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Modern Trends of Using Animal Models for Glaucoma

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Abstract: Glaucoma is a heterogeneous group of optic neuropathies that eventually cause blindness as a result of retinal ganglion cell loss and optic nerve damage. Increased Intraocular pressure is the major risk factor associated with the onset of glaucoma. Many patients are continuously suffering from glaucoma despite using several advanced intraocular pressure-reducing therapies. It is the primary cause of blindness and visual impairment globally. Despite advancements in treatment methods, there is still a need for a better understanding of its pathophysiology to understand the underlying disease mechanism completely. Although there has been extensive study on glaucoma, the pathophysiologic processes that cause glaucoma are not fully understood. Animal models are playing an important role in glaucoma research for a long time. Glaucoma research has been conducted using a wide range of animal models such as Monkeys, dogs, cats, rats, and other animals. Animal models enabled researchers to investigate the mechanism of disease and the discovery of novel treatments. The objectives of this review will provide details of different animal models used in glaucoma research and analyze the role these models have played in understanding the disease mechanism and the development of novel treatment methods. Despite, extensive research on Glaucoma, there is no optimal model for understanding it due to its complexity. The purpose of this review is to describe most animal models that have been produced and employed for the research of various forms of glaucoma, as well as the strengths and limitations associated with each model and some prospective criteria for developing an appropriate model.

Keywords: Glaucoma, increased intraocular pressure, blindness, animal models, retinal ganglion cell loss, optic nerve damage

Introduction

Glaucoma is a prevailing reason for irreversible visual loss around the world, influencing a large number of people over 50 years [1]. Approximately, in 2020, around 4.13 million people of this age suffered from moderate to extreme vision loss, and 3.6 million were visually impaired because of glaucoma [2]. This condition represented 11% of all worldwide visual impairment in those aged 50 or above [3]**.** Given the varying pervasiveness of glaucoma across various countries and regions, it is necessary to focus on work to reduce vision loss due to glaucoma. Strangely, glaucoma is predominant among people of African descent, going from 6.5% to 7.3% [4, 5]. Followed by the

East Asian region population, where prevalence is from 2.59% to 3.54[6-8]. Compared to European populations, where it falls less than 2.0% [1, 9].

The stress of visual impairment from glaucoma may rise with time. Even though information on the worldwide prevalence of vision loss due to glaucoma is available [3] its dominance in regions with different economies remains unknown. Raised IOP causes changes in the eye, so it would follow that the retrobulbar area would be less impacted and would in this manner show fewer changes. Examination tests of retrobulbar regions in raised IOP models support this suspicion and have not shown extracellular collections that are found in the eye. Glaucomatous neurodegeneration is much of the time gone before by a decrease of visual perfusion because of the diminished blood stream.

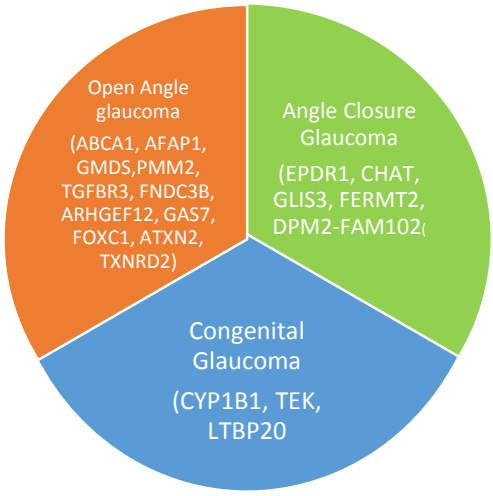
Animal models play an important role in improving our understanding of the reasons and onset of human diseases and have proved helpful tools for discovering target areas for therapeutic drugs. All animal models do not mimic human diseases thoroughly so several diseases are still incurable. Glaucoma is a heterogeneous disorder group that causes blindness by damage of the nerve optic and loss of ganglion cells of the retina. Worldwide Leading cause of vision loss and visual disorders is glaucoma. Due to substantial research, pathophysiological mechanisms responsible for glaucoma are not fully known. A wide range of animals such as monkeys, cats, dogs, Rodents, and other species have been used as models to study glaucoma and various other disorders. Animal models provide valuable insight into the disease but still ideal model to study glaucoma is not available due to its complexity.

Several studies have been conducted by utilizing experimental models such as Rodents, cats, dogs, and primate models such as rhesus monkeys to find the therapeutic target regions and discovery of new drugs for the treatment of increased ocular pressure. Currently, the main focus of clinical therapies is to lower ocular pressure. However, this treatment is not effective in all patients and the other problem is that in normal tension glaucoma IOP is normal. So, the therapies used to lower IOP to treat glaucoma are not effective in such cases where any change in IOP is not associated with the disease. Researchers are working to develop new drugs for treatment and the development

of such models that better mimic glaucoma in humans. Researchers are using genetically modified animals as models and inducing conditions such as oxidative stress to discover novel therapeutic targets and advance glaucoma therapies. High IOP model, genetically modified animal models such as GLAST knockout Marmosets, and Normal Tension Glaucoma animal models provide insight into different aspects of Glaucoma [10].

These animal models helped researchers to understand the onset of disease, test new drugs, and investigate therapeutic targets which proved helpful for patients other than therapies for reducing IOP [9]. Mutations in genes like MYOC, WDR36, and OPTN account for less than 10% of Primary open-angle glaucoma cases[11]. And in *TBK1* gene copy number variation accounts from 0.4 to 1.3% in NTG [12]. This article will thoroughly explain the animal models of different species that are used in clinical research of different types of glaucoma. The most prominent genes of the three major types of glaucoma are illustrated in the diagram.

Figure 1



Animal Models of Glaucoma

Various species of animals like cats [13], dogs[14], monkeys [15], pigs [16], and rodents [17] have been used as models in glaucoma research[18, 19] there are various spontaneous and induced

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glaucoma models. Although these models provide an understanding of some limitations and drawbacks associated with each model, commonly optic nerve damage leads to vision loss in glaucoma but each type has different causes. High IOP is the most prevalent cause of glaucoma and a major risk for loss of vision. These models are illustrated in the table.

Table1

Primary Open Angle Glaucoma (POAG)	Animal Model	First Use	Year	Reason/Notes	Reference(s)
	Dog	Spontaneous POAG in Beagles	1974	Dogs naturally develop POAG, providing a close resemblance to the human condition.	[20]
	Rat	Steroid-induced model	1985	Used for studying elevated intraocular pressure (IOP) and optic nerve damage.	[21]
	Mouse	Genetic models (DBA/2J strain)	1998	Spontaneously develops elevated IOP and glaucomatous damage, useful for genetic studies.	[20]
	Monkey	Laser-induced ocular hypertension	1974	Monkeys' ocular anatomy closely resembles humans, making them ideal for studying the disease	[22]

				progression and treatment effects.	
	Rabbit	Steroid-induced model	1961	Used for studying the effects of IOP elevation on ocular structures.	[23]
	Zebrafish	Transgenic bug eye mutant	2005	Exhibits high IOP and retinal ganglion cell (RGC) death, useful for genetic studies.	[24]
	Sheep	Steroid-induced model	1991	Provides a model for studying large-animal responses to glaucoma treatments.	[18]
	Cow	Steroid-induced model	1991	Large-eye model for studying ocular pharmacology and IOP dynamics.	[18]
	Avian	Light-induced model	1987	Used to study the effects of light on IOP and ocular health, and to test glaucoma medications.	[25]

1- Primary Open Angle Glaucoma

Primary open-angle glaucoma is the most prevalent form of glaucoma in different populations. Three causative genes Myocilin, Optineurin, WDR36, and 20 genetic loci have been reported for POAG [11]. Various kinds of animal models are used to study induced and spontaneous glaucoma.

Monkey Model

A series of investigations that started at the end of the 1950s and began in the 1960s reported the different forms of severely elevated IOP in non-human primates. In 1974 Gasterland and Kupfer described the current model of chronic laser-induced, High unilateral IOP in a publication [22].

Due to the close anatomical association of the NHP optic nerve head with human ONH experimental glaucoma models of NHP are frequently utilized in human glaucoma research in the previous 40 years. Because this association between NHP and humans remains consistent throughout each section of the vision system. This model is of great importance as it provides insight into a systematic study of the earliest vision system responses to severe IOP changes such as high IOP causes Glaucoma, at this stage of glaucoma human eyes cannot be recognized clinically.

Increased IOP was first reported in animals from a small colony of rhesus Macaque monkeys from Cayo Santigo Colony of Puerto Rico University, in the absence of increased IOP detection the changes in ONH and the onset of optic neuropathy in the ocular hypertension setting are suspicious for glaucoma in 1993 [26]. Another group of visual hypersensitive animals has been reported in Singapore in an NHP colony. The close phylogenetic and homologous links between monkeys and humans make them ideal models in glaucoma studies. Retinol and optic nerve anatomy of monkeys has a close resemblance with humans. Unfortunately, limited availability, handling problems, cost, and the need for highly experienced researchers make it difficult to use monkeys for experiments in laboratories.

Dogs

Four mutations of primary open-angle glaucoma are reported which follows the autosomal recessive mode of inheritance. two mutations are present in ADAMTS10 which causes glaucoma in Norwegian Elkhounds, Beagles[27-29]. Another, gene ADAMTS17 has additional mutations that cause open-angle glaucoma. Two additional mutations that are present in the closely related gene known as *ADAMTS17* have recently been identified that cause POAG in the Petit Basset Griffon Vendéen and Basset Hound, respectively [30].

In most breeds, PCAG is more complex genetically in comparison to POAG.DNA tests are not available for dogs with a risk of glaucoma. PCAG dogs have been used as POAG models of humans for decades. PCAG clinical signs in dogs are similar to POAG clinical signs in humans which results in vast literature although this disease is rare [31]. The similarity of physiology and anatomy of the eyes of dogs with humans makes them suitable animal models for glaucoma research because they mimic the natural onset of glaucoma in humans. As dogs have longer life spans they can be utilized in long-term study of disease and treatment effectiveness but their ethical concerns in using animals as disease models. Genetic diversity causes variations in experiment results.

Mice models

A large number of mouse models of glaucoma have been created and described. A transgenic (Tg) mouse strain with a designated change in the gene for the α1 subunit of collagen type I exhibits a slow increase of IOP and progressive damage of the optic nerve axon [32]. Transformations in the MYOC gene were present in about 3-4% of patients having POAG[33]. From reported mutations, the Tyr437His change in MYOC is linked to one of the most extreme types of glaucoma for which the typical age at diagnosis was 20 years. That is about 40 years before that brought about by the slight mutations in the MYOC gene [34]. The Tyr437His conversion in MYOC in humans is similar to the Tyr423His change in MYOC in mice.

Rodents, specifically mice, have been used frequently because of their fertility and short life cycles. Besides, the genomes of rodents and humans are profoundly conserved, and the murine eye has a great anatomical and physiological similarity with human visual structures and physiology. Rodents are likewise subjected to hereditary and trial control, considering the formation of transgenic animals with explicit human disorder alleles. However, there are limitations linked with the rodents to be used as human disease models. There are several anatomical differences such as lamina cribrosa being absent in mice instead astrocytes organized into glial lamina are present[35]. There are several retinol differences Several displaced amacrine cells are present in the retinal ganglion cell layer in mice [36]. Besides, the rodents ' small size makes' experimental procedures challenging. In any case, rat models have been a vital tool in the investigation of human visual disorders.

Rat model

A glaucoma rodent model, incited by the effective use of dexamethasone, was constructed for research on MYOC. Even though IOP was raised following 14 days of treatment, the protein and mRNA levels of myocilin in the TM and around Schlemm's channel in the treated eyes were not unique to those of the controls hypothesizing that myocilin may not be straightforwardly connected to visual hypertension [37]. There is a significant increase in IOP as retinal and ON changes have similarities to those found in humans. Additionally, a decrease in IOP in response to glaucoma medication has been found but the drug impacts were not similar to the results in humans [38]. Moreover, rodents such as mice are easy to handle and provide insight into genetics.

Zebrafish

The zebrafish has emerged as a key model animal for the study of human illnesses due to its ability to undertake robust forward and reverse genetic analyses, allowing researchers to swiftly discover genetic loci and investigate their involvement in disease progression. The anatomical, physiological, and genetic conservation of essential eye structures that play key roles in regulating intraocular pressure (IOP) in zebrafish and humans strongly implies that the fish is a good model animal for glaucoma research. The annular ligament (AL) in the zebrafish eye is a specialized

tissue physically positioned near the mammalian trabecular meshwork (TM). Because TM is the principal tissue in controlling IOP, a critical risk factor for glaucoma, zebrafish may develop glaucoma or glaucoma-like symptoms.

Zebrafish may develop glaucoma or symptoms similar to glaucoma if the natural structure of the AL is changed by genetic ablation or manipulation of the AL cells. This is because TM is the principal tissue in regulating IOP, a major risk factor for glaucoma. To test this hypothesis, transgenic fish will be developed by introducing three different types of genes into their genomes: the mutated MYOC gene, which altered the TM cells and caused glaucoma, DTA, and the E. coli NTR gene. Aqueous humor outflow blockage and high intraocular pressure (IOP) may arise from the expression of these genes in the AL, which may cause cell death or aggregation. An inducible cre/loxP system and the AL-specific promoter regulate tissue-specific cell ablation and modification. An evaluation of the transgenic fish's eye structure, morphology in the AL, alterations in intraocular pressure, quantity and viability of retinal ganglion cells, and appearance of the optic nerve will be conducted using histological, physiological, immune histochemical, and molecular techniques.

Little freshwater fish known as zebrafish (Danio rerio) are commonly used as model animals in human disease research because they can be genetically modified by removing or changing specific cells that are necessary for maintaining normal intraocular pressure (IOP), pressure inside an eye which helps to preserve eye shape [39]. Additionally, zebrafish models of glaucoma have exhibited improved visual acuity after being given a carotenoid molecule called Zeaxanthin. Zeaxanthin injections can improve visual acuity in the injected eye by up to 13%, suggesting that they may have a protective impact on retinal health and eyesight [40].

Avian Model

Scientists can intentionally cause glaucoma in domestic chicks by simply raising them in a constant light environment. A model system for open-angle glaucoma in humans is provided by light-induced avian glaucoma (LIAG). In addition to comparing the LIAG system with many other glaucoma model systems in dogs, rabbits, and monkeys, many morphological and physiological

discoveries in LIAG are discussed. Numerous anti-glaucoma medications have been shown to respond to intraocular pressure in patients with LIAG; as a result, the system may be utilized for further drug testing accordingly, it is proposed that LIAG might be particularly helpful in research aimed at comprehending human glaucoma and determining preventative or therapeutic measures for it [25]. Although using avian models for research has several benefits in understanding the pathophysiology of glaucoma and providing significant connections to human diseases, researchers must consider issues like model specificity, availability, and technological difficulties.

Primary congenital glaucoma models

Animal models play an important role in understanding the pathogenesis and treatment of primary congenital glaucoma. Various species of animals, birds, and rodents are used to study the disease onset. These animal models either natural or transgenic, provide useful information about the role of animal models in disease research.

PCG is caused by congenital anterior segmental development and involves genes such as cytochrome P450 and TGF-β-binding protein 2. The actual pathogenic process of PCG is not completely understood, highlighting the need for more studies to find novel treatments to address this disease [41] Some of these models are below.

Table 2

Primary Congenital Glaucoma (PCG)	Animal Model	First Use	Year	Reason	References
	Mouse	CYP1B1 knockout mouse model for PCG	2002	Mice are genetically similar to humans and can be easily manipulated genetically to study disease mechanisms.	[42]

	Rabbit	First transgenic model for PCG	1985	Rabbits have ocular anatomical and physiological features that are similar to humans, making them suitable for glaucoma research.	[43]
	Cat	Study of congenital glaucoma in Siamese and Burmese cats	2005	Cats have relatively large eyes, which makes clinical and surgical interventions easier, and their ocular features closely mimic human glaucoma.	[44]
	Quail	Albino quail model with all mutation	1986	Quails are small and easy to handle, and the albino mutation provides a model for studying eye enlargement and RGC degeneration similar to human glaucoma.	[45]
	Rat	Genetic model using Cyp1b1 knockout rats	2003	Rats are widely used due to their genetic similarity to humans and the ability to create	[46]

				specific gene knockouts.	

Rabbit

In rabbits, PCG is inherited spontaneously and presents as a congenital anomaly in anterior chamber development, similar to glaucoma in humans. Corneal edema, increased corneal diameter, ciliary body swelling, iris column distortion, and changes in structure in the trabecular meshwork are among those issues. This animal also displays fluctuating intraocular pressure rise, optic nerve deterioration, and flow channel abnormalities. The rabbit model plays an important role in PCG research, offering facts about its causes and possible ways to treat it [47].

RAT MODEL

The Brown Norway rat magnetic bead model replicates numerous clinically important aspects of human glaucoma, such as RGC degradation across many regions. Eye enlargement is probably triggered by rat scleral adaptability, and we advise that this should be taken into account when estimating the retinal thickness [48].

MICE MODEL

The nee mouse model, which has congenital glaucoma-like features, has been employed to investigate the particular susceptibility of ON-OFF channel-specific RGCs to increased eye pressure. The new mouse model mimics congenital glaucoma, a leading cause of congenital vision loss. The recent research of nee mice involved two aspects. We examined the development of degeneration in ocular flat mounts as time passed using BRN3A, TO-PRO-3, and H&E staining methods.

The B6.Sh3pxd2b nee mutant mouse is another important model, since it has higher IOP, entire RGC mortality, and RGC subtype-specific distortion, offering crucial insights into the cause of

PCG. These mice models provide multiple perspectives on PCG, demonstrating an understanding of various features of the disorder and facilitating the development of novel treatment possibilities [49, 50].

Cat model

The Siamese cat is being identified to possess PCG and POAG, which makes it an excellent natural model organism for glaucoma studies. This animal model possesses symptoms identical to human PCG, including an early progression, a slight rise in eye pressure, and gradual loss of vision. The suffering cats exhibit bilateral moderate to severe buphthalmos, raised IOP, raised corneal operations, Haab's striae, the subluxation of the Lens, and other signs of glaucoma[44].

Zebrafish models

Several zebrafish models have been designed for PCG study, providing insight into the causes of disease and options for treatment. One model uses the foxc1 LoF zebrafish, which gives significant information on stereotypes of glaucoma, demonstrating an involvement in RGC division issues in PCG [51]. Another model employs guca1c-deficient zebra fish produced by CRISPR/Cas9 gene editing to examine the impact of GUCA1C functional loss in PCG. The model used exhibited alterations in cornea epithelial cell thickness, rise of neuronal fibrillary acidic proteins, RGC death, and defects in Schlemm's drainage canal and trabecular meshwork structures via a cGMP-dependent route [52]. These models provide novel insights into the hereditary and molecular processes of congenital glaucoma, serving as a foundation for future study and possible treatment innovations.

Albino Quail Model

The albino quail model has been used to investigate congenital glaucoma. This model, established in 1986, uses an albino quail that carries a sexually related semi-lethal recessively inherited alteration that shows characteristics such as eye expansion, RGC collapse corneal cupping, cataracts in the past and retinal cells histopathological modifications identical to those observed in

transgenic or natural glaucoma in various vertebrates. This model has drastically raised IOP at the age of 6 months, accompanied by an initially open iridocorneal angle which gradually seals in the later phases of the disease. While this model has features such as simplicity of maintenance and manipulation inside the laboratory, its drawbacks include the cornea's fragile size, which may make monitoring of IOP difficult, however, a tono open is suitable for monitoring. In addition, the supply of albino quails for experiments is restricted [53].

Angle Closure Glaucoma

Animals of various species such as dog breeds, basset hounds, and cockers used for experimental purposes. Beagles express the autosomal recessive phenotype and begin to develop the disease between 6 and 12 months of age. At the age of 2 to 3 years, as glaucoma progresses, the drainage angle begins to close and the excavation of the ON head can be observed. Some of the models are given below.

Table 3

Primary Angle Closure Glaucoma (PACG)	Animal Model	First Use	Year	Reason for Use	References
	Dog	Spontaneous PACG in Beagles	1975	Dogs naturally develop PACG, providing a close model for studying the disease progression and genetic factors.	[54]
		Steroid-induced	2006	Rabbits have similar ocular anatomy to	[55]

	Rabbit	PACG model		humans, aiding in studying pharmacokinetics and pharmacodynamics of treatments.	
	Rat	Surgically-induced PACG model	1997	Rats are used for genetic manipulation and studying molecular mechanisms in PACG.	[56]
	Mouse	Genetic PACG models (DBA/2J mice)	2002	Mice are useful for genetic studies due to their genetic similarity to humans and their ability to manipulate their genome.	[57]
	Turkey	Light-induced PACG model	1985	Turkey models are used to understand comparative ocular physiology and the effects of light-induced IOP changes.	[58]

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Dog Model

To better understand this illness, substantial research has been conducted on canine experimental models of angle-closure glaucoma. In these models, glaucoma is induced in dogs to imitate the disease process seen in humans. Hereditary primary angle-closure glaucoma in Beagles is one such model, with a gradual rise in pressure inside the eye, diminished optic nerve operation, and retina ganglion deaths [59].

This model showed a steady increase in IOP with age, iridocorneal angle disintegration, and physiological modifications in the optic nerve that corresponded to glaucoma. An additional study examined primary angle-closure glaucoma with goniodysgenesis in a beagle-breed dog, emphasizing the medical and prediction importance [60].

The case report presented a Beagle exhibiting a narrow angle between the iris and goniodysgenesis, which resulted in elevated IOP and eventual glaucoma progression. The research demonstrated the significance of gonioscopy in finding and managing glaucoma in The Beagle breed. In general, these dog models give significant insight into the pathophysiology, progress, and prospective therapies for closed-angle glaucoma, providing a foundation for future study and treatment advancement in this area of research.

Mice Model

The DBA/2J mouse model has been linked to higher IOP and glaucoma owing to iris defects caused by mutations in the Gpnmb and Tyrp1 genes [53, 61]. Additionally, Grm4 mutant mice have been found as a model for angle closure glaucoma, with unusually narrow angles detected by gonioscopy and optical coherence tomography[62]. These mice had well-formed trabecular meshwork and Schlemm's canal, which shed light on the structural alterations associated with angle closure glaucoma. The DBA/2J mouse model and Grm4 mutant mice are useful tools for

researching angle closure glaucoma in mice, providing researchers with a platform to analyze the pathogenesis, progression, and potential therapies for this disease.

Rat Model

To understand better this condition, researchers have studied the rat model of closed-angle glaucoma. The rat glaucoma "Bead Model," which promotes rapid-onset rise of intraocular pressure (IOP) leading to persistent glaucomatous damage to the retina and optic nerve [63] is one famous experimental model.

This model uses microbeads to raise IOP, causing repeatable and severe damage to ocular structures, making it a useful tool for Furthermore, the DBA/2J mouse strain, while not a rat model, is a prominent model for secondary glaucoma and has morphological and developmental similarities with rat models [53].

This model shows pigment dispersion, iris atrophy, and high IOP, all of which are associated with glaucoma development in people. However, it is crucial to emphasize that the higher IOP phenotype in this paradigm is related to systemic pigment dispersion syndrome, which limits its direct relevance to primary angle closure glaucoma. To summarize, while rat models such as the "Bead Model" are important for researching angle closure glaucoma, information from similar mouse models such as the DBA/2J strain can also help to understand the disease process and potential therapeutic approaches investigating glaucoma etiology and potential therapies.

Challenges

Because of the disease's complicated character, developing appropriate animal models for glaucoma presents several hurdles. One of the most difficult challenges is replicating the complicated pathophysiology of glaucoma, which includes high intraocular pressure (IOP), optic nerve injury, and retinal ganglion cell (RGC) loss. To address this difficulty, researchers frequently use a variety of methodologies that simulate distinct components of the illness, such as models incorporating IOP rise, optic nerve damage, retinal ischemia, or genetic risk.

Another key problem is species variations, since human glaucoma may differ from animal models.

To address this, researchers select animal species that have anatomical and physiological characteristics with humans in important eye structures. Glaucoma is also a chronic, progressive illness that requires long-term monitoring and evaluation in animal models. As a result, models that correctly represent the disease's chronicity and development are required for translational research. However, due to anatomical variations and technical constraints, effective measurement of IOP in animal models can be difficult, necessitating the use of various approaches to reduce variability. Furthermore, establishing experimental techniques and assuring repeatability across studies and facilities is crucial for moving research forward in this field. Ethical issues are particularly important, as glaucoma models sometimes require intrusive procedures and considerable discomfort for animals, necessitating the use of ethical criteria and the investigation of alternative approaches wherever available. Researchers may construct more robust and clinically relevant animal models of glaucoma by tackling these issues with suitable methodology and experimental design, allowing us to increase our understanding of the disease and develop novel therapies.

Criteria

Creating appropriate glaucoma models necessitates following particular criteria to ensure their efficacy in research and clinical applications. One key requirement is to capture the multidimensional character of glaucoma, beyond high intraocular pressure (IOP), to portray the disease's complexity and risk factors. Another important factor to examine is an anatomical and physiological resemblance to human eyes since models must reproduce critical traits to correctly imitate real glaucoma development Furthermore, models should be reproducible and reliable to provide consistent outcomes across investigations and increase the credibility of study findings. Furthermore, choosing models that can effectively answer research questions while admitting inherent restrictions requires aligning with specific experimental demands and taking into account each model's limitations Researchers may construct robust and relevant models for glaucoma research by following these criteria, expanding our understanding of the illness and improving patient outcomes overall.

Future Prospective

The goal is to develop improved animal models that simulate the complex character of human glaucoma, rather than only high intraocular pressure (IOP). To better simulate actual glaucoma pathogenesis, these models contain genetic mutations, age effects, oxidative damage, and other related components [10, 53, 64]. Stem cell-based treatments can regenerate damaged retinal ganglion cells and restore vision in glaucoma patients. Cell transplantation techniques are being enhanced, maximizing cell survival and integration to increase its effectiveness in treating glaucomatous retinal degeneration [65] [49] Closing the gap between preclinical research and practical use is critical for developing glaucoma therapy. Before transferring innovative medicines into human trials, well-designed translational research is needed to assess their safety and effectiveness[10, 65].

Conclusion

The future of animal models for glaucoma research includes developing more sophisticated models that closely resemble human pathology, investigating stem cell-based therapies for cell replacement, and translating research findings into clinical trials to advance treatment options for glaucoma patients. These techniques aim to expand our understanding of the disease, develop novel therapeutics beyond IOP reduction, and eventually improve patient outcomes.

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