HILL PUBLISHING

Scientific Access, 2026, 2(1), 24-28
https://www.hillpublisher.com/journals/sa/
ISSN Online: 3068-7500

An Experimental Study on the Influence of Material Properties of Scleral RGP Lenses on the Settlement Rate

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How to cite this paper: Dekun Li, Haiyu Mao. (2026) An Experimental Study on the Influence of Material Properties of Scleral RGP Lenses on the Settlement Rate. *Scientific Access*, 2(1), 24-28.
DOI: 10.26855/sa.2026.03.003

Received: January 29, 2026
Accepted: February 28, 2026
Published: March 31, 2026

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Abstract

This study focuses on the settlement behavior of scleral lenses and conducts an investigation on it, while intrinsic characteristics of rigid gas permeable materials regulate the rate of settlement, with mechanism pathways having also been systematically sorted out. By examining key physicochemical parameters, including oxygen permeability, elastic modulus, surface wettability, and anti-deposition properties, while integrating established quantification methods with the time evolution of the post-lens tear reservoir, this study elucidates coupled interactions between material properties and corneal physiological and biomechanical environment. Research results reveal an obvious staged pattern of scleral lens settlement, with an average reduction of approximately 126 ± 33 μm during the initial four-hour wearing period, and notably, inter-material variability manifests through differential regulation of corneal metabolism, tissue compression, and interfacial friction, thereby collectively shaping the trajectory of the settlement process. These results emphasize that material optimization must achieve a delicate balance between physiological biocompatibility and mechanical stability, thus providing a theoretical framework for improving the precision of scleral lens fitting.

Keywords

Scleral lens; RGP materials; Settling rate; oxygen permeability; tear reservoir; corneal physiology

1. Introduction

Scleral lens is now a key tool in everyday eye care because it holds a steady layer of tears behind it and gives much better sight to people with tough cornea problems. Their fitting works only as well as the lens settles into place. This settling depends on how the lens moves and lands, shaped by its shape plus how the eye surface varies across people. Eye surface texture and lens material mix in ways that differ from person to person. Studies show fluid trapped behind the lens shrinks after placement, usually fading fast at first, then slowing down, but how fast or how much changes a lot from one person to the next. These insights do not change the fact that doctors mostly focus on lens shape when fitting scleral lenses. They pay little attention to how lens material affects settling. We need clear answers about how RGP material traits control settling speed and pattern. Getting this right helps fit lenses more accurately and keeps them stable longer on the eye.

2. Main Traits of RGP Materials and What They Mean

2.1 How much oxygen gets through and why that matters for lens steadiness

RGP material lets oxygen pass through it. People measure this using DK and DK over t numbers. These numbers

show how well the material moves and holds oxygen. Adding silicone or fluorine monomers boosts how much oxygen gets through the lens, so the cornea stays closer to normal breathing level. Scleral lenses sit on top of the eye with fluid trapped underneath. When not enough oxygen reaches the cornea, that fluid pocket can turn low in oxygen and cause swelling or mess up cell activity. That might change how the cornea looks and make lens settling happen faster [1]. Doctors see over and over that lenses with higher DK/t let more oxygen through, which cuts down on oxygen shortage stress. They also hold corneal shape better and let the lens settle more slowly and steadily.

2.2 Elastic modulus and material rigidity keep the lens shape steady

Elastic modulus shows how much a material resists bending. It decides whether the RGP lens holds its shape when something pushes or pulls on it. Stiffer material means the lens holds its shape better under pressure. A scleral lens sits across the cornea and rests on the sclera. It deals with eyelid push tear motion and eye movement all at once.

Stiffer materials hold their original shape better, fit more steadily in the sclera landing zone, and cut down on tight spots and one-sided sinking. In real clinics, softer stuff feels nicer at first but often lifts at the edges, drops unevenly, or bends out of shape, messing up how evenly it settles and how well vision works. So today, scleral lens design focuses more on tuning material stiffness together with edge shape to hit a sweet spot where the lens stays put without sliding too much.

2.3 Surface wettability and its link to tear film stability

RGP materials hold little water by nature. So, how well they work in the eye depends mostly on how wettable their surface feels and how steady the tear film stays. People check wettability by measuring the contact angle. A smaller angle means tears spread more easily, making the tear film more even and steady. In scleral lenses, tear fluid pools behind the lens and forms a thin layer over the front of the lens. Together, they build up an optical interface. If surface wettability falls short, the tear film may split apart, dry patches may show up, and friction between surfaces may increase. These problems hurt image clarity. They also mess with how the lens moves and settles on the eye. Clinicians notice plasma-treated or water-loving surface coatings help the tear film last longer before breaking up. They also cut down jumpy shifts while the lens settles. The result is a smoother, steadier settling curve.

2.4 Material ionicity and differential deposition behavior

RGP material ionicity affects how it reacts with tear film stuff like proteins and lipids. Ionic materials have charged functional groups, so they get wet faster at first. That boost fades fast, though, because proteins stick to them more strongly. Surface deposits show up as a result. Non-ionic materials resist buildup better than other types. They often need surface treatment later to get enough wetting. People wearing scleral lenses for a long time see deposits pile up. That pile up shifts how energy spreads across the surface and changes how slippery it feels. Lens and conjunctiva then drag more against each other. Settling takes longer to finish. Final lens position ends up different [2]. Deposits can mess up fluid movement near the lens edge, making settling less even. Material engineers now focus more on tweaking the lens makeup while adding smart surface treatments. This combo helps balance how well tears spread across the lens and how well it resists gunk buildup, keeping the scleral lens settled right over time.

3. Scleral Lens Settling Changes Over Time and Needs Simple Ways to Measure It

3.1 How fast the lens settles and how to track that change

Scleral lens settling rate means how far the lens moves down vertically while worn. This movement happens because the conjunctiva gets squeezed, and the fluid layer under the lens shifts around. People usually measure it by watching how fast the fluid layer thins over time. Today in the clinic, anterior segment optical coherence tomography captures sharp cross-sectional pictures of the tear layer behind the contact lens. This lets doctors compare changes over time with good precision. Newer software tools now handle image analysis automatically. They measure tear thickness across several spots inside a 12 mm circle. This has made measurements more objective and boosted reproducibility a lot. A clear shift has taken place in this field—moving away from single-point central measurements to an assessment framework that covers more regions, changes over time, and gives a fuller picture. This method lets the settling rate show more than just how far the lens moves. It reflects lens fit and how the eye surface gradually adjusts itself.

3.2 How the tear layer thickness changes over time under the scleral lens

A scleral lens sits on the eye surface and forms a liquid space between its back side and the cornea. This reservoir changes a lot over time. Studies show the liquid layer gets much thinner fast at first. After that, it settles into a steady state. The thinning often looks like an exponential decay curve. This temporal behavior varies across space. Regional differences show up all the time; the lower region keeps more thickness, while the upper and central regions tend to get thinner. This asymmetry comes from gravity and lens shifting a bit off center, working at the same time. Right now in clinics, people see more clearly that measuring just central clearance does not tell the full story about how well the lens fits. Looking at it another way, a holistic assessment that tracks how peripheral thickness changes matters a lot. It helps prevent local mechanical contact when clearance is too tight. It also stops reservoir thickness from getting too big, which could make the cornea more likely to suffer from low oxygen. That is why analysis broken down by location plays a key role in grasping and managing how settling behaves.

3.3 How scleral lens settling changes over time, and when it settles

Scleral lens settling shows two clear stages over time. First, it drops fast, then it slows down and settles into place. Most real-world reports say about half to seven-tenths of total settling happens in the first one or two hours after putting the lens in [3]. After this time interval, the rate of change drops sharply, and the system slowly moves toward a plateau state. Over longer periods, like an eight-hour wear session, total settling can hit or go past 80 percent of its final value. These timing features matter for how clinicians fit lenses. If they check too soon—especially during the early fast stabilization phase—they might miss how far the lens will drop in the end. That leads to design mistakes built into the process. So, most clinical guidelines now say to wait at least two hours before measuring key fitting parameters. This wait makes measurements line up better with real steady state conditions and lifts the accuracy and reliability of lens design.

3.4 Corneal shape affects how the scleral lens settles on the eye

Cornea shape is key to how the scleral lens settles and varies from person to person. Curvature changes, asymmetry, and elevation profile shift how mechanical forces spread across the lens and change how tears move under it. Eyes with normal corneal shape settle differently than eyes with keratoconus, as comparison shows. For example, keratoconus often shows clear central thinning in the tear reservoir layer when the lens settles, while a normal cornea usually has changes near the edge. Cornea height and sclera shape are not the same, so the lens may sit a bit off center, making the fluid reservoir thicker at the top than at the bottom [4]. To handle these tricky issues, today's eye clinics often use corneal topography together with scleral profiling to shape lenses just right for each person. Therefore, the speed at which a lens settles into place depends on more than just what it is made of or how it is shaped. It starts with how the eye surface shape and lens design work together. That means fitting a scleral lens needs to look at the whole person, not just one part

4. Mechanistic Pathways Linking RGP Material Properties to Scleral Lens Settling Dynamics

4.1 How high oxygen permeable materials change corneal metabolism and affect how fast the scleral lens settles

RGP material with high oxygen permeability changes the cornea's metabolic microenvironment because it lets more oxygen pass through. This shift affects how the scleral lens settles on the eye. Studies show that if a material lets too little oxygen through, the cornea uses less oxygen and sometimes swells a bit in its middle layer. Materials with a DK over 100 cut down on those low oxygen effects. One example: after wearing lenses for 8 hours, corneal thickness goes up about 1.37 percent with low oxygen material but only about 0.58 percent with high oxygen material. So, a high oxygen-permeable material did more than just let oxygen pass through. It stepped in to keep tissue from changing shape when oxygen ran low, made tissue less likely to squeeze down, and dragged out how fast it settled. Once the DK value went past about 125, the extra gain in metabolism slowed down. This shows settling behavior needs a full rethink—mixing material choice and shape design—not just pushing oxygen flow higher [5].

4.2 How material stiffness and how the lens touches the eye shape settling patterns

The stiffness of RGP material sets how much the scleral lens bends when it meets the uneven surface of the eye, which controls how the lens fits and where it ends up. Scleral lenses rest on the sclera, so their position ties closely to how the conjunctiva and Tenon's capsule get squeezed over time. The stiffness of lens material shapes where mechanical stress is applied. A stiffer material holds its shape better. That helps spread pressure evenly across the scleral landing zone and makes settling slow and steady. Softer material bends more easily. It often pushes down harder at edges, slides off center, and settles in odd ways [6]. Clinical observations show that settling behavior often feels unstable, not because shapes look wrong, but because tiny shifts happen in lens structure. This pushes designers to tune material stiffness, edge curvature, and scleral fit together.

4.3 Surface wettability guides how the tear film moves and stays stable on the scleral lens surface

It shapes tear film spread and refresh rate, which in turn affects lens settling behavior. The scleral lens system has a tear layer split into two parts: one sits in front of the lens and the other pools behind it. Surface does not always grab water well, so the tear layer breaks up faster. That makes friction jump up in spots and stops tiny smooth shifts; the lens needs to settle right. Therefore, the settling process can jump around or look uneven.

Materials with excellent water attraction help tear fluid spread evenly, cut down on interface resistance, and keep the lens moving steadily downward as conjunctival tissue slowly compresses. Doctors often change surface properties using plasma treatment or hydrophilic coating to make materials wetter. This makes settling curves look smoother and less bumpy, so wettability is more than just about how comfortable a lens feels on the eye. It plays a big role in how lens surface and tear film interact, shaping how tear film moves and holds steady [7].

4.4 Key properties of RGP materials and their theoretical foundations

Anti-deposition characteristics of RGP material play a crucial role in maintaining the stability of lens surface performance during the long-term wearing period, thereby affecting the long-term consistency of settlement behavior. Components of tear film—including proteins, lipids, and environmental pollutants—gradually accumulate on the lens surface, altering its surface energy and roughness, which leads to increased friction coefficient and enhances adhesive interaction at the lens-conjunctiva interface. Although effects of this type are negligible in short term, their cumulative impact becomes increasingly apparent with extension of wearing time, potentially leading to acceleration of Settling rate, premature arrival of stable stage, and even triggering of local tissue compression, while industry data indicates that materials with poor anti-deposition performance may exhibit significant deposit accumulation within few weeks, necessitating frequent cleaning or replacement of lenses [8]. In response, current technological development has focused on strategies such as fluorination and advanced surface coatings to reduce protein adsorption and maintain the initial physicochemical state of materials, which in turn ensures greater reproducibility and stability of settling behavior over time.

5. Conclusion

Current analysis shows scleral lens settling rate depends on RGP material properties working together in several ways. Oxygen permeability mostly affects how cornea cells handle energy. Elastic modulus shapes how force spreads across the eye surface. Surface wettability changes how the tear film moves and stays put. Anti-deposition performance helps keep the lens stable over time. The settling process starts fast, then slows down until it stops moving. What the material is made of really affects how quickly it settles and where it ends up. This means scleral lens design needs to go beyond just tweaking shape. It needs to handle both material choice and structure together in one plan.

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