β-cell mass; cost-effective with easy handling and housing.	Partial-thickness wounds are hard to create in thin skin and often remove exocrine acinar cells.
Rabbit, dog, pig, primates	Pancreatomy, Islet Trans - plantation, Thymectomy	Easy care, large, long-lived, with human-like islet function.	Requires high skill, invasive, limited availability, risk of hypoglycemia, ethical concerns. [1, 21]
2) Type 2 Diabetic Mellitus Animal Models [1, 21]			
1. Chemically induced T2D animal models			

Animal	Chemical	Advantages	Limitations
Rabbit	STZ	More cost-effective with human-like burn wound metabolism and pathology.	Difficult to produce irreversible diabetes. Risk of infections and morbidity compared to mouse rats.
Pig	STZ plus Nicotinamide	Useful for T1DM - T2DM studies; anatomy and physiology closely match humans.	Requires higher doses to produce diabetic conditions. Difficult to produce irreversible diabetes.
2. Genetically/spontaneously induced T2D animal models			
Animal	Gene	Advantages	Limitations
db/db mouse **(diabetic /diabetic)**	Autosomal recessive point mutation, Glyto-Thr.	Widely used T2D mouse model showing hyper-glycemia, hyperphagia, insulin resistance.	db/db mice are sterile and must be bred from heterozygous pairs, increasing cost and effort.
Ob/ob mouse **(obese/obese)**	ob/ob mutant, a nonsense mutation	Used in obesity-induced T2D and hyperphagia drug studies.	Ob/ob mice share db/db limitations; males may reproduce on restricted diets.
GK rat (goto kakizaki)	Repeated inbreeding of glucose intolerant Wistar rats	Ideal for T2DM studies on insulin resistance and β-cell survival.	Early ß cell destruction remains a limitation for mimicking T2DM.
OSHR rat	Hypertensive females bred with normotensive males over generations.	Used to study endocrine-metabolic links to obesity.	Rats induced diabetic via high-calorie diet.
Akita mouse	Ins-2 autosomal dominant mutation	Used to study chronic stress relief in pancreatic islets and T2DM.	Mechanism of mesangial matrix increase is unknown; IgA deposit observations have limited value.
Zucker **fatty rat**	Bred from Sherman ,Merck M rats with recessive mutation.	Displays renal lesions resembling those in human T2DM.	Develops severe diabetes in only males. Complete descriptions of insulin resistance are unknown.
ZDSD rat	Crossbred rat models selected for obesity and diabetes traits.	Important for investigating diabetic ulcer conditions. Used to study T2DM.	May display an impaired renal function. May display progressive albuminuria.
NONENZO10 mouse	Recombinant congenic strain from Jackson Laboratory.	Ideal for studying obesity-induced T2D and metabolic syndrome.	Only male mice develop hyperglycemia.
TALLYHO Ing (TH) mouse	Inbred polygenic T2D model with moderate obesity.	Shares T2D traits with NONENZD 10/Lt.	Only males show glucose intolerance and hyperglycemia, limiting the model.
KK mouse **(congenital strain mice)**	Polygenic diabetic model with moderate obesity, polyphagia, and polyuria.	Used to discover insulin resistance treatment	High cost. Limited availability. Possible genetic variations between individual mice
3. Surgical T2D animal models			
Animal	Surgery type	Advantages	Limitations
Rat, pig, **Zebrafish, primates**	Partial pancreatomy , Bariatric surgery, Renal Denervation	Models reduced β-cell mass; high reproduction; cost-effective housing.	Partial-thickness wounds are difficult to create because skin is too thin.
4. Diet/nutrition induced T2D animal models			
Animal	Description	Advantages	Limitations

Sand Rat	Top diet-induced polygenic diabetic rat model.	Avoids chemical toxicity; used to study obesity-diabetes link and dietary effects.	Requiring extended periods of time for treatment. Not suitable for screening antidiabetic agents
Spiny Mouse	Shows islet hyperplasia and elevated pancreatic insulin.	Avoids chemical toxicity; useful for T2DM studies.	
C57BL/6J Mouse	Marked obesity with hyperinsulinemia, insulin resistance, glucose intolerance.	Avoids chemical toxicity; ideal for T2DM pathogenesis research.	Takes long for treatment; unsuitable for antidiabetic screening.
Rhesus macaque (Monkey)	Rapid adipose loss leads to ketosis; insulin needed for survival.	Develops metabolic syndrome, coronary disease, and diabetic complications.	Slow treatment, unsuitable for screening; limited availability and ethical issues.
Gottingen Minipigs	Need high-fat diet to develop obesity then T2DM.	Models T2DM, metabolic syndrome, coronary disease.	Slow treatment; not fit for antidiabetic screening.

*OSHR rat (obese spontaneously hypertensive rat), ZDSD rat (zucker diabetic Sprague dawley), NONENZO10 mouse (recombinant congenic strain), KDP rat (komeda diabetes – Prone)

Table 6: Animal models utilized in preclinical studies of cancer related products

Trade name	Indication	Animal model	Category	Comment
Gendicine	Head and neck cancer	Mice	Genetically engineered	Conditional knockout mouse model [30, 31]
Oncorine	Nasopharyngeal carcinoma	Guinea pig	N/A	Injected with Oncorine at dose levels of 5.0×10^{10} TCID50/kg, 1.0×10^{11} TCID50/kg, or 2.0×10^{11} TCID50/kg subcutaneously
Rexin – G	Soft tissue sarcoma and osteosarcoma	Mice	Xenograft	A nude mouse model of liver metastasis and in a subcutaneous human xenograft model of pancreatic cancer [32]
Imlygic	Melanoma	Mice	Xenograft	Nude BALB/c mice injected subcutaneously with 2×10^6 tumor cells; tumors grown to ~0.5 cm diameter.[30]
Kymriah	Relapsed B cell	Mice	Xenograft	An immunodeficient NOD/Shi-scid IL-2Rγ null human leukemia xenograft mouse model [31]
Tecartus	Relapsed/re- fractory mantle cell lymphoma	None	-	There are no representative in vitro assays, ex vivo models, or in vivo models [16]
Abecma	Multiple myeloma	Mice	Xenograft	NSG mice with and without BCMA + xenografts [16]
ARI-0001	Adultrelapsed/refractory acute lymphobasti c leukemia	Mice	Xenograft	NOD/scid-IL-2Rnull— They were inoculated intravenously (i.v.) with 0.3×10^6 GFP-NLuc Namalwa cells per mice [16, 31]
Breyanzi	Relapsed or refractory diffuse large B-cell lymphoma	Mice	xenograft	Raji xenograft in nude mice used as proof of concept; no lymphoma model developed. [16, 31]
Carteyva		N/A	N/A	No more information was found for this product
Delytact	Malignant Glioma	Mice	xenograft	005 GSCs ($2–5\times10^4$) in 3 µL PBS were stereotaxically implanted into the striatum to form brain tumors. [16]
Adstiladrin	Bladder cancer	Mice	xenograft	An orthotopic mouse model of human bladder cancer [16]
Carvykti	Relapsed or refractory multiple myeloma	Mice	Xenograft	NOG mice (6–8 weeks) received s.c. NCI-H929 cells (5×10^6); tumor volume measured twice/week blindly. [16]

Recent advancement of animal models in biomedical research

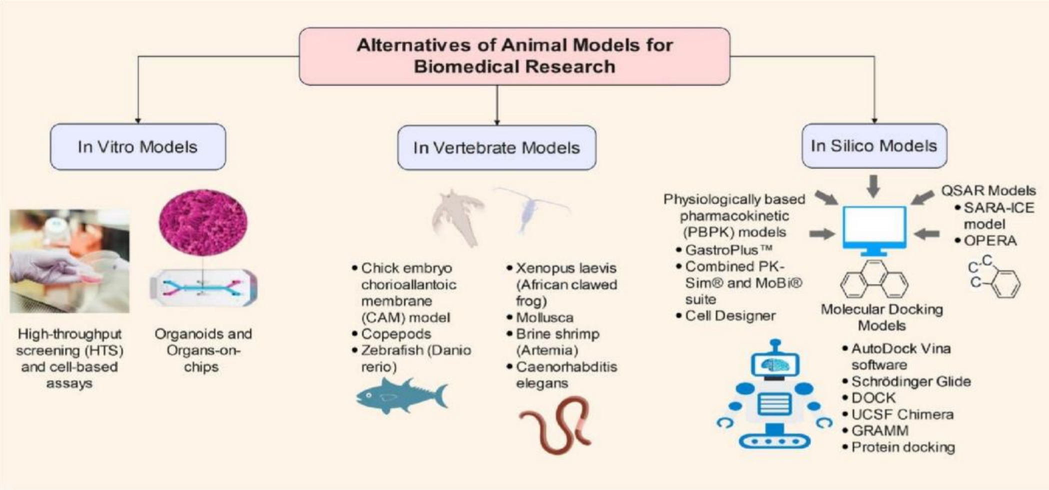

Figure 3: Alternatives of animal models for biomedical research [20]

Conclusion

Animal models are vital for replicating human and animal diseases in research. Over the past five years, they've helped advance studies on COVID-19, cancer, diabetes, genetic and neurological disorders, and more. Before human trials, therapies, diagnostics, and surgical techniques are tested in animals. Researchers must ensure that models accurately represent diseases and align with intervention needs. Ethical considerations and animal welfare are essential for achieving valid and meaningful scientific outcomes.

Funding: This research received no external funding.

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

Acknowledgement: NA

References

1) Mukherjee P, Roy S, Ghosh D, Nandi SK. Role of animal models in biomedical research: a review. Laboratory Animal Research. 2022 Jul 1;38(1):18. https://doi.org/10.1186/s42826-022-00128-1

2) Ribitsch I, Baptista PM, Lange-Consiglio A, Melotti L, Patruno M, Jenner F, SchnablFeichter E, Dutton LC, Connolly DJ, van Steenbeek FG, Dudhia J, Penning LC. Large Animal Models in Regenerative Medicine and Tissue Engineering: To Do or Not to Do. Front Bioeng Biotechnol. 2020 Aug 13;8:972. doi: 10.3389/fbioe.2020.00972

3) Domínguez-Oliva, A.; Hernández-Ávalos, I.; Martínez-Burnes, J.; Olmos-Hernández, A.; Verduzco-Mendoza, A.; Mota-Rojas, D. The Importance of Animal Models in Biomedical Research: Current Insights and Applications. Animals 2023, 13, 12-23. https://doi.org/10.3390/ani13071223

4) Hong, J.Y.; Kim, H.; Jeon, W.-J.; Yeo, C.; Kim, H.; Lee, J.; Lee, Y.J.; Ha, I.-H. Animal Models of Intervertebral Disc Diseases: Advantages, Limitations, and Future Directions. Neurol. Int. 2024, 16, 1788–1818. https://doi.org/10.3390/neurolint16060129

5) Jura J. (2024). Animal models for the treatment of human diseases, Annals of Animal Science, DOI: 10.2478/aoas-2024-0058

6) Cui M, Liu Y, Men X, Li T, Liu D and Deng Y (2023), large animal models in the study of gynecological diseases. Front. Cell Dev. Biol. 11:1110551. doi: 10.3389/fcell.2023.1110551

7) Dissanayake, H.A.; de Silva, N.L.; Sumanatilleke, M.; de Silva, S.D.N.; Gamage, K.K.K.; Dematapitiya, C.; Kuruppu, D.C.; Ranasinghe, P.; Pathmanathan, S.; Katulanda, P. Prognostic and therapeutic role of vitamin D in COVID-19: Systematic review and meta-analysis. J. Clin. Endocrinol. Metab. 2022, 107, 1484–1502. *DOI:* https://doi.org/10.1210/clinem/dgab892

8) Muñoz-Fontela, C.; Dowling, W.E.; Funnell, S.G.P.; Gsell, P.-S.; Riveros-Balta, A.X.; Albrecht, R.A.; Andersen, H.; Baric, R.S.; Carroll, M.W.; Cavaleri, M.; et al. Animal models for COVID-19. *Nature* 2020, *586*, 509–515. DOI: https://doi.org/10.1038/s41586-020-2787-6

9) Sun, S.-H.; Chen, Q.; Gu, H.-J.; Yang, G.; Wang, Y.-X.; Huang, X.-Y.; Liu, S.-S.; Zhang, N.-N.; Li, X.-F.; Xiong, R.; et al. A mouse model of SARS-CoV-2 infection and pathogenesis. *Cell Host Microbe* 2020, *28*, 124–133. DOI: 10.1016/j.chom.2020.05.020

10) Dvořák, Z.; Stupka, I. Atypical replantation and reconstruction of frozen ear. *Medicine* 2020, *99*, 20-68. *DOI:* 10.1097/MD.0000000000020068

11) Kania, K.; Chang, D.K.; Abu-Ghname, A.; Reece, E.M.; Chu, C.K.; Maricevich, M.; Buchanan, E.P.; Winocour, S. Microsurgery training in plastic surgery. Plast. Reconstr. Surg.—Glob. *Open* 2020, *8*, e28-98. DOI: 10.1097/GOX.0000000000002898

12) Ozols, D.; Zarins, J.; Petersons, A. Novel technique for toe-to-hand transplantation: The fourth-toe as an alternative option for toe-to-hand transplantation for pediatric patients. *Tech.* Hand Up. Extrem. Surg. 2019, 23, 74–80. DOI: 10.1097/BTH.0000000000000234

13) Zhang F., Wang S., Li B., Tian W., Zhou Z., Liu S. Intradiscal injection for the management of low back pain. JOR Spine. 2022;5:e1186. DOI: https://doi.org/10.1002/jsp2.1186

14) Amin R.M., Andrade N.S., Neuman B.J. Lumbar Disc Herniation. Curr. Rev. Musculoskelet. Med. 2017; 10:507–516. doi: 10.1007/s12178-017-9441-4.

15) El Melhat, Ahmed M., et al. "Non-surgical approaches to the management of lumbar disc herniation associated with radiculopathy: a narrative review." *Journal of clinical medicine* 13.4 (2024): 974. https://doi.org/10.3390/jcm13040974

16) Soufizadeh, P., Mansouri, V. & Ahmadbeigi, N. A review of animal models utilized in preclinical studies of approved gene therapy products: trends and insights. *Lab Anim Res* 40, 17 (2024). DOI: https://doi.org/10.1186/s42826-024-00195-6

17) Wu, P.H.; Kim, H.S.; Jang, I.T. Intervertebral Disc Diseases PART 2: A Review of the Current Diagnostic and Treatment Strategies for Intervertebral Disc Disease. Int. J. Mol. Sci. 2020, 21, 2135. DOI: https://doi.org/10.3390/ijms21062135

18) Hansen K, Khanna C. Spontaneous and genetically engineered animal models: Use in preclinical cancer drug development. Eur J Cancer. 2004;40, 58–80. https://doi.org/10.1016/j.ejca.2003.11.031.

19) Xue Y, Shi W, Lun B, Kan M, Jia M, Wu Y, Yang L. Preclinical research models for endometrial cancer: development and selection of animal models. Frontiers in Oncology. 2025 Feb 5; 15,151-261. doi: 10.3389/fonc.2025.1512616

20) Vashishat A, Patel P, Das Gupta G, Das Kurmi B. Alternatives of animal models for biomedical research: a comprehensive review of modern approaches. Stem Cell Reviews and Reports. 2024 May; 20(4):881-99. DOI: https://doi.org/10.1007/s12015-024-10701-x

21) Singh, R., Gholipourmalekabadi, M. and Shafikhani, S.H., 2024. Animal models for type 1 and type 2 diabetes: advantages and limitations. Frontiers in Endocrinology, 15, p.135. https://doi.org/10.3389/fendo.2024.1359685

22) Pramod RK, Atul PK, Pandey M, Anbazhagan S, Mhaske ST, Barathidasan R. Care, management, and use of ferrets in biomedical research. Laboratory Animal Research. 2024 Mar 26;40(1):10. DOI: https://doi.org/10.1186/s42826-024-00197-4

23) Ryan VE, Bailey TW, Liu D, Vemulapalli T, Cooper B, Cox AD, et al. Listeria adhesion protein-expressing bioengineered probiotics prevent fetoplacental transmission of Listeria monocytogenes in a pregnant guinea pig model. Microb Pathog. 2021;151:104752. https://doi.org/10.1016/j.micpath.2021.104752

24) Cruz ISS, Garabalino MA, Trivillin VA, Itoiz ME, Pozzi ECC, Thorp S, et al. Optimization of the classical oral cancerization protocol in hamster to study oral cancer therapy. Oral Dis. 2020;26(6):1175–84. DOI: https://doi.org/10.1111/odi.13358

25) Brunner AM, Henn CM, Drewniak EI, Lesieur-Brooks A, Machan J, Crisco JJ, et al. High dietary fat and the development of osteoarthritis in a rabbit model. Osteoarthr Cartil. 2012;20(6):584–92. DOI: https://doi.org/10.1016/j.joca.2012.02.007

26) Gleerup KB, Forkman B, Lindegaard C, Andersen PH. An equine pain face. Veterinary anaesthesia and analgesia. 2015 Jan 1;42(1):103-14. DOI: https://doi.org/10.1111/vaa.12212

27) Martines E, Brun P, Cavazzana R, Cordaro L, Zuin M, Martinello T, Gomiero C, Perazzi A, Melotti L, Maccatrozzo L, Patruno M. Wound healing improvement in large animals using an indirect helium plasma treatment. Clinical Plasma Medicine. 2020 Mar 1;17:100095. DOI: https://doi.org/10.1016/j.cpme.2020.100095

28) Meng X, Ziadlou R, Grad S, Alini M, Wen C, Lai Y, Qin L, Zhao Y, Wang X. Animal models of osteochondral defect for testing biomaterials. Biochemistry research international. 2020;2020(1):9659412. DOI: https://doi.org/10.1155/2020/9659412

29) Tellegen AR, Dessing AJ, Houben K, Riemers FM, Creemers LB, Mastbergen SC, Meij BP, Miranda-Bedate A, Tryfonidou MA. Dog as a model for osteoarthritis: the fgf4 retrogene insertion may matter. Journal of Orthopaedic Research®. 2019 Dec;37(12):2550-60. DOI: https://doi.org/10.1002/jor.24432

30) Guo H, Xu X, Zhang J, Chen Y, Wang J, Li Y. The pivotal role of preclinical animal models in anti-cancer drug discovery and personalized cancer therapy strategies. Pharmaceuticals (Basel). 2024;17(8):1048. doi:10.3390/ph17081048

31) Hansen K, Khanna C. Spontaneous and genetically engineered animal models: use in preclinical cancer drug development. Eur J Cancer. 2004;40(6):858–880. doi:10.1016/j.ejca.2003.11.031

32) Sajjad H, Imtiaz S, Noor T, Siddiqui YH, Sajjad A, Zia M. Cancer models in preclinical research: a chronicle review of advancement in effective cancer research. Anim Models Exp Med. 2021;4(2):87–103. doi:10.1002/ame2.12165