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REVIEW **Open Access**

Postoperative amblyopia in children with congenital cataracts: a systematic review and meta-analysis

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Abstract

This systematic review and meta-analysis aimed to estimate the prevalence of amblyopia following congenital cataract surgery in children and evaluate key prognostic factors, including age at intervention, cataract phenotype, and follow-up duration. We systematically searched PubMed, EMBASE, and the Cochrane Library for studies published between January 1, 1981, and March 1, 2023. We included clinical trials, case series, and observational studies to analyze surgical timing, visual outcomes, and complications. Among 28 studies (2,167 patients, 3,371 eyes), the pooled amblyopia prevalence was 62% (95% CI: 0.55–0.69, $I^2=91.7\%$). Early surgery (≤ 8 weeks for unilateral, ≤ 12 weeks for bilateral cases) significantly reduced amblyopia risk ($P<0.001$) but increased complications, notably glaucoma (26% vs. 6%, $P=0.001$). In contrast, intraocular lens (IOL) implantation timing had no significant effect on visual outcomes ($P=0.096$). Unilateral partial obstruction conferred a higher amblyopia prevalence than bilateral complete obstruction (68% vs. 36%, $P=0.003$), and prolong amblyopia therapy beyond 6 years of age showed limited efficacy. These findings highlight the critical role of timely surgery in optimizing visual recovery, despite its association with complications. Early IOL implantation demonstrated no significant clinical benefits, and the therapeutic window for amblyopia rehabilitation in congenital cataracts is narrower than in other forms.

Keywords Congenital Cataract, Intraocular lens implantation, Amblyopia, Visual acuity, Postoperative complications

Introduction

Congenital cataracts are a leading cause of treatable childhood blindness worldwide, with a global prevalence of 1–15 per 10,000 children [1]. Characterized by lens opacity that induces deprivation amblyopia and irreversible visual impairment if untreated [2–4]. Usually present at birth or within the first months of life, affecting one or both eyes [5].

Early intervention (≤ 6 weeks for unilateral, ≤ 8 weeks for bilateral) is widely recommended to optimize visual development [6–8]. However, conflicting evidence exists regarding the risks of early surgery, particularly the elevated incidence of aphakic glaucoma and other complications [9, 10], leaving the optimal timing debated.

The use of intraocular lens (IOL) implantation in children remains controversial, despite the well-established role in adult cataract surgery [11]. While some advocate delayed implantation (≥ 2 years), demonstrating that primary IOL placement before 2 years increases risks of secondary glaucoma, visual axis opacification (VAO), and inflammation [12, 13]; Additionally, it offers no significant visual advantage over aphakic correction [14]. Others propose primary IOL implantation before 6 months reduced surgical burden (single-stage procedure),

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continuous optical correction, and mitigation of anisometropia in unilateral cases [15, 16]. This controversy underscores the need for evidence-based guidelines.

Furthermore, few studies have investigated the relationship between cataract phenotypes and postoperative outcomes. To address these gaps, this systematic review and meta-analysis evaluates amblyopia incidence following congenital cataract surgery, analyzes modifiable risk factors (surgical timing, IOL strategy), and provides clinical recommendations.

Method

This meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [17, 18].

Databases and search strategy

For this systematic review and meta-analysis, we searched PubMed, EMBASE, and the Cochrane Library for articles published between January 1, 1981, and March 1, 2023. Search terms included: "congenital cataract," "infantile cataract," "cataract extraction," "lensectomy," "IOL implantation," "amblyopia" and "lazy eye" in various combinations. Full search terms and the PRISMA flow diagram are provided in the Supplementary Material. (Literature search strategy and Supplementary Table 4).

Eligibility and exclusion criteria

We included published articles reporting monocular and binocular visual outcomes after surgical intervention for congenital cataracts. The inclusion criterion for sight restoration intervention was cataract removal surgery followed by intraocular lens implantation. Congenital cataracts were defined as those diagnosed by a pediatrician or ophthalmologist within 30 days of birth. Additionally, articles were included if they (i) reported measures that allowed for the calculation of proportions (response rate) with a 95% confidence interval (CI); (ii) reported outcomes separately for unilateral and bilateral types of cataracts; (iii) reported the timing of cataract removal surgery and IOL implantation; (iv) reported preoperative diagnoses of cataract phenotype; (v) provided information on follow-up timing for each patient; and (vi) provided outcomes for postoperative complications. Studies were excluded if they (i) focused on populations with congenital cataracts in which the subjects were aged over 18 years of age at the time of surgery; (ii) focused on congenital cataracts secondary to genetic syndromes, metabolic disorders, or intrauterine infections; (iii) excluded patients with concurrent ocular congenital anomalies (e.g., microphthalmos, microcornea, ptosis, congenital glaucoma, Lowe syndrome, persistent hyperplastic primary vitreous (PHPV)/persistent fetal vasculature (PFV) or systemic birth defects; (iv) were not published within the date range of January 1, 1981, to March 1, 2023; (v) were not initially published in English. Quality assessment of the included studies was conducted independently by two researchers using the Newcastle–Ottawa Scale (NOS) [19]. The NOS evaluates quality across three domains, with a maximum score of 9. Studies scoring 7–9 were of high quality, while scores of 4–7 indicate moderate quality. Disagreements were resolved by a third author.

Data extraction and statistical analysis

The extracted data included (i) type of article, (ii) country of origin, (iii) number of participants, (iv) clinical and ocular characteristics, (v) average age at surgical intervention, (vi) type of intervention(s), (vii) whether amblyopia treatment was administered postoperatively, (viii) postoperative follow-up timing, and (ix) suitability for the review and reason for exclusion. The key outcome of this study was the proportion of patients with congenital cataracts and low vision quality after surgical intervention. Amblyopia was defined based on criteria from the 2021 Expert Consensus in China [20] and the 2022 Clinical Practice Guidelines of the American Academy of Ophthalmology [21]. Statistical analyses were performed via single-arm meta-analyses using Stata version 16.0. A meta-analysis was conducted for each outcome reported in more than two studies. Heterogeneity among the included studies was evaluated using Cochran's Q statistic and the I2 index score. Values of I2 >50% or $P>0.1$ were considered indicative of high heterogeneity. When heterogeneity was high, a random-effects model (DerSimonian and Laird method) was used for analysis; otherwise, a fixed-effects model (inverse variance method) was used [18]. The pooled prevalence of postoperative amblyopia was calculated and the outcome was reported with a 95% confidence interval (CI). Subgroup analyses were conducted based on the timing of cataract removal surgery, IOL implantation, cataract phenotype, and follow-up duration. Sensitivity analysis was performed to assess the robustness of the main meta-analysis results. Publication bias was assessed using Egger's linear regression method. A *P*-value threshold of less than 0.05 was established for statistical significance.

Results

Study characteristics

Twenty-eight articles met our criteria for this systematic review and meta-analysis, including 1 randomized controlled trial (RCT) [22], 1 cohort study [23], 20 case series [6, 7, 15, 24–42], and 6 clinical trial studies [4, 38, 39, 43–45]. (Supplementary Tables 1 and 2 for the characteristics and quality evaluation of the included articles). A total of

2,167 patients were included, with 3,371 eyes included in our analysis (Fig. 1). Among them, 963 had unilateral congenital cataracts and 1,204 had bilateral congenital cataracts (Supplementary Table 3). Below, we describe the results for various groups in detail.

Pooled amblyopia prevalence

We recorded the best-corrected visual acuity (BCVA) of all patients in each study reported at the final follow-up and measured the prevalence of amblyopia. The results revealed a pooled proportion of 62% for the presence of amblyopia after surgical intervention using a random-effects model (95% CI: 0.55–0.69, $I^2 = 91.7\%$) (Fig. 2).

Effect of cataract extraction timing

We categorized our subjects into four subgroups based on age at the time of surgical intervention. For patients who underwent surgery before 8 weeks, the proportion of patients with amblyopia was 53% (95% CI: [0.42, 0.64]; $I^2 = 8.6\%$). For those who underwent surgery between 8–12 weeks, the proportion was 56% (95% CI: [0.42, 0.70]; $I^2 = 63.0\%$). The proportion of patients who underwent surgery between 12 weeks and 12 months was 79% (95% CI: [0.69, 0.88]; $I^2 = 59.2\%$). The proportion of patients who underwent surgery after 12 months was 79% (95% CI: [0.68, 0.90]; $I^2 = 86.8\%$). There were statistically significant differences among the subgroups ($P < 0.001$) (Fig. 3A).

The results in the bilateral group were consistent with the trends observed in the unilateral group. For those who underwent surgery within 12 weeks, the proportion of patients with amblyopia was 39% (95% CI: [0.31, 0.47]; $I^2 = 0.00\%$). The prevalence rates for those who underwent surgery between 12 weeks and 12 months and those who underwent surgery after 12 months were 52% (95% CI: [0.46, 0.58]; $I^2 = 31.2\%$) and 71% (95% CI: [0.50,

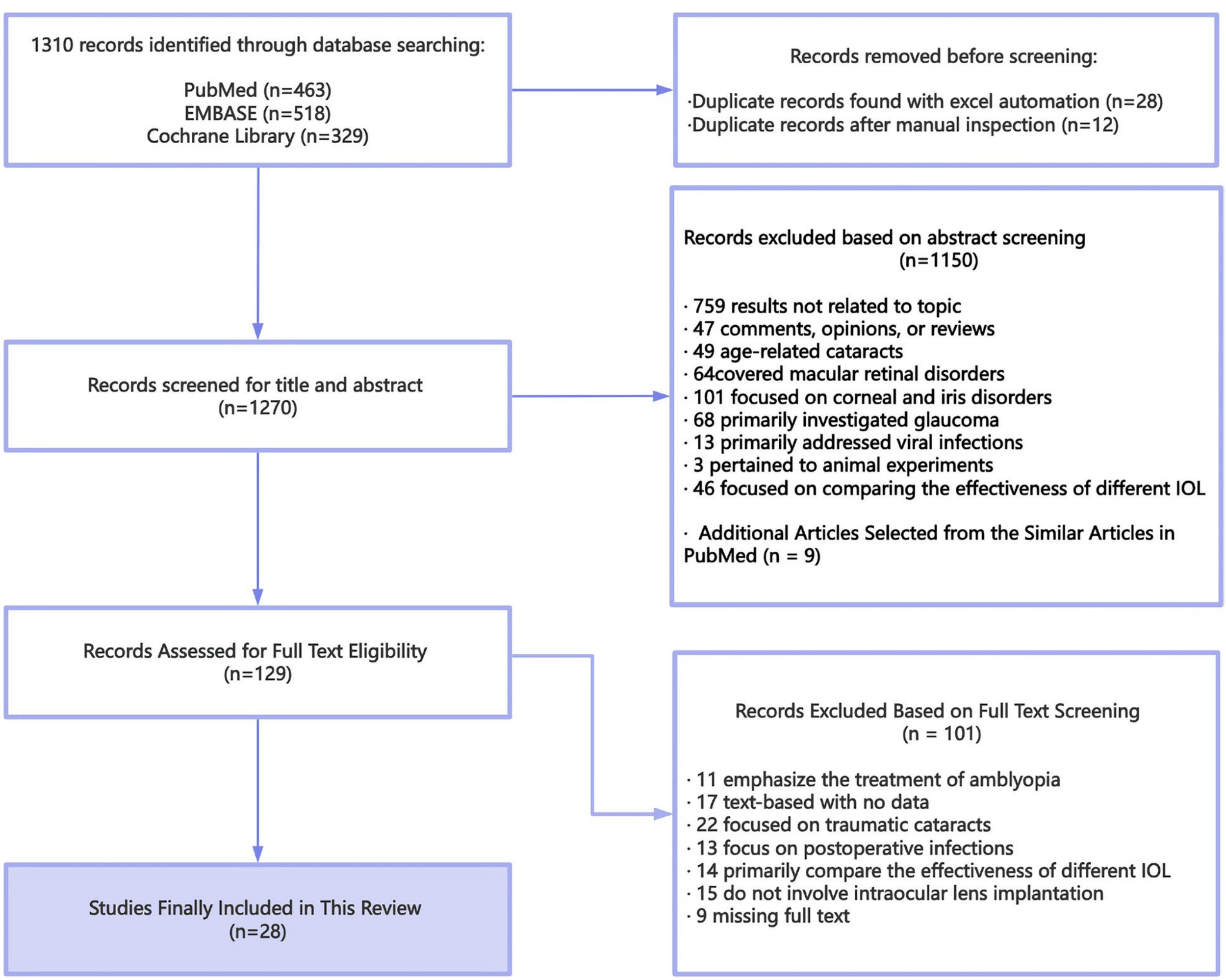

Fig. 1 Flow diagram of the literature search and study selection process

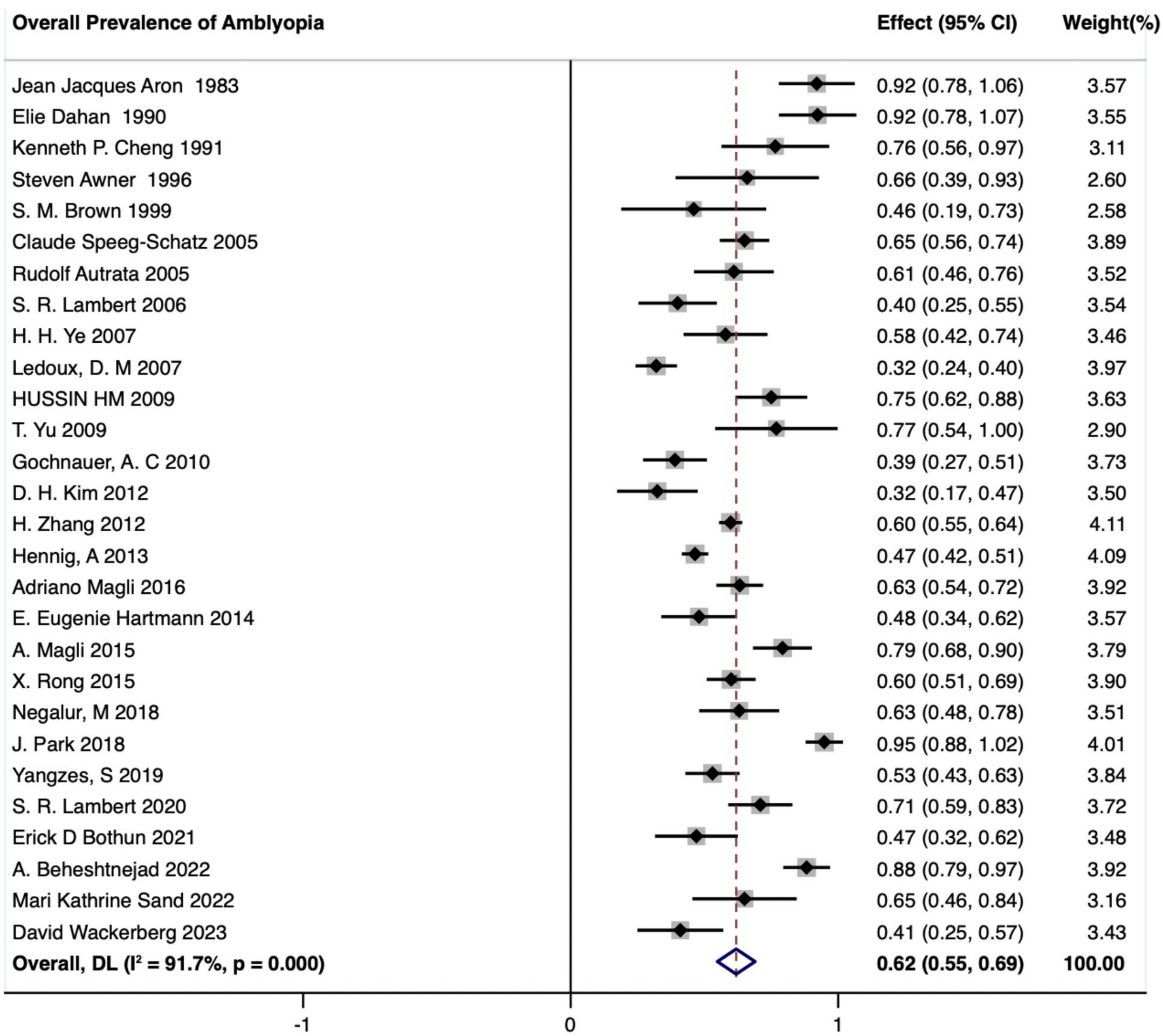

Fig. 2 Forest plot of the pooled proportion estimates of amblyopia following surgical intervention in congenital cataract, using a random-effects model. CI = confidence interval; DL = DerSimonian-Laird random-effects model

0.92]; I^2 = 90.3%), respectively. There were statistically significant differences among the subgroups (P = 0.005) (Fig. 3B).

Impact of IOL implantation timing

Comparing the prevalence of amblyopia among different IOL implantation groups, we observed a lower rate in the primary implantation group 61% (95% CI: [0.51, 0.71]; I^2 = 90.7%) than in the secondary implantation group 66% (95% CI: [0.57, 0.74]; I^2 = 90.2%) (Fig. 4A). However, no statistically significant difference were detected between these subgroups (P = 0.527). When categorized by the timing of IOL implantation—pre-12 weeks, between 12 weeks and 12 months, and post-12 months—the rates

(See figure on next page.)

Fig. 3 Forest plot of the pooled proportion of amblyopia following surgical intervention for the subgroups: **A** Age at the time of surgery before 8 weeks, 8–12 weeks, 12 weeks-12 months, and after 12 months within the unilateral congenital cataract group; **B** Age at the time of surgery before 12 weeks, 12 weeks-12 months, and after 12 months within the bilateral congenital cataract group. Subgroup analyses are presented with effect sizes (proportions), 95% confidence intervals (CI), and heterogeneity metrics (I^2 statistic and P-value). CI = confidence interval; DL = DerSimonian-Laird random-effects model

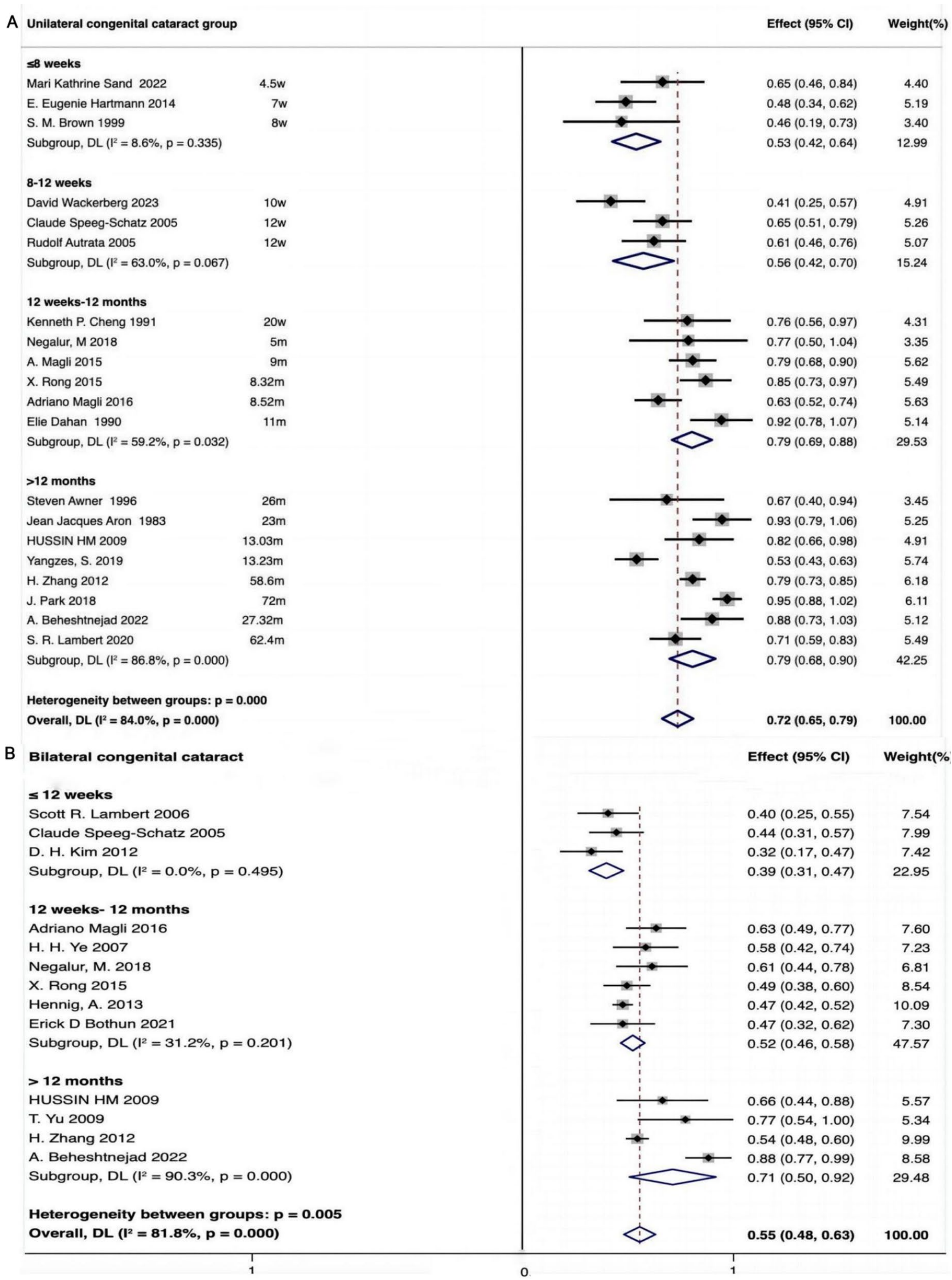

Fig. 3 (See legend on previous page.)

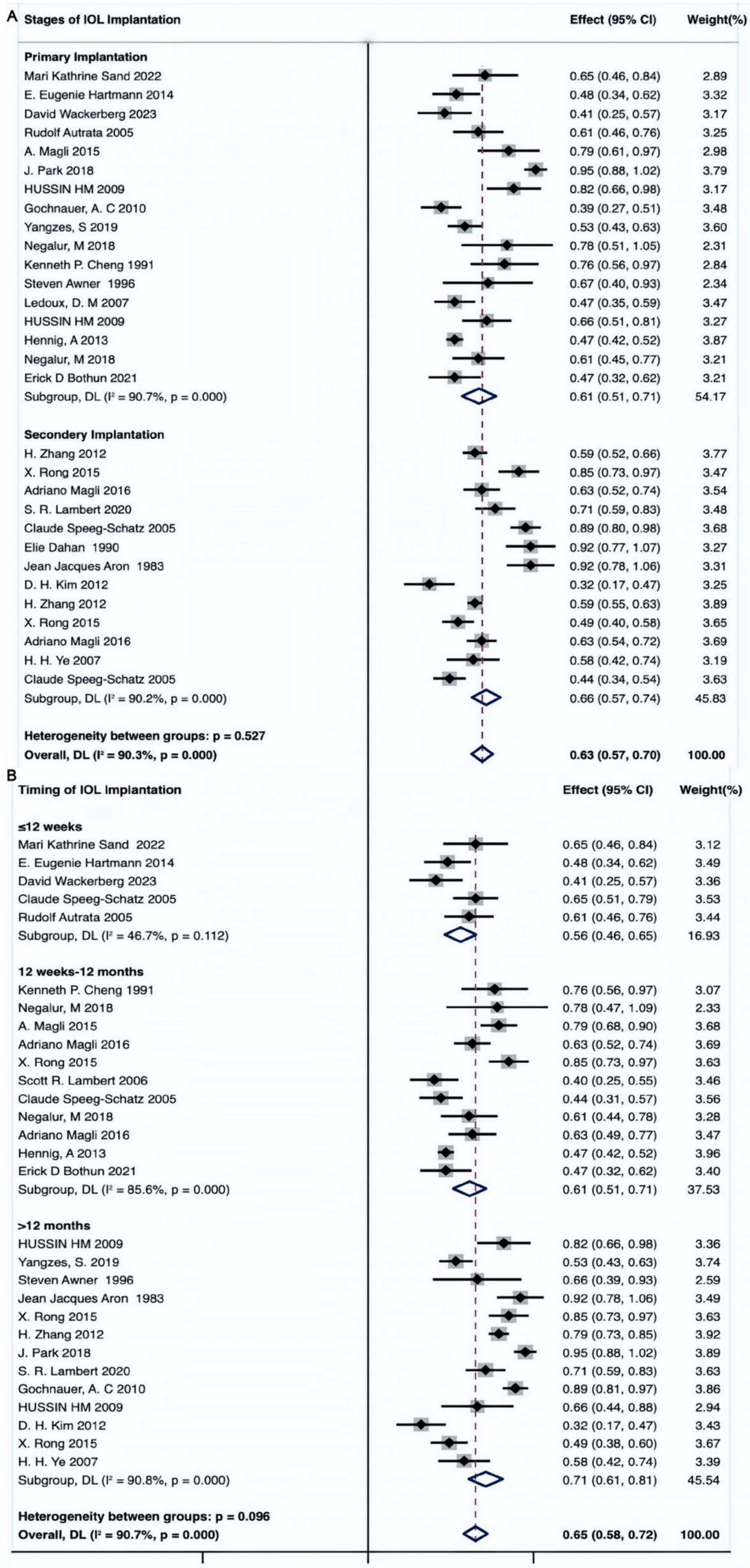

Fig. 4 Forest plot of the pooled proportion of amblyopia following IOL implantation for the subgroups: **A** Primary implantation versus secondary implantation; **B** Subgroup categorized by IOL implantation timing: Before 12 weeks, 12 weeks-12 months, and after 12 months. Subgroup analyses are presented with effect sizes (proportions), 95% confidence intervals (CI), and heterogeneity metrics (I^2 statistic and *P*-value). CI = confidence interval; DL = DerSimonian-Laird random-effects model

of amblyopia were 56% (95% CI: [0.46, 0.65]; I^2 = 46.7%), 61% (95% CI: [0.51, 0.71]; I^2 = 85.6%), and 71% (95% CI: [0.61, 0.81]; I^2 = 90.8%), respectively. However, no significant differences were observed among the subgroups (*P* = 0.096) (Fig. 4B).

Cataract phenotype and amblyopia risk

To assess the influence of cataract phenotype on postoperative visual acuity, we categorized the preoperative diagnoses into four groups: unilateral complete obstruction, unilateral partial obstruction, bilateral complete obstruction, and bilateral partial obstruction. Our analysis revealed a higher prevalence of amblyopia in the unilateral complete obstruction group, reaching 69% (95% CI: [0.47, 0.91]; I^2 = 89.2%), followed by unilateral partial obstruction with a prevalence of 68% (95% CI: [0.47, 0.90]; I^2 = 84.5%).

For bilateral cataracts, the prevalence rates of complete and partial obstruction were 38% (95% CI: [0.28, 0.48]; I^2 = 50.8%) and 36% (95% CI: [0.25, 0.47]; I^2 = 43.0%), respectively. We compared the occurrence across the four classifications. Significant differences were found between unilateral partial obstruction and bilateral complete obstruction (*P* = 0.01) and partial obstruction (*P* = 0.008) and between unilateral complete obstruction and bilateral complete obstruction (*P* = 0.009) and partial obstruction (*P* = 0.007) (Fig. 5A).

Using an alternative classification method, we categorized cataract phenotypes into four groups: Total, Nuclear, Posterior Subcapsular, and Other (including lamellar, anterior polar, punctate, and other opacities) to examine the prevalence of amblyopia in patients. Subgroup analysis results showed that the prevalence of amblyopia in the total cataract group was slightly higher than that in the other subgroups; however, no significant differences were observed among them (*P* = 0.725) (Fig. 5B).

Follow-up duration and age at last assessment

Our analysis of the relationship between follow-up duration and postoperative visual outcomes revealed prevalence rates of 75% (95% CI: [0.60,0.91], I^2 = 96.4%) for less than 4 years, 64% (95% CI: [0.53,0.75], I^2 = 82.6%) for 4–8 years, and 65% (95% CI: [0.52,0.77], I^2 = 88.8%) for ≥ 8 years. However, no statistically significant correlation was observed among the subgroups (*P* = 0.444) (Fig. 6A).

Additionally, we conducted another subgroup analysis based on age at the last follow-up, dividing patients into two groups with a cutoff age of 6 years, to investigate whether tracking specific ages correlates with long-term visual recovery. Our results showed a 69% prevalence rate of amblyopia (95% CI: [0.60,0.78], I^2 = 91.9%) for children followed up beyond the age of 6, while for those followed up at or below 6 years old, it was 66% (95% CI: [0.52,0.79], I^2 = 91.6%). No statistically significant difference was observed between the two subgroups (*P* = 0.679) (Fig. 6B).

Postoperative complications

We analyzed postoperative complications based on the timing of cataract extraction and IOL implantation, dividing the patients into three groups: pre-12 weeks, 12 weeks to 12 months, and post-12 months. Patients who underwent surgery before 12 weeks had significantly higher risks of VAO (31%) and glaucoma (26%), while those underwent surgery between 12 weeks and 12 months showed lower risks (VAO, 13%; glaucoma, 3%). Surgery after 12 months was associated with intermediate risks (VAO, 20%; glaucoma, 6%). Similar trends were observed for IOL implantation timing, with significantly higher risks of VAO (31%) and glaucoma (25%) before 12 weeks, lower risks between 12 weeks and 12 months (VAO, 12%; glaucoma, 3%), and intermediate risks after 12 months (VAO,15%; glaucoma, 6%). Significant differences were found among the glaucoma subgroups (*P* = 0.001) but not among the VAO groups (*P* = 0.067) (Supplementary Fig. 2–5).

In the sensitivity analysis, omitting a single study at a time did not result in significant changes in the overall results. The Egger's test indicated no evidence of publication bias (Egger's *P* = 0.671) (Supplementary Fig. 1).

Discussion

Our meta-analysis indicated that approximately 62% of children who underwent surgery for congenital cataracts developed amblyopia. The timing of cataract extraction is closely related to the prevalence of amblyopia, with earlier removal being associated with a lower prevalence. Conversely, the timing of IOL implantation appears to

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Fig. 5 Forest plot of the pooled proportion of amblyopia categorized by phenotype for the subgroups: **A** Unilateral complete occlusion, unilateral partial occlusion, bilateral complete occlusion, and bilateral partial occlusion; **B** Subgroup categorized by phenotype: Total, Nuclear, Posterior subcapsular, and other (including lamellar, anterior polar, punctate, and other opacities). Subgroup analyses are presented with effect sizes (proportions), 95% confidence intervals (CI), and heterogeneity metrics (I^2 statistic and *P*-value). CI = confidence interval; DL = DerSimonian-Laird random-effects model

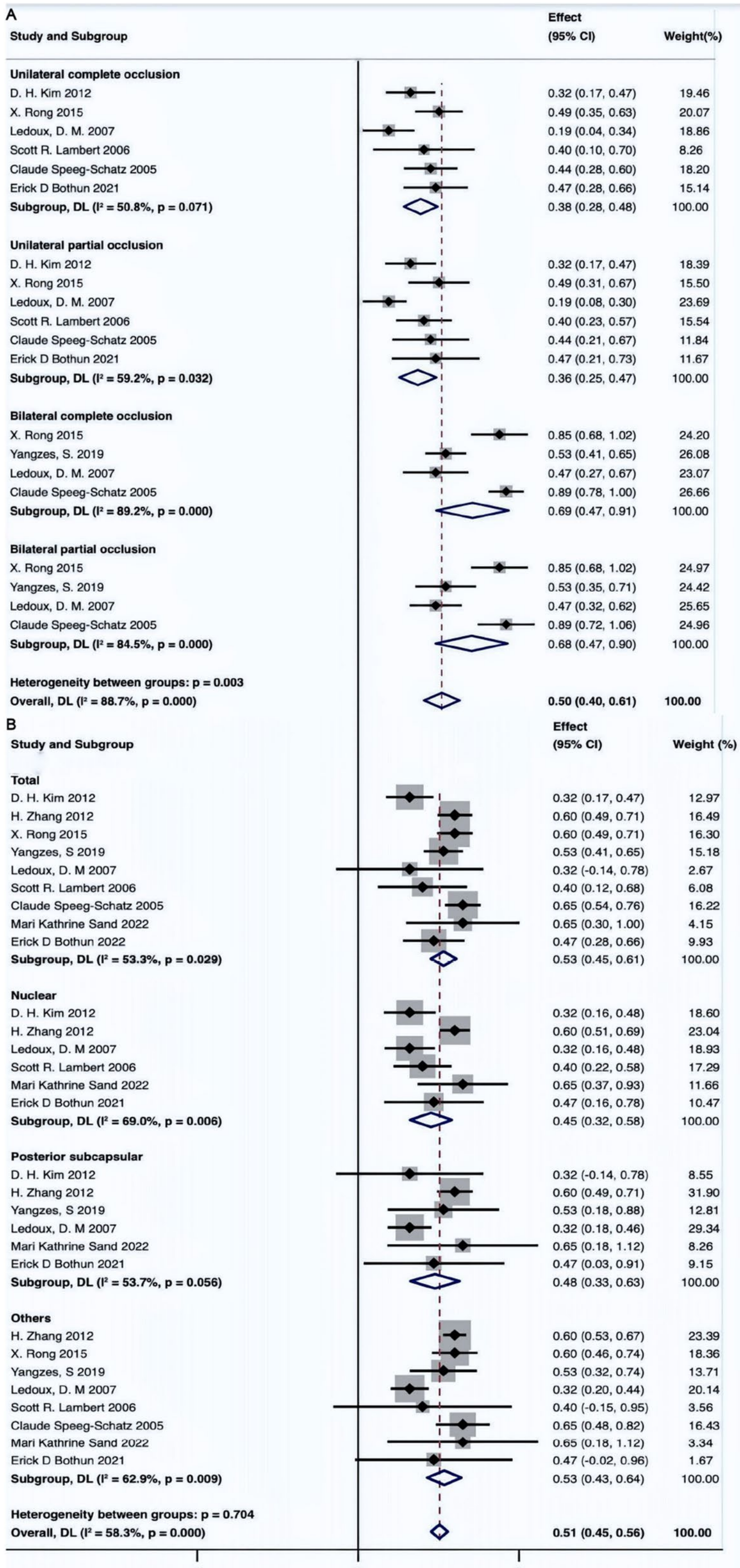

Fig. 5 (See legend on previous page.)

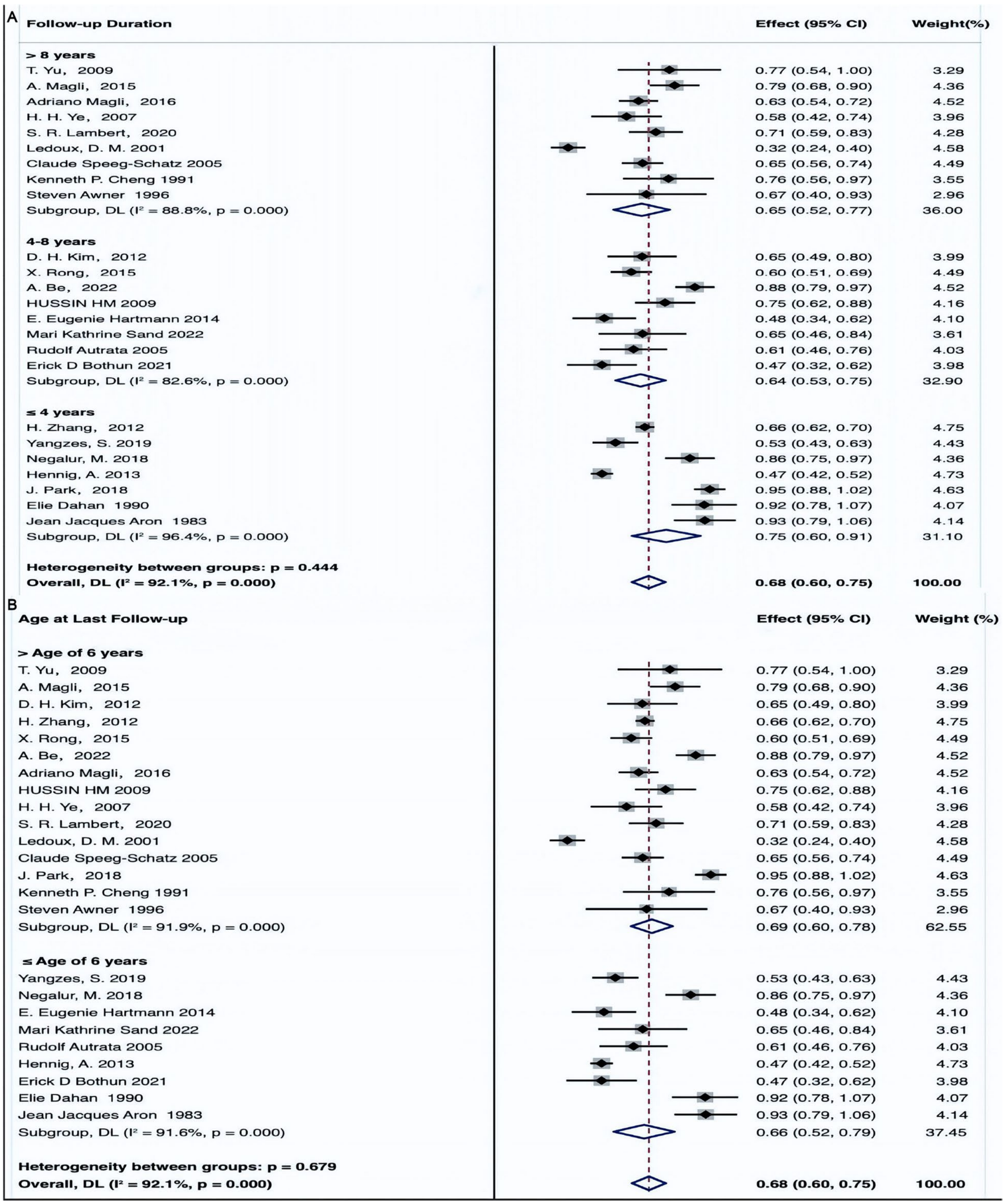

Fig. 6 Forest plots of the pooled prevalence of amblyopia stratified by: **A** Follow-up duration (≤ 4 years, 4–8 years, > 8 years post-surgery); **B** Age at last follow-up (≤ 6 years vs. > 6 years). Subgroup analyses are presented with effect sizes (proportions), 95% confidence intervals (CI), and heterogeneity metrics (I^2 statistic and *P*-value). CI = confidence interval; DL = DerSimonian-Laird random-effects model

have a minor impact on postoperative visual outcomes. Regardless of whether lens removal or IOL implantation is performed earlier, patients face significant risks of complications, such as glaucoma and VAO. Additionally, our study found that patients with complete obstruction in both eyes exhibited better visual recovery than those with partial obstruction in a single eye ($P = 0.01$). Interestingly, beyond 6 years of age, an extended follow-up period did not result in a significant visual recovery. We discuss these findings in greater detail below.

Our findings underscore the importance of early diagnosis and intervention to reduce the incidence of amblyopia. Data show that the prevalence of amblyopia in patients with unilateral cataract decreases from 79% when surgery is performed after 12 months to 53% when conducted before 8 weeks, and from 72% to 39% in patients with bilateral cataract. These findings align with Birch and Stager's study, which demonstrated that surgery before 6 weeks of age significantly improves visual prognosis in patients with unilateral cataracts [46]. This 6-week threshold, known as the latent period, relies on subcortical pathways in the developing visual system to prevent form deprivation-induced vision loss [47, 48]. Emerging evidence suggests that this critical window is modulated by broader neuro developmental processes. For instance, infants with congenital cataracts may exhibit delayed myelination of the optic radiations, as observed in diffusion tensor imaging studies [49], which could further constrain the time frame for effective visual rehabilitation. Additionally, cross-modal plasticity where auditory or somatosensory cortices encroach on visually deprived area may compete with residual visual plasticity, potentially explaining why delayed intervention beyond the latent period yields diminished gains [50]. Additionally, research suggests that the latent period for bilateral visual deprivation may extend for up to 10 weeks [7]. These data emphasize the importance of performing surgery within the latent period to maximize the development of visual function and further elucidate the critical role of the latent period in visual recovery.

Our results show that the timing of IOL implantation, whether in the primary or secondary phase, or within the first 12 weeks or after 12 months of life, does not significantly affect the prevalence of amblyopia in patients. This might be attributed to the fact that almost all patients received proper visual correction after cataract removal, such as wearing spectacles or contact lenses while in an aphakic status. However, earlier intervention ($\leq$ 12 weeks) was associated with higher complication rates with VAO (52% in the $\leq$12-week group vs. 47% in the >12-month group ($p = 0.32$)) and Glaucoma (26% vs. 6% ($p = 0.004$)). Our findings indicates that the occurrence of VAO tends to be higher with earlier surgical intervention; however, no significant correlation was observed in the subgroup analysis based on timing, consistent with Negalur's observations that VAO development is not linked to age at the time of surgery [15]. Nevertheless, a substantial increase in the prevalence of glaucoma warrants further attention. A recently published meta-analysis on the correlation between congenital cataract surgery and the incidence of secondary glaucoma indicated that the average age at surgery was an independent factor influencing the development of secondary glaucoma [51]. Birch and Cheng also found that surgery within the first 4 weeks of life led to a higher occurrence of glaucoma [52]. An examination of 147 eyes with congenital cataracts in Victoria, Australia, revealed that the prevalence of glaucoma was the highest in surgeries performed within the first month of life [53]. The risk of glaucoma decreases as the age at the time of surgery increased [54, 55].

Combining the conclusions drawn from cataract extraction, we believe that early removal of opacified lenses is crucial for postoperative vision recovery and the prevention of amblyopia. While ensuring that patients receive appropriate visual correction and rehabilitation, delaying the timing of IOL implantation could strike a balance between maximizing visual recovery and minimizing the risk of serious complications, such as glaucoma.

Our results showed clear differences in visual outcomes with respect to the various cataract phenotypes. The prevalence of amblyopia was significantly higher in unilateral complete and partial obstruction cataracts (69% and 68%, respectively) than in bilateral cataracts (38% and 36%, respectively). This result is understandable, as unilateral congenital cataract leads to early monocular deprivation, adversely affecting visual outcomes compared with deprivation in both eyes [47]. Studies on monocularly deprived animals have shown that the columnar regions of the deprived eye in layer 4c of the primary visual cortex are almost three times narrower than those of the non-deprived eyes [47, 56]. In humans, functional MRI studies corroborate these findings, demonstrating reduced blood-oxygen-level-dependent (BOLD) signals in the primary visual cortex of children with untreated congenital cataracts [57]. These structural and functional alterations highlight the critical role of early surgical intervention in preserving cortical organization, as delayed treatment may lead to irreversible neural remodeling. Lambert et al. showed that bilateral visual deprivation during early childhood has a less severe impact on visual system development than unilateral deprivation [58]. In our study, relatively poorer postoperative visual acuity was observed in monocularly deprived unilateral congenital cataracts than in bilateral congenital cataracts ($P = 0.01$). When both eyes were deprived, the damage was less severe, indicating that the impairment was not solely due to lack of use, but also due to competition between the two eyes. Therefore, the prognosis for patients with unilateral congenital cataracts is generally regarded as less favorable, and visual acuity is higher in patients with bilateral congenital cataracts even in cases of complete obstruction. This can assist clinical ophthalmologists in predicting the prognosis of patients before surgery while raising awareness for children with unilateral cataracts encountered in clinical practice.

We also categorized the patients into four groups based on the following cataract phenotypes: total, nuclear, posterior subcapsular, and other cataracts (including lamellar, anterior polar, punctate, and other opacities). Unlike previous classifications, the detailed classification of cataracts did not significantly affect postoperative visual outcomes. In fact, in the reviewed studies, a detailed description of the diagnostic process was often lacking. We believe that the limited availability of studies investigating the correlation between cataract phenotypes and postoperative visual outcomes might explain the lack of a significant effect.

Another important finding of our study is that the recovery of vision tends to plateau after a certain period. Specifically the prevalence rate of amblyopia was 75% with a follow-up duration of 4 years postoperatively. Extending the follow-up period to 4–8 years resulted in a prevalence rate of 64%. We found that the prevalence rate decreased significantly from 75 to 64%, indicating that prolonged follow-up contributes to a reduction in the prevalence of amblyopia. However, when comparing the follow-up periods of 4–8 years and ≥ 8 years, the decrease in amblyopia rates was minimal, suggesting a relatively short golden period for visually deprived amblyopia caused by congenital cataracts. When exploring the relationship between the last follow-up age and amblyopia, using 6 years as the dividing point, we found no significant difference between the two groups. This finding indirectly confirms that, beyond 6 years of age, prolonged follow-up may not significantly contribute to visual recovery. The sensitive period is the timeframe during which the developing visual system retains plasticity and can be manipulated, influenced, or modified before full visual maturation [56, 59]. Suwal et al. indicated that for patients with amblyopia caused by ptosis and refractive error, proactive amblyopia treatment can significantly improve vision even at the age of 16 [60]. Studies have reported that for non-visually deprived amblyopia patients, significant improvements in vision can be achieved through active amblyopia training even at older ages [61, 62]. When categorizing follow-up timing, we attempted several subgroup analyses within smaller age groups. However, due to the limited availability of useful data for patients younger than 6 years in the literature, we could only observe differences in percentages without significant intergroup distinctions. Based on our conclusions, we believe that amblyopia caused by congenital cataracts has a shorter postoperative recovery time than the other types of amblyopia. Therefore, if we can effectively harness this period of visual plasticity for amblyopia training, it has the potential to maximize visual recovery in patients.

We acknowledge the limitations of this study. First, we categorized the timing of unilateral surgery as before eight weeks. However, previous studies suggest that the optimal timing for unilateral surgery is within the first 4–6 weeks of life [46]. The discrepancy in our categorization stems from the limited availability of studies that provided data for early intervention. This highlights a potential gap in the literature, emphasizing the need for further research on the earliest possible intervention times to optimize the visual outcomes in children with congenital cataracts. Second, our exclusion criteria intentionally omitted congenital cataracts associated with genetic syndromes [63, 64] or prenatal infections [65]. While this approach enhanced the homogeneity of our cohort, it limits the generalizability of findings to syndromic cataracts, where amblyopia risk may be compounded by additional ocular or systemic anomalies [66]. Future studies should address phenotype-specific outcomes in these populations. Although preventive measures are critical in reducing congenital cataract incidence, our analysis focused on postoperative outcomes rather than etiology. The interplay between prevention strategies and surgical timing warrants dedicated investigation. Third, our data predominantly represent small populations and thus may not offer a comprehensive representation of the entire population. Fourth, these data were extracted from several studies, making it difficult to unify surgical procedures, IOL types, and the process of amblyopia training. Finally, there might be language bias because our study included only studies published in English.

Conclusion

Our study demonstrates that early surgical intervention (≤ 8 weeks for unilateral, ≤ 12 weeks for bilateral congenital cataracts) significantly reduces amblyopia prevalence, although it comes with an increased risk of postoperative complications. Notably, IOL implantation timing showed no clinically meaningful impact on visual outcomes, challenging the rationale for early IOL placement in infants. Additionally, our findings indicate that the cataract phenotype critically influences prognosis, emphasizing the urgency of prioritizing unilateral cataract management. Furthermore, the therapeutic window for amblyopia rehabilitation is constrained, with limited efficacy observed beyond 6 years of age, emphasizing the need for age-targeted interventions during the critical period of visual plasticity.

Abbreviations

BCVA	Best-corrected visual acuity
BOLD	Blood-oxygen-level-dependent
IOL	Intraocular lens
NOS	Newcastle–Ottawa Scale
PHPV/PFV	Persistent hyperplastic primary vitreous / Persistent fetal vasculature
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RCT	Randomized controlled trial
VAO	Visual axis opacification

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13052-025-02010-x.

Supplementary Material 1.

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Authors' contributions
STXC and AH conceived and designed the study. AH conducted the literature search, data extraction, and preliminary analysis. YXN and AH drafted the initial manuscript and performed statistical analysis. STXC, YXN, and AH revised and edited the manuscript. YK and STXC supervised the study and ensured quality control.

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Data availability
All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declarations

Ethics approval and consent to participate
This study was based on previously conducted studies and did not involve any new experiments with human participants or animals performed by the authors.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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