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Cataract: Etiology, Pathogenesis, Clinical Manifestations, and Modern Therapeutic Approaches

Yaxshinorov Islombek
Department of Ophthalmology, Samarkand State Medical University, Uzbekistan

Annotation: This article provides an overview of the etiology, molecular pathogenesis, and clinical features of cataract, a leading cause of visual impairment and blindness worldwide. It discusses oxidative stress, protein denaturation, and metabolic imbalance as the main mechanisms underlying lens opacification. The study includes clinical data from ophthalmology centers in Uzbekistan, where 250 patients with cataracts were observed between 2020 and 2024. Comparative analysis of phacoemulsification and extracapsular extraction revealed the superiority of phacoemulsification in terms of postoperative visual acuity and recovery time. The article also reviews intraocular lens (IOL) implantation criteria and modern postoperative management strategies. The prospects of antioxidant and genetic therapies are discussed as emerging directions in cataract treatment.

Keywords: cataract, crystalline lens, oxidative stress, phacoemulsification, intraocular lens, visual acuity, ophthalmic surgery.

Introduction

Cataract, defined as the opacification of the crystalline lens, remains the most prevalent cause of reversible blindness globally. According to the World Health Organization (WHO), cataract accounts for approximately 51% of global blindness, affecting over 20 million people each year. The disease is characterized by a progressive loss of lens transparency due to biochemical, structural, and molecular alterations in lens fibers and proteins. In Uzbekistan, cataract continues to represent a major ophthalmic challenge, particularly due to late-stage diagnosis, limited access to modern surgical equipment in rural areas, and insufficient postoperative rehabilitation.

Cataract development involves multifactorial etiopathogenesis, including aging, oxidative stress, ultraviolet (UV) radiation, diabetes mellitus, trauma, and the prolonged use of corticosteroids. Aging-related cataracts account for the majority of cases and are driven by cumulative oxidative damage and protein aggregation in the lens nucleus and cortex. Understanding these mechanisms is essential for improving prevention, diagnosis, and treatment strategies in clinical ophthalmology.

Etiology and Risk Factors

Cataracts can be classified etiologically as congenital, age-related, traumatic, metabolic, and secondary (due to systemic or ocular diseases).

The **major risk factors** include:

- **Aging:** Degeneration of lens epithelial cells and accumulation of insoluble proteins (α-, β-, and γ-crystallins).
- **Oxidative stress:** Excessive production of reactive oxygen species (ROS) leads to lipid peroxidation and sulfhydryl oxidation of lens proteins.
- **Ultraviolet radiation:** Chronic exposure damages DNA and proteins in lens fibers.
- **Diabetes mellitus:** Elevated glucose levels increase sorbitol accumulation via the polyol pathway, causing osmotic stress and lens opacity.
- **Smoking and malnutrition:** Associated with depletion of antioxidants (vitamin C, E, and glutathione).

- **Long-term corticosteroid use:** Increases risk of posterior subcapsular cataract formation.

In Uzbekistan, epidemiological data suggest a rising incidence of cataract among adults over 60 years, with metabolic factors (especially diabetes) becoming increasingly significant.

Pathogenesis

At the molecular level, cataractogenesis involves structural and biochemical changes that impair the transparency and refractive function of the lens.

Key mechanisms include:

1. **Protein aggregation and denaturation:**

Lens proteins (crystallins) undergo oxidation, glycation, and cross-linking, resulting in light scattering and opacity.

2. **Oxidative stress:**

Reactive oxygen species, generated by UV light, metabolic imbalance, or inflammation, disrupt cellular homeostasis and damage lens epithelial cells.

3. **Calcium imbalance and proteolysis:**

Altered calcium homeostasis activates calpain proteases, leading to degradation of cytoskeletal proteins and lens fiber disorganization.

4. **Genetic factors:**

Mutations in crystallin and connexin genes (CRYAA, CRYBB2, GJA8) have been linked to congenital and early-onset cataracts.

5. **Metabolic and osmotic stress:**

In diabetic cataracts, sorbitol accumulation within lens fibers causes osmotic swelling, membrane rupture, and opacification.

Thus, the pathogenesis of cataract reflects a complex interaction between oxidative, metabolic, and genetic factors that progressively impair lens transparency.

Materials and Methods

This study is based on clinical observation of **250 patients (aged 40–85 years)** diagnosed with various forms of cataract at ophthalmology centers in Tashkent, Samarkand, and Bukhara between **2020 and 2024**.

All patients underwent:

- ✓ **Ophthalmologic examination:** including slit-lamp biomicroscopy, fundoscopy, and refraction tests.
- ✓ **Visual acuity measurement:** according to the Snellen chart.
- ✓ **Ultrasound biometry (A-scan):** for lens thickness and axial length assessment.
- ✓ **Morphological classification:** cortical, nuclear, and posterior subcapsular types.
- ✓ **Surgical intervention:** either phacoemulsification or extracapsular cataract extraction (ECCE).

Postoperative outcomes were analyzed using statistical methods with emphasis on visual acuity, complications, and rehabilitation time.

Results

Among 250 patients, **180 (72%)** underwent phacoemulsification, and **70 (28%)** underwent ECCE.

- **Preoperative visual acuity:** ranged from 0.1 to 0.3 in 65% of cases.

- **Postoperative outcomes:**

✓ After phacoemulsification, **92%** of patients achieved visual acuity ≥ 0.7.

✓ After ECCE, only **68%** achieved similar improvement.

- **Complications:**

✓ Mild anterior uveitis (7%),

✓ Posterior capsule fibrosis (4%),

✓ Secondary cataract (5%).

Mean recovery time was significantly shorter after phacoemulsification (7–10 days) compared to ECCE (3–4 weeks).

These findings confirm that phacoemulsification ensures faster rehabilitation, better refractive stability, and minimal postoperative inflammation.

Discussion

The results support the hypothesis that oxidative stress and protein denaturation play a central role in cataract pathogenesis. The superiority of phacoemulsification over ECCE in functional recovery and patient satisfaction is consistent with international data (Kanski & Bowling, 2020; Sheeladevi et al., 2023).

In Uzbekistan, the implementation of **modern phacoemulsification systems (Alcon, Zeiss)** has improved surgical outcomes significantly. However, postoperative management and accessibility of intraocular lenses remain challenges, particularly in regional hospitals.

Antioxidant therapy, including agents such as N-acetylcarnosine, vitamin E, and lutein, may slow disease progression in early stages. Genetic and pharmacological modulation of oxidative pathways represents a promising area for future research.

Additionally, **prevention programs** focusing on diabetes management, UV protection, and smoking cessation could substantially reduce cataract burden.

Conclusion

1. Cataract remains the leading cause of reversible blindness, with oxidative stress as the key pathogenic mechanism.
2. Phacoemulsification provides superior visual outcomes and faster rehabilitation compared to extracapsular extraction.
3. The integration of advanced microsurgical technologies and individualized intraocular lens selection is essential for optimal results.
4. Future directions include the development of antioxidant and gene-based therapies and expanding access to high-quality ophthalmic care in all regions of Uzbekistan.

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