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Review

Animal Models in Neuroscience: What "Culture of Care"?

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Abstract: Since alternative methods (AAs), such as *in vitro* cultures, organs *in silico*, or mathematical methods, are not fully able to reproduce the complexity of the human organism, particularly neural processes, and brain structures, animal experimentation remains the only way in which research can obtain the necessary knowledge to suggest drug therapies or targeted therapeutic interventions. Particularly in neuroscience, transgenic animals allow us to model neurological diseases, study the relationship between the brain and behavior, and decipher the function of genes involved in pathological conditions. However, it should never be forgotten that animals are "sentient beings" capable of feeling pleasure and pain (Art. 13 of the 2007 Lisbon Treaty). For this reason, it is crucial to prioritize the welfare of animals involved in testing by considering their physical, psychological, adaptive, and relational well-being. This is where the concept of a Culture of Care comes in, where the responsibility of care extends beyond the veterinary aspects to include everything that can safeguard the welfare of animals before, during, and after experimentation. This chapter explains the advantages of using the animal model while practicing the culture of care in neuroscience, as both animals and research outcomes benefit from this approach.

Keywords: animal welfare; 3Rs; neuroscience research; neurological disorders; transgenic models

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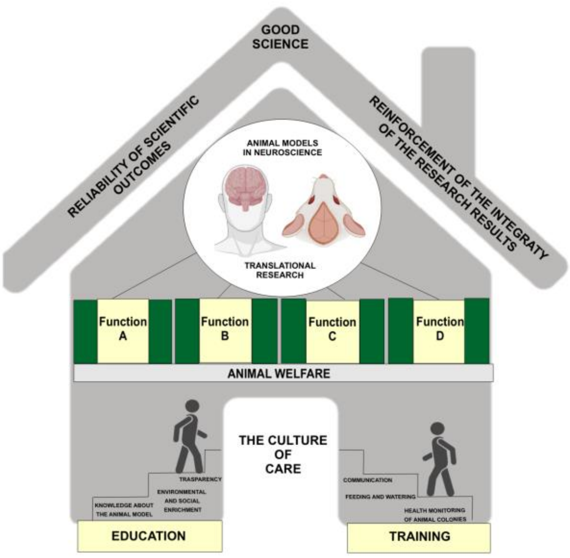

Graphical Abstract: A culture of care in animal research is like a well-built structure where animal welfare is the main priority supported by key elements. Staff, including technicians, researchers,

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and veterinarians, are vital in making this culture a daily reality, not just an idea. Think of education and training as the foundation of this structure. Like a strong base supports a building, comprehensive training on rules, species knowledge, and ethical principles forms the base for caring for animals properly. When staff understand these principles well, they can consistently prioritize animal welfare (Created with BioRender.com.

Introduction:

Animal models (AMs) play a pivotal role in neuroscience research, serving as invaluable tools in understanding the intricate workings of the brain and nervous system (NS) [1–3]. These models allow scientists to explore neurological phenomena, from essential functions like sensory perception and motor control to complex processes such as learning, memory, and emotional responses [4–6]. Researchers can simulate human neurological conditions and diseases by studying animals like mice, rats, and non-human primates, offering insights into their causes and potential treatments [1]. AMs also facilitate testing experimental therapies and the evaluation of their efficacy and safety before transitioning to human trials. Moreover, these models enable the investigation of brain development, neural plasticity, and the effects of environmental factors on the NS, contributing significantly to advancing our understanding of the brain and its disorders [7].

Tracing the Evolution: Animal Models in Unveiling Neuroscience's History:

The use of AMs in scientific research, including neuroscience, has a rich history dating back thousands of years. From ancient anatomical observations to modern genetic manipulations, animals have advanced our understanding of neurological functions and disorders [7].

Galen's (129 – 199 / 217 AD) pioneering work in anatomy revolutionized the understanding of the NS [8]. He delved into the intricacies of the spinal cord and nerves through meticulous experiments, meticulously documenting observations on paralysis and its effects [8]. The Renaissance and Enlightenment eras saw scientists like William Harvey utilizing animal dissections to comprehend brain function and its relationship with bodily systems [9]. The 19th century saw significant advancements in using AMs for research. Louis Pasteur's experiments on rabies and germ theory and Claude Bernard's research on physiology involved AMs [10].

The 20th century marked a significant shift, with advancements in genetics and technology leading to the creation of genetically modified animals, enabling precise studies of specific genes and disease modeling. From simple organisms like Aplysia to complex mammals like mice, rats, and non-human primates, AMs have elucidated neural circuits, disease mechanisms, and behavioral patterns, propelling neuroscience forward [11–14]. With technological advancements, scientists refined techniques for studying animal behavior, genetics, and brain function [14–16]. This era saw the emergence of non-invasive imaging methods like MRI, allowing for detailed brain studies in live animals [17]. Ethical considerations persist, prompting the exploration of alternative methods (AAs). Yet, the historical contributions of AMs remain indispensable in shaping our current understanding of the brain and its intricate workings [18].

Animal Models: Essential Tools in Unraveling the Mysteries of Neuroscience:

The continued progress in genetic engineering, molecular biology, and neuroscience has expanded the scope and precision of AMs [14]. Researchers now use genetically modified animals to study specific genes' roles in brain function and disease [19]. Each AMs offers distinct advantages for different aspects of neuroscience research, allowing scientists to explore various facets of the brain's complexity, from fundamental cellular processes to complex behaviors and cognitive abilities [20–22]. Integrating findings from these diverse models enhances our understanding of the brain and neurological disorders, paving the way for potential treatments and interventions [7]. Furthermore, there is an increasing emphasis on developing AAs, such as organoids (miniature organ-like structures grown in the lab) and computer simulations, to complement or replace animal studies where feasible [23–25].

Nevertheless, AMs remain fundamental in neuroscience research due to several advantages that current AAs might not fully replicate [26]. Animal brains, especially in mammals and primates, share structural and functional similarities with human brains, enabling researchers to study complex behaviors and cognitive processes that simpler models might not exhibit [12,22,26].

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Many neurological diseases manifest differently in humans than in simpler models or cell cultures. AMs allow for a closer representation of disease pathology, aiding in understanding disease mechanisms and testing potential treatments [12]. Mammalian AMs, like mice and rats, share a significant portion of the genetic background of humans [11]. This genetic similarity makes them valuable for studying genetic factors underlying neurological disorders. AMs allow researchers to study behaviors related to memory, learning, cognition, and social interactions in ways that might be challenging to replicate in AAs [7,11,15].

AMs offer the advantage of studying the brain in the context of a whole organism, considering the brain's interactions with other organ systems and the body [27]. Long-term studies and interventions can be conducted in animals to observe developmental changes, disease progression, and responses to therapeutic interventions over time, which might be more challenging in AMs [27–29]. Regulatory agencies often require data from animal studies before approving human clinical trials. Animal studies provide critical data on treatments' safety, efficacy, and potential side effects before human trials [30,31].

However, despite these advantages, there are ethical considerations, limitations, and challenges associated with AMs, leading to the development and exploration of AAs in neuroscience [19]. While AAs like cell cultures, organoids, computer simulations, non-invasive diagnostic imaging, and human-based models are advancing, they might not fully encompass the complexity of the whole brain or exhibit certain behaviors or disease phenotypes observed in AMs [19]. Hence, a combination of animal and AAs is often used to comprehensively address questions in neuroscience [2].

Xenopus laevis, commonly known as the African clawed frog, represents a significant model for studying developmental disorders due to its unique characteristics: their large and externally developing embryos allow for easy manipulation and observation of neural development, offering insights into early neurodevelopmental processes [32].

Caenorhabditis elegans (*C.elegans*), a microscopic roundworm, is invaluable in neuroscience due to its well-characterized NS comprising just 302 neurons, allowing for comprehensive mapping and understanding of neural circuits [33,34]. Its genetic manipulability and short lifecycle enable precise studies on neural development, synaptic plasticity, and aging, offering insights into fundamental principles of neural function and behavior [35].

Due to their unique advantages, *Drosophila melanogaster* (the fruit fly), and Zebrafish (*Danio rerio*) are essential models in neuroscience research [36,37]. *Drosophila melanogaster* offers rapid generation times, genetic tractability, and a relatively simple NS, facilitating studies on fundamental neurobiological processes like synaptic transmission and neural circuitry [38]. With their transparent embryos and rapid external development, zebrafish allow for real-time observation of neural development, making them invaluable for studying early neurodevelopmental events [39]. While these models provide crucial insights into basic neural mechanisms, rats and mice remain preferred for many neuroscience studies due to their closer genetic and physiological resemblance to humans [1,40]. Their more complex NS, cognitive abilities, and similarity in pathology make rats and mice superior models for studying complex behaviors, cognitive functions, neurodegenerative diseases, and cellular bases of learning and memory, offering greater translational relevance to human conditions [40,41]. Their established genetic tools, ease of genetic manipulation, and extensive behavioral assays further enhance their importance in neuroscience research [40,41] **(Figure 1).**

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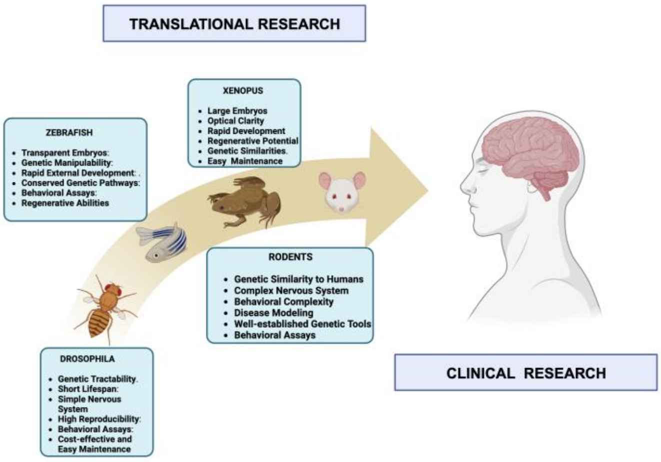

Figure 1. From Lab to Clinic: Bridging Neuroscience with Diverse Animal Models: the image illustrates several AMs, *Drosophila*, Zebrafish, *Xenopus*, and Rodent, integral to neuroscience research. These models bridge preclinical studies and clinical applications, enabling an understanding of neural development, disease mechanisms, and therapeutic approaches. Their collective contributions translate basic research findings from the laboratory to clinical advances, offering promise for understanding neurological disorders and developing potential treatments. (Created with BioRender.com. and adapted by Bédard et al. 2020).

However, we must never forget that AMs require a mandatory focus on adherence to ethical principles regarding reducing their numbers and exploring AAs [42]. Indeed, the usefulness of these models for scientific research is closely linked to their welfare. [40,43] Ensuring the welfare of animals involved in research is an ethical responsibility and integral to the quality and reliability of scientific results [42,44]. By providing optimal care, minimizing stress, and meeting ethical standards, researchers ensure that the data collected from these models are more reliable, consistent, and translatable to human health [42,44]. Ethical treatment of animals is in line with moral responsibility. It enhances the credibility and validity of neuroscience research, promoting progress and respecting the dignity of the creatures that contribute to our scientific exploration [45].

The Vital Role of Mice and Rats in the Advancement of Neuroscience:

The progression of neuroscience owes much of its momentum to the indispensable contributions made possible by AMs, particularly mice and rats [46,47]. These models have been instrumental in elucidating intricate neural processes, unraveling disease mechanisms, and exploring behavioral patterns that underpin neurological function [47]. Through meticulously designed experiments using these AMs, researchers have gained invaluable insights into the complexities of the NS [43]. From studying genetic influences on brain function to modeling various neurological disorders like Alzheimer's (AD), Parkinson's (PD), and epilepsy, mice and rats have been invaluable tools in furthering our understanding of the brain [48–50]. Their genetic similarity to humans and the ease of genetic manipulation and behavioral testing have propelled neuroscience research forward, bridging basic scientific discovery and potential clinical applications [40,41].
For several reasons, mice and rats are cornerstone models in neuroscience: despite evolutionary differences, these rodents share significant genetic similarities with humans. This genetic resemblance facilitates the study of genes implicated in neurological functions and diseases. Their genomes can be easily modified, allowing scientists to create transgenic models expressing specific genes or mutations linked to neurological disorders [51,52]. This enables targeted investigations into disease mechanisms and potential therapeutic targets. Their behavior, social interactions, learning abilities, and memory functions can be studied in controlled settings, offering insights into various neurological and behavioral phenomena [40,43].

Mice and rats are essential models for testing the efficacy and safety of potential drugs and therapies before advancing to human trials [11]. This step is crucial in drug development for

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neurological disorders. These models allow researchers to investigate neural plasticity, brain development, and responses to stimuli, providing insights into how the brain adapts and learns [47]. Studies using these models have propelled the development of cutting-edge technologies like optogenetics, brain imaging, and gene editing tools. These advancements expand the scope and precision of neuroscience research. Findings from these models provide critical bridges between fundamental research and clinical applications, offering promising avenues for developing novel therapies and interventions [30]. Their relatively low cost, ease of breeding, and availability make them accessible models for various experiments, contributing to their widespread use in neuroscience. The diverse and multifaceted contributions of mice and rats in neuroscience research have revolutionized our understanding of the brain's complexities and hold significant promise for advancing treatments and interventions for neurological disorders [30]. Their role continues to evolve, guiding researchers toward groundbreaking discoveries and innovative approaches in neuroscience [11,30] **(Table 1)**.

Table 1. Advantages of Rat and Mouse Models in Neuroscience Research: The Table highlights the key advantages inherent in utilizing rat and mouse models, which are fundamental to advancing neuroscience research.

Advantages	Rat Models	Mouse Models
Size	Larger brain size allows for easier surgical procedures and brain imaging.	Smaller size facilitates handling, breeding, and genetic modifications
Genetic Insights	Helpful for genetic studies in complex physiological pathways	Excellent for genetic research due to extensive genetic manipulation. .
Disease Modeling	Used in various disease models, e.g., hypertension, Parkinson's Disease. Models' various neurological disorders aiding in understanding disease progression and potential treatments.	Widely used in disease modeling, offering diverse models for diseases. Models' various neurological disorders aiding in understanding disease progression and potential treatments.
Behavioral Studies	Complex behaviors like humans enable diverse behavioral studies. Facilitates studies on learning, memory, addiction, and social behaviors, offering insights into neural mechanisms behind behavior.	Well-characterized behaviors make them useful for behavioral tests. Facilitates studies on learning, memory, addiction, and social behaviors, offering insights into neural mechanisms behind behavior.

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Pharmacological Testing	It is commonly used for drug testing, especially in behavioral tests. Primary models for testing potential therapeutics are crucial in assessing drug efficacy and safety before human trials.	Excellent for genetic research due to extensive genetic manipulation. Effective for testing drug responses and toxicology in various settings .
Neural Plasticity	Insight into neural plasticity and brain development due to brain size	Valuable for studying neural plasticity. and developmental neuroscience .
Technological Advances	Utilized in various technological advancements, including brain imaging. Propels the development of advanced technologies like optogenetics, brain imaging, and gene editing tools.	Often used in pioneering technology advances in neuroscience research. Propels the development of advanced technologies like optogenetics, brain imaging, and gene editing tools.
Bridging Research	Useful in translating findings from basic research to clinical applications. Provides critical connections between fundamental research and clinical applications, paving the way for novel therapies.	Important for translating research. into clinical and translational areas. Provides critical connections between fundamental research and clinical applications, paving the way for novel therapies.
Accessibility:	Generally, less accessible due to size and cost considerations	More accessible, widely used due to their smaller size and cost.
Genetic Manipulation	Enables precise genetic manipulation, allowing the study of specific genes' roles in brain function and diseases.	Extensive genetic manipulation tools, including knockout, transgenic models

Ethical Treatment in Research: The Culture of Care:

In recent decades, there has been a significant evolution in the approach to human-animal interactions, particularly with laboratory animals. Therefore, their care has undergone a remarkable transformation, with an increased emphasis on addressing the animals' suffering, stress, and distress. Animal care programs now consider experimental animals’ physical and psychological well-being. Promoting a "culture of care" within research facilities is critical. This change occurred when the scientific community realized that animals have many behavioral needs that, if not met, can negatively affect their behavior, physical health, and research outcomes [53].

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In the early 2000s, researchers introduced the concept of a "culture of care" regarding AMs. This concept, borrowed from the health and patient care field, has gained significant importance since the European Directive 62/2010/EU and the subsequent publication of the working document on Animal Welfare Bodies and National Committees to fulfill the requirements under the Directive in 2021.

Embracing a 'Culture of Care': Defining and Advocating Ethical Practices:

The "Culture of Care" is strongly dedicated to animal welfare, staff well-being, transparency, and scientific excellence. Research facilities should go beyond legal obligations to ensure kindness and respect for animals and employees [54].

It is essential to approach experimental research with animals with the right attitude. More than merely complying with regulations or following the 3Rs principle (Replacement, Reduce, Refinement) is required. Researchers must consider the animals' physiological and behavioral needs, be aware of their potential suffering, understand the research's scientific objectives, and acknowledge the benefits it can bring to safeguard human health, the environment, and the animals' well-being [55].

Proper management of laboratory animals involves providing sufficient living spaces, closely following experimental procedures - particularly those that can cause suffering - to reduce discomfort, creating enriched environments that mimic their natural behavior, and encouraging positive interactions with caretakers. Essential practices include constant animal welfare monitoring, administering analgesics and anesthetics, and minimizing the use of animals whenever possible. Furthermore, transparent data sharing and results foster a culture of scientific collaboration and accountability [55].

The culture of care not only addresses ethical considerations but also reflects positively on the quality of the scientific results obtained, ensuring that the gathered information is reliable and pertinent. In 2021, [54,56] effectively portrayed how the culture of care serves as the foundation for a structure where animal welfare acts as the overarching roof supported by essential pillars, such as staff support, the Animal Welfare Body, access to information on the 3Rs [54,56].

After starting with this image, we aimed to envision what the staff who work daily with the animal model would find inside this well-structured building. The staff includes animal facility technicians, researchers, a veterinary doctor, an animal welfare officer, and other members of the animal welfare body. The culture of care should be actively implemented daily, not just as an abstract concept [57]. The foundation of a building must be strong, resilient, and well-structured. In this case, the foundation consists of solid education and training, covering current regulations, the 3Rs principle, knowledge of the species to be worked with, and the rules for optimal use of the facility and equipment. This information is necessary to understand the essence of animal welfare and determine strategies to safeguard it [58].

As mentioned above, the approach ensures animals' ethical and scientifically sound use in research. Animal welfare can be compared to the covering of the floor and each step in the staircase. The steps represent additional ongoing training and education for all personnel involved [59].

Acquiring knowledge about the animal model is one of the initial steps to climbing the metaphorical staircase. This includes knowing about the species and the different strains, focusing on transgenic ones. However, theoretical knowledge alone is not enough; practical knowledge is equally essential. Spending time with animals, observing their behavior, and detecting and recording any signs of distress is crucial. Adopting score sheets can help identify these signs of distress early, facilitating prompt intervention. Several models are available in the bibliography (e.g., [60–62]. It is essential to customize models to fit specific needs based on the type of research and animal model being used. However, the entire research team and technical staff must be adequately trained using these score sheets [59].

To have a successful team, it is essential to have individuals inclined towards communication and collaboration while having clearly defined roles. This is essential to ensure animal welfare and generate reliable scientific results that can be easily reproduced and translated to humans.

Monitoring the health of animal colonies is crucial for reliable scientific data. It helps prevent variables in experimental designs and safeguards personnel health. All Animal Facilities must have a periodic health monitoring program for pathogens [63,64]. Health controls can be either direct or indirect: tests on the animals themselves, their products, the environment in which they live, and the

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personnel involved in their management. Effective research requires proper planning with established timelines and a clear list of pathogens. FELASA guidelines and standardized health reports aid in information exchange among cooperating labs. Daily observations made by staff are crucial, in addition to routine health surveillance, assays, sampling, and testing [64,65].

Environmental control is also essential to ensure animal health. Monitoring environmental parameters such as temperature, humidity, and ventilation carefully and regularly helps prevent the spread of diseases [66]

Equally crucial in this field is the training and ongoing education of colony care and management staff. A deep understanding of the health status enables the staff to be vigilant in recognizing any signs of disease in animals. Moreover, it heightens attention to procedures to prevent contact with zoonotic agents or the development of laboratory animal allergies (LAA) [65].

A proactive approach is paramount in an animal facility. Health monitoring protocols must continually be improved based on the latest research and advancements in veterinary medicine.

Environmental and social enrichment are crucial in ensuring the welfare of laboratory animals. Programs should be customized based on the specific needs and behaviors of the species involved while complying with applicable regulations and ethical principles. Providing adequate space and complexity is essential for allowing animals to express normal species-specific behaviors [67].

Enrichment programs should grant some control over the surroundings to minimize stress-related behaviors like stereotypies. Social enrichment is crucial; isolation should only be for health and experimental reasons [68].

Varying the diet and mode of feeding, hiding food, and involving animals in training activities are ways to offer environmental enrichment. Humans can also be environmental enrichment, particularly for rats, by stimulating them cognitively and creating a bond with handlers. Positive interactions with animals can contribute to their emotional well-being, benefiting the overall outcome of experimental procedures [67].

Feeding and watering are crucial for the well-being of laboratory animals. It is necessary to provide them with a well-balanced diet and clean water. High-quality feeds are now available, optimizing the growth, maintenance, and reproduction of most species. Different species of animals have different nutritional needs, and feed formulations must be tailored to meet their biological needs. Animals must have access to fresh food regularly. Alternative feeding strategies should be implemented if animals encounter locomotor difficulties. Reports on the nutritional requirements of various animal species are available, and most animal research facilities purchase laboratory animal feeds from commercial manufacturers. [69] Feed types include natural, purified ingredients and chemically formulated options. It is essential to use certified diets that meet contaminant concentrations below predetermined levels. For example, the nutritional requirements of pregnant and lactating females differ from those of adult males. Moreover, it is essential to consider whether the animals are conventional, Specific Pathogen-Free (SPF), or germ-free (GF), as this may necessitate supplementation of vitamins, especially K and B. Therefore, feed formulations must be tailored to meet the biological needs of the animals [70].

Regularly monitoring animal body weight and water intake is essential to ensure their overall health and well-being. Water must be clean and easily accessible, and different watering methods must be carefully and regularly maintained to prevent contamination. Changes in drinking habits can indicate potential health or stress problems in animals. Regularly monitoring animal body weight and water intake is essential to ensure their overall health and well-being. Water must be clean and easily accessible, and different watering methods must be carefully and regularly maintained to prevent contamination. Changes in drinking habits can indicate potential health or stress problems in animals. Finally, it should not be forgotten that the feeding and watering of laboratory animals are regulated by ethical and regulatory guidelines designed to ensure animal welfare (European Recommendations 526/2007). Proper feeding and watering align with the 3Rs principle and prevent animal loss. Adjust them regularly to meet animal needs and ensure accurate data. Consider them during planning and evaluation. All personnel must receive adequate training in animal care.

To ensure proper animal care, all personnel, Functions A, B, C, and D, must receive adequate training as described in the refereed normative (European Directive 62/2010/EU).

The last step to climb is that of Communication and transparency. Often, this step is the most difficult to climb. Scientists are used to sharing their research and findings within a scientific context,

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but more is needed. In AMs studies, transparency concerns the accurate sharing of the results and the chosen experimental methods, including the selection, care, and use of laboratory animals. Detailed information on experiment design, ethical procedures adopted, and animal welfare monitoring should be provided. Transparency and effective communication also include disclosing any limitations or challenges encountered during the research. This honest approach fosters a deeper comprehension of the studies conducted and facilitates mutual learning among researchers. Collaboration and transparency play pivotal roles in establishing a robust knowledge base in neuroscience, ensuring that research is ethically grounded and that results are beneficial for the progress of science and medicine. Clarity in communication is equally important, not only among researchers working in the same field and disseminating results to the broader scientific community and the public. European Directive 2010/63/EU also highlights the importance of communication, especially transparency, as these principles are essential for fostering sustainable scientific progress and establishing an open dialogue between science and society.

Climbing the steps of this metaphorical staircase enables all personnel working with laboratory animals to acquire the information and updates essential to embrace the culture carefully. This involves those who perform procedures on animals (Function A), those who design the experimental study (Function B), those who maintain the colonies (Function C), and those who euthanize the animals (Function D). Everyone needs to be well versed in current regulations, the specific animal model they are working with, and all strategies to ensure animal welfare, starting with the 3Rs principle. A comprehensive knowledge of the animal model, encompassing its characteristics and limitations coupled with careful analysis of relevant literature, can guide efforts towards Replacement and Reduction. This knowledge empowers people to consider an alternative animal model that is more suitable and informative for all or part of the study.

Harmonizing procedures and cultivating a culture of care that serves as a common thread throughout the animals' lifespan and the entire study period is also beneficial for establishing international scientific collaborations [56].

There needs to be more than experience and expertise in a specific research field; it is crucial to establish that. Both parties involved in a collaboration share similar perspectives on animal welfare and maintain ethical research standards. The culture of care in laboratory animals emphasizes the importance of balancing scientific research with ethics and respect for the living beings involved. Its implementation helps to ensure that scientific research is conducted responsibly, with a prioritization of animal welfare. This is essential to ensure the reproducibility of the research and the potential for publishing the obtained results [56].

Although it is desirable to use alternatives to live animals, they are still needed in biomedical research. Keeping this in mind, it is evident that a collaborative network among all personnel revolving around the AMs is crucial. Collaboration, coupled with communication and accountability of all involved people, allows for ethical work with animals, rigorous scientific endeavors, and transparency to the public within a One Health perspective.

Conclusion

In conclusion, the trajectory of neuroscience advancement intertwines with the invaluable contributions of AMs, particularly mice and rats, in unraveling the mysteries of the brain. These models have been pivotal in elucidating fundamental aspects of neurological function, modeling diseases, and exploring behavioral intricacies. However, alongside their significance lies an ethical imperative—the welfare and culture of care surrounding these animals. Ensuring their well-being is not merely a moral responsibility; it directly impacts the quality and reliability of scientific outcomes. Upholding high welfare standards and cultivating a culture of care within research settings not only respects the dignity of these creatures but also ensures more consistent, reliable, and translatable research findings. The ethical treatment of AMs in neuroscience is not just a moral compass; it is an essential component in pursuing rigorous and impactful scientific discoveries that hold promise for understanding the complexities of the brain and advancing human health.

Future Prospective

Looking to the future, the prospects for neuroscience, supported by AMs, particularly mice and rats, are poised for remarkable advances. Harnessing the potential of these models offers promising avenues for deeper exploration and innovation. Continued advancements in genetic manipulation techniques will enable more precise and targeted modifications, allowing for the creation of increasingly accurate disease models and the exploration of specific neural circuits. Further integration of cutting-edge technologies, such as advanced imaging techniques and optogenetics, with AMs, will enable a more comprehensive understanding of brain function at the cellular and circuit levels. Utilizing AMs, particularly in conjunction with human genetic data, will facilitate the development of personalized treatments for neurological disorders, optimizing efficacy and minimizing side effects. Advancements in behavioral assays and analyses in AMs will lead to a more nuanced understanding of cognitive processes, emotions, and social behaviors, shedding light on complex human behaviors. Continued efforts in developing AAs and refining ethical guidelines will drive innovation, potentially reducing reliance on AMs while upholding scientific rigor and ethical standards. Collaborations between neuroscience, genetics, engineering, and data science will expand, fostering novel approaches and perspectives in understanding brain function and neurological disorders. Fostering a culture of care and ethical considerations within the scientific community will ensure the humane treatment of AMs, reinforcing the integrity and credibility of research outcomes. The future of neuroscience, propelled by AMs and underpinned by a culture of ethical care, promises groundbreaking discoveries that will deepen our understanding of the brain and offer novel insights into neurological diseases and potential therapeutic interventions, ultimately enhancing human health and well-being.

Abbreviations:

Animal models (AMs)

Nervous System (NS)

Alternative Methods (AAs)

Replacement, Reduce, Refinement (3Rs)

Specific Pathogen-Free (SPF)

Laboratory Animal Allergies (LAA)

Germ-Free (GF)

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