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Modern Capabilities of Laser Surgery for Closed-Angle Glaucoma

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Abstract: The literature review discusses modern laser surgical approaches in primary angle-closure glaucoma. Epidemiology, pathogenesis, efficacy of laser peripheral iridotomy, iridoplasty, selective laser trabeculoplasty, and early lens extraction are analyzed. LPI is effective for pupillary block, while complex anatomical cases benefit from combined approaches. Phacoemulsification provides more stable IOP control and reduces long-term complications.

Keywords: angle-closure glaucoma, laser peripheral iridotomy, iridoplasty, phacoemulsification, intraocular pressure.

Introduction

Glaucoma is a group of ocular disorders characterized by progressive damage to the optic nerve. If left untreated, glaucoma can ultimately lead to blindness. Primary angle-closure glaucoma (PACG) is a form of glaucoma that develops when the eye's drainage pathways (the "angles") become obstructed, similar to a sink with a blocked drain. This obstruction can result in elevated intraocular pressure (IOP), which in turn reduces the extent of peripheral (visual-field) sensitivity [1].

Research Objective:To systematically examine and evaluate current laser surgical techniques used in the management of angle-closure glaucoma, with particular attention to their efficacy, safety, and potential applicability in clinical practice.

Laser iridotomy involves the use of a laser to create a small opening in the iris—the pigmented tissue surrounding the pupil. This opening restores aqueous humor outflow, thereby helping to regulate intraocular pressure and potentially slow the progression of visual-field loss [1].

Glaucoma is one of the leading causes of blindness and, due to its irreversible nature, represents a significant global public health challenge [2–5]. The World Health Organization identifies glaucoma as one of its priority ocular diseases, and researchers estimate that approximately five million people worldwide are currently blind as a result of this condition [5, 6]. A recent systematic review reported that the global prevalence of glaucoma among individuals aged 40 to 80 years is 3.54%, and projected that the number of affected individuals will reach 76 million by 2020 and 111.8 million by 2040 [7].

Although angle-closure glaucoma is less common than open-angle glaucoma, it often presents with greater severity and carries a higher likelihood of causing irreversible blindness if left untreated [8]. Among the 64.3 million individuals aged 40 to 80 years affected by glaucoma, an estimated 20.2 million had primary angle-closure disease (PACD) in 2013; within this subgroup, approximately 14.5 million individuals were living in Asia [9, 7]. For example, in China, the estimated numbers of people with PACS (primary angle-closure suspect), PAC (primary angle closure), and PACG (primary angle-closure glaucoma) are 28.2 million, 9.1 million, and 3.5 million, respectively [9]. Moreover, 91% of the 1.7 million cases of bilateral blindness within this population are attributed to PACG [9].

The five-year risk of progression from PACS to PAC and from PAC to PACG has also been estimated at 22% and 29%, respectively [19, 20].

PACG is less prevalent among individuals of European descent, with an estimated overall prevalence of 0.4% in persons aged 40 years and older [11]. Additional risk factors for angle-closure disease include female sex, older age, and a family history of angle-closure pathology [8, 12, 11].

The prevalence of glaucoma varies by age and ethnic background. Among individuals of European descent around the age of 45, the prevalence is estimated to be between 2.1% and 3% for primary open-angle glaucoma (POAG) and approximately 0.3% for primary angle-closure glaucoma (PACG). By age 55, the prevalence in Europeans ranges from 2.2% to 5%, whereas in certain Asian populations—such as Vietnamese individuals of the same age group—it may be as high as 47.8%. Globally, however, angle-closure glaucoma remains a leading cause of glaucoma-related blindness [10].

Primary angle-closure glaucoma is a form of glaucoma associated with anatomical narrowing or obstruction of the anterior chamber angle. For example, contact between the iris and the lens at the pupillary margin can produce a pupillary block, increasing resistance to aqueous humor outflow. Obstruction of the anterior chamber angle limits the drainage of aqueous humor from the eye and may lead to elevated intraocular pressure (IOP). Elevated IOP is strongly associated with glaucomatous optic neuropathy and progressive visual-field loss.

Laser peripheral iridotomy (LPI), or simply "iridotomy," is a procedure that relieves pupillary block by allowing aqueous humor to pass directly from the posterior chamber to the anterior chamber through a small laser-created opening in the iris [1, 13]. Iridotomy is employed in the management of patients with primary angle-closure glaucoma (PACG), those with primary angle closure (PAC)—characterized by narrow angles without glaucomatous optic neuropathy—and patients classified as primary angle-closure suspects (PACS), in whom angle obstruction is reversible.

Nevertheless, the effectiveness of iridotomy in slowing the progression of visual-field loss remains uncertain [13].

According to Vasconcelos JPC and Sakata LM (2012), the process of angle closure is characterized by partial or complete obstruction of the anterior chamber angle due to anatomical features that promote apposition or adhesion of the peripheral iris to the trabecular meshwork. This mechanism is frequently accompanied by an elevation in intraocular pressure (IOP). An IOP above physiological levels may result in glaucomatous optic nerve damage and threaten vision through two mechanisms: acute angle closure (previously referred to as an acute attack of glaucoma) and primary angle-closure glaucoma (the chronic form of the disease) [13].

Particular attention should be given to the epidemiological and ophthalmic factors predisposing individuals to angle closure and the development of primary angle-closure glaucoma, including female sex, advanced age, East Asian ethnicity, anatomically narrow angles, shallow anterior chamber depth, reduced corneal diameter, smaller corneal radius of curvature, decreased axial ocular length, and anterior displacement or increased anteroposterior thickness of the crystalline lens [11,12].

According to Parikh SR and Parikh RS (2022), blindness caused by primary angle-closure glaucoma (PACG) can be significantly reduced if the ongoing angle-closure process is halted at an early stage. Several treatment modalities—such as laser peripheral iridotomy (LPI), iridoplasty, and clear-lens extraction (CLE)—are recommended as first-line therapies for primary angle closure (PAC), PACG, and high-risk primary angle-closure suspects (PACS) [14, 15]. The EAGLE study demonstrated the superiority of CLE over LPI in the management of primary angle closure, sparking substantial debate regarding the role of LPI as a first-line procedure.

Randomized controlled trials (RCTs), systematic reviews, and meta-analyses of RCTs addressing this topic provide a strong evidence base for developing guidelines applicable to routine clinical practice. A systematic review was conducted using searches of multiple databases—including PubMed, the Cochrane Library, EMBASE, and ClinicalTrials.gov—covering the past 16 years (January 2005 to December 2021), identifying RCTs with published data related to primary angle-closure disease (PACD) [14].

According to the study by He M, Jiang Y, and Huang S (2019), primary angle-closure glaucoma affects approximately 20 million people worldwide. Individuals classified as primary angle-closure suspects have an elevated—but poorly quantified—risk of developing glaucoma.

In a randomized controlled trial conducted in China, patients aged 50–70 years with bilateral primary angle-closure suspicion were recruited from the Zhongshan Ophthalmic Center, a tertiary-level specialty hospital in Guangzhou. Participants received laser peripheral iridotomy (LPI) in one randomly selected eye, while the fellow eye served as an untreated control.

The primary outcome was the development of primary angle-closure disease, defined as the occurrence of intraocular pressure elevation, the formation of peripheral anterior synechiae, or an acute angle-closure event during 72 months of follow-up. Analyses were performed according to the intention-to-treat principle, comparing treated eyes with contralateral controls.

Of 11,991 screened individuals, 889 were randomly assigned to the treated and untreated groups as of June 19, 2008 (889 treated and 889 untreated eyes). The incidence rate of the primary outcome was 4.19 per 1,000 eye-years in treated eyes versus 7.97 per 1,000 eye-years in untreated eyes (hazard ratio 0.53; 95% CI 0.30–0.92; $p = 0.024$). The primary outcome occurred in 19 treated eyes and 36 untreated eyes, with paired-eye analysis demonstrating a statistically significant difference ($p = 0.0041$).

No serious adverse events were reported during follow-up. The incidence of angle-closure disease among community-screened primary angle-closure suspects was very low. LPI demonstrated a modest but statistically significant prophylactic effect. However, given the low event rate and the absence of outcomes posing an immediate threat to vision, the authors conclude that the overall benefit of prophylactic laser peripheral iridotomy is limited and do not recommend its widespread use among individuals classified as primary angle-closure suspects [15]

Japanese researchers Fujita A and Konishi T (2024) note that glaucoma is the second leading cause of blindness worldwide. Among the various types of glaucoma, primary angle-closure glaucoma (PACG) is associated with severe visual morbidity, and 77% of patients with PACG reside in Asia. Primary angle-closure suspect (PACS) refers to anatomically narrow angles without additional abnormalities. Some individuals with PACS experience acute angle-closure crises, whereas others progress chronically toward PACG. Prophylactic laser peripheral iridotomy (LPI) is widely performed in PACS to prevent acute angle-closure attacks and future development of PACG. Although the exact prevalence of PACS in Japan remains unknown, PACS is reported to be relatively common in Asian populations (with a prevalence of 10.4% in China). Consequently, the cost of universal LPI for PACS represents a substantial economic burden in Asia [16].

Several mechanisms underlie narrow angles, including relative pupillary block, lens thickness and positioning, and plateau iris configuration. Prophylactic LPI is effective in cases of relative pupillary block; however, its effectiveness is limited in individuals with plateau iris. A previous study demonstrated persistence of plateau iris configuration in 26% of cases after peripheral iridotomy. Because existing evidence on the effectiveness of prophylactic LPI does not differentiate between the underlying mechanisms of angle narrowing, the present analysis evaluated the overall cost-effectiveness of LPI for PACS. The effectiveness of prophylactic LPI for PACS arising from each specific mechanism should be clarified in future studies to optimize treatment strategies [16]

Prediction of Laser Peripheral Iridotomy Outcomes for Primary Angle-Closure Suspect Eyes Using Anterior Segment Optical Coherence Tomography (AS-OCT) is presented in the study by Koh V and Keshtkaran MR (2019). The authors aimed to develop an algorithm capable of predicting the success of laser peripheral iridotomy (LPI) in eyes with primary angle-closure suspect (PACS) using pre-treatment anterior segment optical coherence tomography (AS-OCT) imaging.

A total of 69 PACS eyes underwent LPI, and time-domain AS-OCT scans (temporal and nasal quadrants) were obtained both before and after the procedure. Post-LPI success was defined as a change in one or more quadrants from angle closure to angle opening. All pre-LPI AS-OCT images were analyzed using an anterior segment analysis program to obtain anterior chamber angle (ACA) measurements. These measurements from each quadrant were combined with quadrant-independent parameters, resulting in a total of 42 variables that served as features for the prediction algorithm.

Of the 69 eyes, 42 (60.9%) met the criteria for successful LPI. Iris concavity, angle recess area (750 μm), and iris concavity ratio demonstrated the highest predictive value and were selected using a correlation-based subset selection method. These features were then classified into two outcome categories ("successful" and "unsuccessful") using a Bayesian classifier. The algorithm predicted LPI success with a cross-validated accuracy of 79.28%, outperforming ophthalmologists ($\kappa = 0.497$ and 0.636, respectively).

Using pre-treatment AS-OCT imaging, this algorithm surpassed ophthalmologists in predicting LPI success for PACS eyes. This new predictive model may assist clinicians in decision-making regarding the recommendation of prophylactic LPI for PACS patients [17].

Sokolovskaya T.V. et al. presented the outcomes of a combined laser treatment method for primary narrow-angle (mixed-mechanism) glaucoma. A total of 72 patients (72 eyes) with early-stage primary narrow-angle (mixed-mechanism) glaucoma were observed. The mean age of the patients was 65.1 ± 6.56 years; 27 were men and 43 were women. The follow-up period extended up to four years after laser treatment.

The baseline intraocular pressure (IOP) averaged 24.47 ± 1.85 mmHg. The mean number of hypotensive medications used before surgery was 2.2 ± 0.4. All patients underwent sequential stages of combined laser treatment—laser iridectomy followed by selective laser trabeculoplasty (SLT). All laser procedures were completed without complications. Widening of the anterior chamber angle was achieved in all cases, confirmed by gonioscopy and anterior segment optical coherence tomography (AS-OCT).

On postoperative day 1, a reactive IOP spike was detected in 9.7% of cases and was controlled with additional hypotensive therapy within 1–2 days. No other complications—such as inflammation or hemorrhage—were observed. One week after laser treatment, a statistically significant ($p < 0.05$) reduction in IOP was achieved, averaging a decrease of 6.9 mmHg (28.2%) from baseline. In the long-term postoperative period, the mean IOP reduction remained at 23.4%. Normalization of IOP occurred in parallel with an increase in the facility of outflow from 0.09 ± 0.01 to 0.18 ± 0.01 ($p < 0.05$).

Long-term IOP normalization was achieved in 87.5% of cases (63 out of 72 eyes). In nine eyes, IOP normalized only after repeat SLT. The mean number of hypotensive medications decreased to 1.02 ± 0.1 following treatment. Visual acuity remained unchanged in 80.5% of cases; a decrease in visual acuity was attributed to the progression of complicated cataract. Peripheral visual field boundaries remained stable in 96% of eyes at the end of follow-up. According to computerized perimetry, negative dynamics were observed in 6 patients (6 eyes, 8.3%). Based on HRT data, negative structural changes—such as reduced neuroretinal rim volume and increased optic disc excavation—were documented in 7% of eyes (5 out of 72).

The proposed combined laser treatment strategy allows IOP normalization through widening of the anterior chamber angle following iridectomy with subsequent activation of the trabecular meshwork via SLT in 87.5% of patients. The normalization of IOP, stabilization of visual function, and preservation of optic nerve structure in the majority of patients during long-term follow-up confirm the effectiveness of this technique. Performing both procedures—laser iridectomy and SLT—during the same session is safe and significantly shortens the overall treatment duration and patient rehabilitation period [18].

Conclusion: Primary angle-closure glaucoma is a serious cause of irreversible blindness, particularly among individuals with anatomically narrow angles. Laser peripheral iridotomy remains the first-line intervention; however, its prophylactic efficacy in primary angle-closure suspects (PACS) is limited and requires an individualized approach. Combined laser modalities (iridectomy + selective laser trabeculoplasty) have demonstrated high effectiveness in normalizing intraocular pressure and stabilizing visual function. Modern imaging techniques and predictive algorithms enhance the precision of therapeutic decision-making and improve overall treatment outcomes.

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