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Corneal Response to Cataract Extraction with Advanced Vacuum-Assisted Technology

Radhika Rampat[1*], Rashmi Deshmukh[2], Xin Chen[3], Daniel S.W. Ting[4,5], Dalia G. Said[6,7], Harminder S. Dua[6,7], Darren S.J. Ting[5-7]

[1]Moorfields Eye Hospital, London, UK.
[2]Department of Ophthalmology, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK.
[3]School of Computer Science, University of Nottingham, Nottingham, UK.
[4]Duke-NUS Medical School, National University of Singapore, Singapore.
[5]Singapore National Eye Center / Singapore Eye Research Institute, Singapore.
[6]Academic Ophthalmology, Division of Clinical Neuroscience, School of Medicine, University of Nottingham, Nottingham, UK.
[7]Department of Ophthalmology, Queen's Medical Centre, Nottingham, UK.

***E-mail** ✉ RadhikaRampat@me.com

Abstract

The high prevalence of cataracts necessitates the development of advanced technologies in ophthalmic microsurgery. A research team has introduced an innovative hydrodynamic scheme designed to increase the safety of phacoemulsification procedures. This system detects occlusion by monitoring the vacuum levels in the aspiration line; when a critical threshold is reached and sustained, the system detects the occlusion and gradually reduces the vacuum to a predetermined value, all while maintaining occlusion. This study aimed to investigate morphological changes in the corneal tissue of rabbit eyes following experimentally induced post-occlusion waves using this novel hydrodynamic scheme. A total of 32 eyes from 16 white laboratory rabbits were studied. Both the conventional technology and the new hydrodynamic model were employed, using phaco needles of different diameters. The corneal samples were subjected to histological examination under light microscopy. The results showed that the least corneal damage occurred in group 4, where the innovative hydrodynamic scheme was combined with a fine needle (diameter = 0.9 mm). These findings suggest that this novel system can significantly reduce corneal trauma during phacoemulsification.

Keywords: Cataract, Ophthalmology, Occlusion, Hydrodynamic scheme, Phacoemulsifier

Introduction

The increasing prevalence of cataracts in today's population underscores the need for advanced surgical technologies that minimize tissue trauma and enable rapid postoperative recovery [1–3]. A fundamental aspect of ocular surgery, particularly phacoemulsification, is maintaining a precise balance between fluid entering and exiting the eye—this principle of hydrodynamic stability is crucial to preserving intraocular pressure during all surgical manipulations [4, 5]. Ensuring a controlled and consistent intraocular environment is essential for minimizing complications during the procedure [6, 7].

Although the engineering and software features of phacoemulsification systems continue to evolve, several challenges remain unresolved [8–10]. A key concern is minimizing the damaging hydrodynamic forces exerted on intraocular structures, which may result from both elevated fluid pressure and the sudden collapse of the anterior chamber due to abrupt drops in intraocular pressure [11, 12]. These rapid pressure fluctuations are particularly harmful, as they can compromise the

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integrity of the corneal endothelium and lens capsule. Moreover, in patients with pre-existing ocular conditions such as high myopia, macular degeneration, or advanced glaucoma, these changes can exacerbate disease progression [13], leading to an increased risk of complications during and after surgery.

Previous experimental findings have shown that occlusion breaks occur when lens fragments enter the aspiration pathway of the ultrasonic or aspiration handpiece during surgery [14].

To address this issue, our research team has developed a novel hydrodynamic control system that dynamically adjusts the vacuum automation settings in response to the characteristics of the aspiration flow. The core innovation lies in the system's ability to detect critical vacuum thresholds within the aspiration line; once these thresholds are sustained for a defined period, the system identifies the onset of occlusion and gradually lowers the vacuum pressure to a preset level—without disrupting the occlusion state. This controlled response reduces excessive fluid aspiration and mitigates sharp pressure fluctuations.

Therefore, this study aims to evaluate corneal morphological changes in rabbits following experimentally induced post-occlusion waves using this newly developed hydrodynamic model integrated into a phacoemulsifier system.

Materials and Methods

This experimental study involved 32 eyes from 16 white laboratory rabbits, all of which were housed under uniform conditions and provided with a standardized diet. The procedures adhered to established ethical guidelines and international regulations concerning the humane treatment of laboratory animals [15].

The investigation was structured into four experimental groups to assess how intraocular pressure fluctuations during occlusion breakthrough affect corneal tissue. In group 1, a conventional hydrodynamic system with a 1.1 mm needle for coaxial phacoemulsification was employed. Group 2 used the new hydrodynamic model with the same needle size. In group 3, the traditional system was combined with a 0.9 mm micro-coaxial needle, while group 4 combined the new hydrodynamic design with the 0.9 mm needle. Surgical access was achieved through corneal tunnel incisions of 2.75 mm for groups 1 and 2, and 2.2 mm for groups 3 and 4.

The control group comprised the untreated corneas from the contralateral eyes of the same animals. These samples were processed in parallel for histological comparison under the same conditions.

The surgical protocol for the rabbits followed a standard approach [16]. General anesthesia was induced using Zoletil. To enhance anesthesia, 1.5 ml of 2% lidocaine was injected into the subtenon space, and 1% dicaine solution was used for conjunctival irrigation. A temporal corneal tunnel incision, either 2.75 mm or 2.2 mm wide, was made using a calibrated steel blade. An ultrasonic phaco tip was introduced into the anterior chamber and positioned parallel to the iris, centered within the pupil. Care was taken to ensure the tip remained above the anterior capsule, avoiding contact with both the capsule and corneal endothelium. To eliminate the risk of unintentional endothelial trauma by lens fragments, no emulsification of the crystalline lens was performed.

The surgical parameters were standardized across all groups: the irrigation bottle was set at a height of 110 cm above eye level; aspiration flow was maintained at 45 ml/min; and the vacuum limit was set to 500 mmHg. The post-occlusion wave was induced by manually clamping the aspiration tubing near the ultrasonic handpiece, thereby causing occlusion. Upon reaching the preset vacuum threshold (verified on the instrument panel), the pump automatically stopped. After a 2-second interval, the tube was released to simulate the occlusion break. This cycle was repeated 10 times per eye. A saline solution was used as the irrigating fluid. This protocol was designed to closely replicate real intraoperative conditions and ensure experimental consistency.

Following the surgical procedure, the animals were euthanized via air embolism [17], and their eyes were enucleated 20 minutes post-mortem. Tissue preparation began with the excision of the cornea along with a rim of the surrounding sclera, as well as the attached lens, iris, and ciliary body to prevent mechanical damage during dissection. The cornea was isolated on a glass slide and carefully separated using fine tweezers.

For histological analysis, corneal samples were embedded in paraffin after dehydration through a graded alcohol series and clearing in xylene. Paraffin blocks were sectioned into 5 μm slices using an LKB-III rotary microtome (Sweden). The sections were stained with hematoxylin and eosin and mounted in Canadian balsam to preserve tissue morphology, coloration, and clarity [18]. Observations were made using a LEICA DM2000

light microscope (Germany) under magnifications ranging from 100× to 400×.

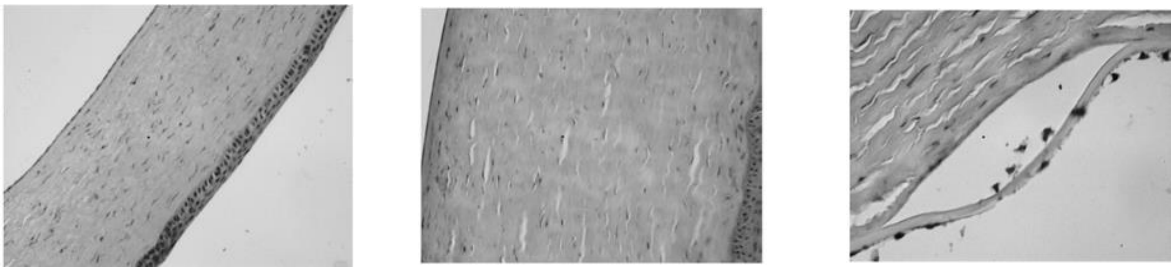
Results and Discussion

Corneal morphology in control (intact) group

In the untreated eyes of the control group, the structural integrity of both the corneal stroma and epithelial layers remained intact, particularly in the central corneal region. Collagen fibers appeared densely packed and aligned in parallel bundles, with spindle-shaped fibroblasts interspersed among them. The cells comprising the posterior corneal epithelium were observed to lie closely and uniformly on the Descemet membrane, exhibiting no signs of pathological alteration **(Figure 1a)**.

Corneal morphology in group 1 (standard hydrodynamic system, 1.1 mm needle)

Microscopic examination of corneal tissues from group 1 rabbits revealed substantial morphological disruptions across all corneal layers. Although the surface multilayered epithelium remained intact in the central region, significant structural changes were evident beneath. The corneal stroma displayed fibrotic characteristics across multiple regions, spanning from the anterior limiting membrane to the posterior limiting membrane **(Figure 1b)**. Notably, in certain sections, complete detachment of the posterior limiting (Descemet's) membrane from the underlying stroma was observed **(Figure 1c)**. Furthermore, there was visible exfoliation and shedding of cells from the posterior monolayer epithelium, indicating marked cellular damage and separation from the basement membrane.

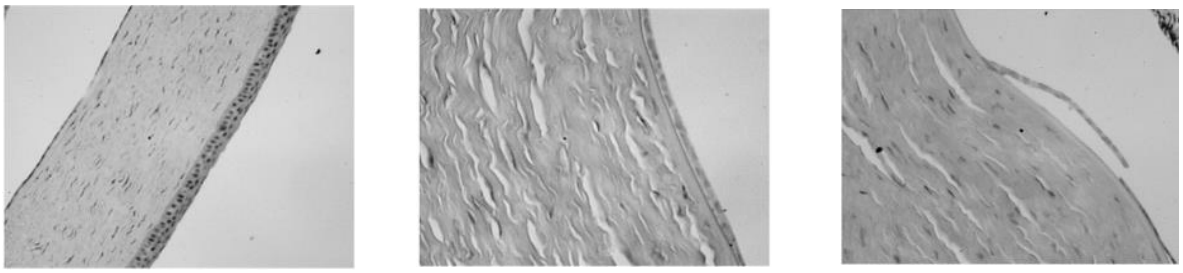


a) b) c)

Figure 1. Histological structure of the rabbit cornea (hematoxylin and eosin stain): a) normal corneal morphology in the control group, showing preserved tissue architecture (magnification ×100); b) structural alterations observed in group 1, with fibrotic changes in the corneal stroma (magnification ×200); and c) separation of the posterior limiting membrane from the connective stroma and sloughing of posterior epithelial cells in the cornea of a group 1 rabbit (magnification ×400).

Morphology of the cornea in rabbits–group 2 (innovative hydrodynamic scheme, 1.1 mm needle)

In Group 2, histological analysis of the central corneal region revealed a preserved structure of the anterior multilayer epithelium **(Figure 2a)**. Directly beneath this layer, the connective tissue stroma displayed densely packed collagen fibers without visible morphological alterations. However, near the posterior limiting membrane, mild fibrous separation of collagen bundles was occasionally observed, accompanied by localized swelling or minor tearing of cells in the posterior epithelial layer **(Figures 2b and 2c)**.



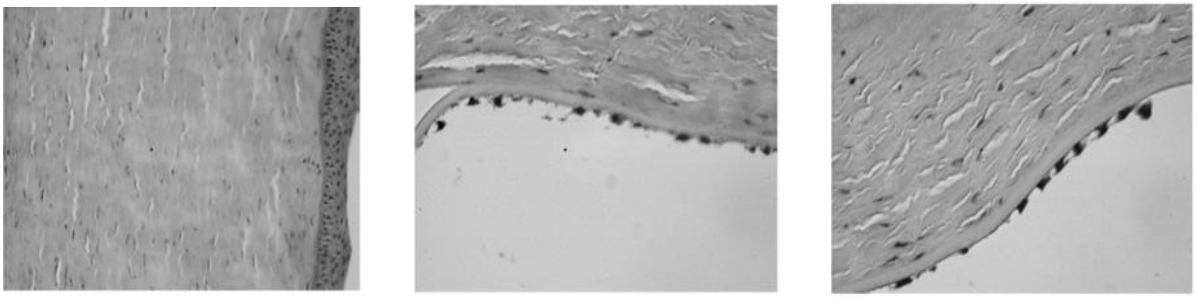
a) b) c)

Figure 2. Histological structure of the cornea in rabbits from group 2 (H&E stain): a) preserved architecture of

the central cornea, magnification ×100; b) mild fibrous separation and cellular swelling in the posterior epithelium, magnification ×400; c) focal rupture of the posterior epithelial layer, magnification ×400.

Morphology of the cornea in rabbits–group 3 (standard hydrodynamic scheme, 0.9 mm needle)

Despite the intact appearance of the anterior multilayer epithelium, histological examination of Group 3 corneas revealed notable changes in the underlying stroma. Collagen fiber bundles appeared fibrotic in multiple areas of the central cornea **(Figure 3a)**. Additionally, partial detachment of the posterior limiting membrane from the stroma was identified, along with swelling and exfoliation of posterior epithelial cells **(Figures 3b and 3c)**.

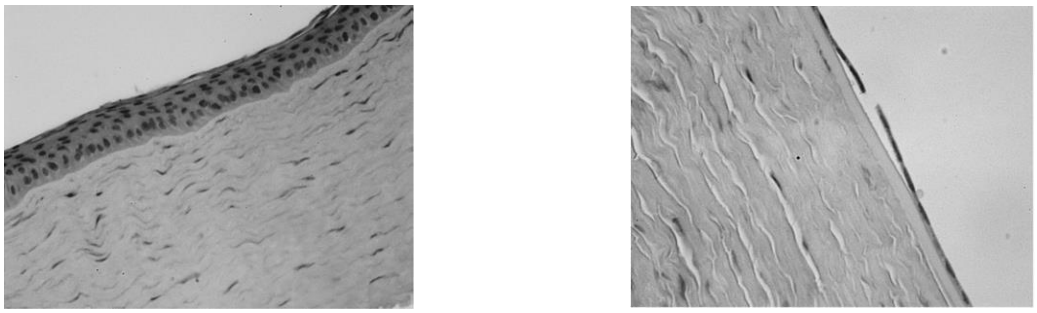


a) b) c)

Figure 3. Histological structure of the cornea in rabbits from group 3 (H&E stain): a) fibrotic changes in the central stromal region, magnification ×200; b) detachment of the posterior limiting membrane, magnification ×400; and c) desquamation of posterior epithelial cells, magnification ×400.

Morphology of the cornea in rabbits–group 4 (innovative hydrodynamic scheme, 0.9 mm needle)

In group 4, the anterior multilayer epithelium in the central region of the cornea remained morphologically intact **(Figure 4a)**. The collagen fibers in the stroma were organized into tightly packed, parallel bundles. Only minor fibrous separation of collagen bundles was observed in isolated regions near the posterior boundary membrane. Opposing these areas, localized swelling or occasional microtears in the posterior epithelial layer were detected **(Figure 4b)**.



a) b)

Figure 4. Histological structure of the cornea in rabbits from group 4 (H&E stain): a) intact anterior epithelium and organized stromal collagen, magnification ×400; and b) small rupture in the posterior epithelial cell layer, magnification ×400.

Conclusion

This study involved four experimental groups of white laboratory rabbits, with the main focus on analyzing the impact of different phacoemulsification methods on corneal tissue. The evaluation was based on changes observed in the corneal epithelium (both anterior and posterior), the arrangement of collagen fibers in the

stroma, and the integrity of the Descemet membrane, which is particularly sensitive to mechanical stress.

The findings revealed that the use of a micro-coaxial system with a 0.9 mm needle, combined with a novel hydrodynamic vacuum technology, resulted in the least morphological alterations in the cornea. This approach proved to be the most effective in minimizing damage after inducing a post-occlusion wave, highlighting its potential for reducing surgical trauma in cataract procedures.

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Ethics Statement: None

References

1. Mundy KM, Nichols E, Lindsey J. Socioeconomic disparities in cataract prevalence, characteristics, and management. Semin Ophthalmol. 2016;31(4):358-63. doi:10.3109/08820538.2016.1154178
2. Kristianslund O, Kure ISH, Drolsum L. Cataract surgery in Norway 2010-19. Tidsskr Nor Laegeforen. 2021;141(9). [In English, Norwegian]. doi:10.4045/tidsskr.20.1005
3. Konjevoda S, Gusar I, Perić S, Striber N, Škara Kolega M, Didović Pavičić A, et al. Fear of blindness in patients undergoing cataract surgery. Psychiatr Danub. 2021;33(Suppl 4):609-12.
4. Mislishayeva MS, Saiyan LA, Frolova PS, Grinenko EV, Abdurakhmanova IM, Chemazokova MZ. Basic principles of pharmacotherapy of diseases of the visual organs. J Adv Pharm Educ Res. 2023;13(2):24-8. doi:10.51847/44gUM9g3fF
5. Adline F, Prastyani R, Wahyuni I. Potential therapy of Asiatic acid to prevent scar remodeling post-strabismus surgery. J Med Pharm Chem Res. 2024;6(2):183-94. doi:10.48309/jmpcr.2024.183798
6. Luo Y, Xu G, Li H, Ma T, Ye Z, Li Z. Application of the active-fluidics system in phacoemulsification: a review. J Clin Med. 2023;12(2):611. doi:10.3390/jcm12020611
7. Bodla MA, Bodla AA, Moazzam A, Tariq N. Correlation between changes in intraocular pressure and refractive error indices post cataract surgery. Pak J Med Sci. 2020;36(3):574-7. doi:10.12669/pjms.36.3.1597
8. AL-Shakarchi W, Abdulaziz N, Mustafa Y. A review of the chemical, pharmacokinetic, and pharmacological aspects of quercetin. J Med Pharm Chem Res. 2022;4(7):645-56.
9. Redd TK, Al-Khaled T, Paul Chan RV, Campbell JP; American Academy of Ophthalmology Task Force on Academic Global Ophthalmology; American Academy of Ophthalmology task force on academic global ophthalmology. Technology and innovation in global ophthalmology: The past, the potential, and a path forward. Int Ophthalmol Clin. 2023;63(1):25-32. doi:10.1097/IIO.0000000000000450
10. Benítez Martínez M, Baeza Moyano D, González-Lezcano RA. Phacoemulsification: proposals for improvement in its application. Healthcare (Basel). 2021;9(11):1603. doi:10.3390/healthcare9111603
11. Sovogui MD, Lama PL, Bah TM, Balde R, Zoumanigui C, Balde AK, et al. Phacoalternative cataract surgery at the Bartimée clinic in Conakry (Guinea). Mali Med. 2022;37(2):1-5.
12. Ninomiya Y, Fuchihata M, Ninomiya S. Phacoemulsification with vitreous loss using phaco-emulsifier and vitrector concurrently: bimanual-bipedal technique. J Cataract Refract Surg. 2022;48(4):504-7. doi:10.1097/j.jcrs.0000000000000884
13. Hong-Kee N, Ahmad-Marwan AA, Julieana M, Fong ChM, Vivian-Gong HM, Liza-Sharmini AT, et al. Central corneal thickness and intraocular pressure changes post- Phacoemulsification surgery in glaucoma patients with cataract. Cesk Slov Oftalmol. 2023;79(2):70-8. [In English]. doi:10.31348/2023/12
14. Lin JC, Song S, Ng SM, Scott IU, Greenberg PB. Interventions for acute non-arteritic central retinal artery occlusion. Cochrane Database Syst Rev. 2023;1(1):CD001989. doi:10.1002/14651858.CD001989.pub3
15. Naderi MM, Sarvari A, Milanifar A, Boroujeni SB, Akhondi MM. Regulations and ethical considerations in animal experiments: international laws and Islamic perspectives. Avicenna J Med Biotechnol. 2012;4(3):114-20.

16. Al-Nawaiseh S, Thieltges F, Liu Z, Strack C, Brinken R, Braun N, et al. A step by step protocol for subretinal surgery in rabbits. J Vis Exp. 2016;(115):53927. doi:10.3791/53927
17. Marsh PL, Moore EE, Moore HB, Bunch CM, Aboukhaled M, Condon SM 2nd, et al. Iatrogenic air embolism: Pathoanatomy, thromboinflammation, endotheliopathy, and therapies. Front Immunol. 2023;14:1230049. doi:10.3389/fimmu.2023.1230049
18. Rzhepakovsky I, Piskov S, Avanesyan S, Sizonenko M, Timchenko L, Anfinogenova O, et al. Composite of bacterial cellulose and gelatin: a versatile biocompatible scaffold for tissue engineering. Int J Biol Macromol. 2024;256(Pt 1):128369. doi:10.1016/j.ijbiomac.2023.128369