

Current Research Status of Posterior Staphyloma in High Myopia

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Abstract: *Posterior staphyloma (PS) is the most characteristic anatomical alteration in pathologic myopia and is considered the core structural basis for irreversible vision loss. It is closely associated with various serious complications, including macular holes and retinal detachment. As the global prevalence of myopia continues to rise, the incidence of PS is relatively high among individuals with high myopia, making research on its prevention and treatment highly significant. Currently, the pathogenesis of PS remains incompletely understood. Various imaging modalities each offer unique advantages in visualizing PS morphology, quantifying parameters, and assessing microcirculatory changes. Artificial intelligence is also being progressively applied to PS. This article reviews the current research status of the pathogenesis, evaluation techniques, and treatment strategies for posterior staphyloma in high myopia, providing a reference for clinical diagnosis, treatment, and subsequent research.*

Keywords: High myopia, Posterior staphyloma, Pathogenesis, Imaging evaluation, Treatment strategies.

1. Introduction

Posterior staphyloma (PS) refers to a localized abnormal outpouching of the posterior wall of the eye, a phenomenon first reported by the anatomist Scarpa in 1801 [1]. As the most characteristic anatomical alteration in pathologic myopia (PM), PS is considered the core structural basis for irreversible vision loss [2] and is closely associated with various serious complications, including macular holes, macular schisis, retinal detachment, and myopic choroidal neovascularization [3]. In recent years, the global prevalence of myopia has been rising. An epidemiological forecasting study by Holden et al. [4] projects that by 2050, approximately 4.98 billion people (49.8% of the world's population) will have myopia, of which 938 million (9.8%) will have high myopia. The incidence of PS is relatively high among individuals with high myopia. A study by Numa et al. [5] reported a PS incidence of 10.9% in a Japanese high myopia population. Zheng et al. [6] reported that approximately one-third of Singaporean adults aged 40 years and older with high myopia have PS. Given the serious threat of PS to visual function and the growing affected population, a deeper understanding of its pathogenesis, diagnostic methods, and effective prevention/treatment strategies is of great significance.

2. Pathogenesis

The pathogenesis of PS remains not fully elucidated. Current research suggests that the formation of PS involves structural changes in multiple layers, including the sclera, choroid, and Bruch's membrane.

The sclera is a highly differentiated fibrous connective tissue primarily composed of collagen fibers, elastic fibers, and extracellular matrix. In highly myopic eyes, due to continuous axial elongation, the balance of collagen synthesis and

degradation in the sclera is disrupted, leading to reduced collagen content and disorganized collagen fiber arrangement.

These changes collectively cause scleral thinning, reduced mechanical strength, and inability to withstand normal intraocular pressure, resulting in localized outpouching along areas of embryonic fissure closure or anatomical weak points, such as the optic nerve and perimacular region [7–9]. Ohno-Matsui et al. [10,11] have pointed out that the histological features of PS include marked disorganization of scleral collagen fibers at the edge of the staphyloma and significant choroidal thinning. They suggest that choroidal atrophy may inhibit scleral collagen synthesis through reduced nutritional support and paracrine effects, and that factors such as genetics and intraocular pressure fluctuations further exacerbate scleral mechanical weakening. Additionally, Bruch's membrane (BM), as an elastic basement membrane between the retinal pigment epithelium and the choroid, possesses inherent tension and elasticity. Under pathological conditions, BM may generate abnormal posterior expansion forces due to metabolic abnormalities, collagen fiber proliferation, or changes in intraocular pressure. These forces directly act on the underlying choroid and sclera, promoting localized posterior bulging of the ocular wall [10,12].

In recent years, with advances in imaging technology and anatomical research, a new hypothesis of extrinsic compression by the extraocular oblique muscles has been proposed: Imaging evidence shows notch-like indentations at the superior and temporal edges of PS (especially type I), and these regions exhibit a high correlation between pigment abnormalities and choroidal thinning [11]. Combined with anatomical findings that the superior oblique muscle (SOM) and inferior oblique muscle (IOM) attach to the posterosuperior and temporal regions of the eye, their angled attachment allows them to exert sustained intermittent compression on the posterior ocular wall during contraction.

Based on the weakened mechanical strength of the sclera and choroid, long-term compression leads to localized remodeling of the ocular shape, forming the characteristic changes of PS [13].

3. PS Evaluation Techniques

3.1 Ophthalmoscopy

In 1977, Curtin [14] first used wide-angle stereo ophthalmoscopy to examine PS and classified PS into 10 types based on the location of the staphyloma relative to the macula. Types I–V were simple, and types VI–X were compound. This classification system laid the foundation for understanding PS morphology and remains a primary reference for clinically defining PS morphology. Ophthalmoscopy allows observation of arcuate light reflections and pigmentary changes in the bulging area at the posterior pole [15]. However, its sensitivity for shallow PS is low, and the evaluation is highly dependent on the examiner's subjective experience. The field of view is also limited by the ophthalmoscope's field and the clarity of the ocular media, making objective assessment of posterior staphyloma difficult.

3.2 B-scan Ultrasonography

B-scan ultrasonography can delineate the contour of the posterior ocular wall and observe localized bulging at the posterior pole caused by PS. Its advantages include ease of operation, low cost, and ability to penetrate opaque refractive media. However, it has limited resolution, provides only two-dimensional cross-sectional images, has a low detection rate for shallow PS [16], and is insufficient for diagnosing complex or multi-directional staphylomas [17].

3.3 Fundus Photography

Early studies [18] used conventional 50° stereo fundus photography to detect the presence of PS. Although fundus photography is intuitive, most PS are wide; the most common type, the wide macular staphyloma, exceeds the scope of conventional 50° fundus photography. Therefore, traditional fundus photography cannot capture the entire morphology of PS [19]. Ultra-widefield fundus photography can obtain extensive fundus images, aiding in the observation of PS-related fundus changes (e.g., myopic crescent, choroidal atrophy) [20] and serving as an effective means of examining PS.

3.4 Magnetic Resonance Imaging (MRI)

As the gold standard for morphological studies, MRI can fully display the three-dimensional shape of the eye and has high detection accuracy for posterior staphyloma. Guo et al. [21] used 3D-MRI to analyze the eyes of Chinese patients with high myopia and found that the spherical shape was most common, but other shapes such as ellipsoid, conical, nasal distortion, and temporal distortion were also observed. Based on Curtin's classification, Ohno-Matsui et al. [22] combined three-dimensional MRI and wide-angle fundus imaging to consolidate and simplify PS types, classifying PS into wide macular type, narrow macular type, peripapillary type, nasal

type, inferior type, and others. This classification system is now widely used. However, MRI has limitations including limited spatial resolution (making it difficult to display intraretinal structures), long examination time, high cost, and high patient cooperation requirements, so it is not yet a routine ophthalmic examination [2].

3.5 Optical Coherence Tomography (OCT)

Conventional spectral-domain OCT (SD-OCT) has high axial resolution (approximately 5–7 μ m) and can clearly display the layers of the retina and the vitreoretinal interface, providing significant value for detecting PS-related complications such as retinoschisis and epiretinal membranes. However, the scanning range of conventional OCT is limited (typically 6–12 mm), making it difficult to fully capture the entire PS morphology [23].

In recent years, with advances in OCT technology, wide-field OCT offers higher resolution and larger imaging range and has been widely used in the clinical evaluation of posterior staphyloma in high myopia. Nakao et al. [9] successfully used UWF-OCT to measure the depth and width of posterior staphyloma in 138 patients (197 eyes) and obtained shape-related parameters. Furthermore, Tan et al. [24] introduced a modified local Gaussian curvature to quantify ocular shape in UWF-OCT and demonstrated its reproducibility in curvature shape measurement. Yang [25] retrospectively analyzed clinical data from 447 myopic eyes of 332 patients, showing that mean retinal curvature decreased with increasing myopia severity. Luo [26] included 205 high myopic eyes and found that the posterior pole curvature deviation was significantly greater in eyes with PS than those without, indicating a highly irregular macular region in PS.

Optical coherence tomography angiography (OCTA) adds blood flow signal detection to OCT, enabling non-invasive visualization of the morphology and density of vessels in each layer of the fundus. Studies have indicated that patients with posterior staphyloma often have structural abnormalities of the sclera, choroid, and Bruch's membrane, which can trigger local tissue remodeling and subsequently lead to changes in microvascular structure and perfusion, causing microcirculatory disturbances at the posterior pole [27]. OCTA can quantitatively assess parameters such as perfusion density around the macula and optic disc and the area of non-perfusion, providing a powerful tool for studying the relationship between PS and microcirculatory disorders.

3.6 Artificial Intelligence (AI)

With the development of deep learning technologies, artificial intelligence has shown potential in imaging recognition of PS. Researchers are exploring the use of convolutional neural networks to automatically segment staphyloma borders, identify types, and quantify curvature parameters [28]. This holds promise for achieving automated screening and quantitative assessment of PS.

4. Treatment Strategies

4.1 Posterior Scleral Reinforcement (PSR)

Posterior scleral reinforcement is currently the main surgical treatment for PS. It was first proposed by Shevelev [29] in 1930. The procedure involves implanting donor sclera, freeze-dried dura mater, or other materials [30] under general anesthesia to directly and mechanically strengthen the posterior ocular wall. Over nearly a century, surgical techniques have been continuously refined. Numerous studies have shown that PSR can effectively slow axial elongation and myopia progression. A meta-analysis by Chen et al. [31] demonstrated that PSR has a significant effect in slowing the progression of refractive error and axial length. The study by Gao et al. [32] also supports the role of PSR in controlling the progression of progressive myopia. However, high-quality long-term follow-up evidence is lacking regarding the safety of PSR, whether it can reverse established PS bulging, and whether it reduces the long-term incidence of fundus complications [30,33].

4.2 Scleral Collagen Cross-linking (SXL)

Scleral collagen cross-linking is an emerging technology explored in recent years. It forms chemical bonds between collagen polymer chains, thereby enhancing the biomechanical strength of the sclera. This approach holds promise for stabilizing or even reshaping the ocular shape and delaying myopia progression by preventing abnormal scleral remodeling [34]. The technology is currently divided into two main types: photochemical cross-linking and purely chemical cross-linking. The former, drawing on the principles of corneal cross-linking, uses a “photosensitizer + light energy” to achieve precise targeted cross-linking, offering outstanding safety and controllability, but faces challenges related to tissue penetration and procedural complexity. The latter acts directly on the sclera using chemical cross-linking agents (e.g., genipin, glutaraldehyde), offering advantages such as ease of operation, good penetration, and low cost, but requires solutions for issues including safety control, cross-linking uniformity, and long-term stability [35]. Animal experiments have confirmed that scleral collagen cross-linking can slow myopia progression in a guinea pig model of form-deprivation myopia and enhance scleral biomechanical strength [36]. However, its safety and efficacy in humans are still in the early exploratory stages, and there is still a considerable gap before clinical application.

5. Summary

Posterior staphyloma is an important risk factor for blindness in high myopia. Its pathogenesis involves multi-level pathological changes including the sclera, choroid, Bruch’s membrane, and extraocular muscle mechanics, requiring further in-depth research. Continuous advances in imaging technology provide reliable tools for the accurate diagnosis, classification, and quantitative assessment of PS, and the integration of artificial intelligence holds promise for efficient automated screening. Posterior scleral reinforcement has certain clinical value in controlling PS progression but lacks high-level evidence-based medical support. Scleral collagen cross-linking shows good application prospects, but clinical translation still faces many challenges. Future efforts should focus on in-depth elucidation of pathogenesis, the development of non-invasive and precise evaluation systems, and the research and development of safe and effective

interventions, in order to establish standardized diagnostic and treatment pathways for PS and reduce the risk of vision loss due to high myopia.

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