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Issues of Prevention of Oculocardial Reflexes during Anesthesia in Pediatric Ophthalmology

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Annotation: This article presents a literature review dedicated to the issues of improving anesthesia in ophthalmic surgery for children, analyzing the unique anatomical, physiological, and behavioral characteristics of pediatric ophthalmosurgery. The primary focus is on the following challenges: maintaining intraocular pressure (IOP) stability, the oculocardiac reflex, the narrowness and propensity for collapse of airways, emergence agitation, sympathetic hyperreactivity, and the high metabolic rate in children. It is emphasized that these factors directly influence the quality and safety of general anesthesia. The review compares the advantages and limitations of volatile anesthetics such as sevoflurane (IOP elevation, emergence agitation) with the positive properties of propofol, ketamine, and particularly dexmedetomidine (IOP reduction, hemodynamic stability, agitation mitigation). Multimodal and opioid-sparing approaches, including dexmedetomidine-based combinations, are highlighted as promising directions in contemporary pediatric ophthalmic anesthesia.

Keywords: pediatric ophthalmology, intraocular pressure, oculocardiac reflex, sevoflurane, propofol, multimodal anesthesia.

Ophthalmic surgeries primarily affect two age groups of patients—children and the elderly. In children, ophthalmopathology often has a congenital nature and is accompanied by other congenital diseases (muscular dystrophy, Down syndrome, and others) [1; 3; 5;]. In elderly patients, the most common comorbidities are ischemic heart disease (IHD), hypertension, and diabetes mellitus [8; 25;]. Ophthalmic surgeries are characterized by the following issues and features: intraocular pressure (IOP); oculocardiac reflex; open eye; adequate respiration [2; 4; 5;]. The process of pediatric ophthalmic surgery is defined by a unique combination of anatomical, physiological, and behavioral factors, which significantly differentiates it from adult ophthalmic surgery. In children, the orbital cavity volume is smaller, tissue elasticity is higher, and the reactivity of extraocular muscles is stronger, which enhances the technical precision of intraoperative manipulations while increasing the risk of abrupt changes in intraocular pressure. According to data from the American Academy of Ophthalmology (2023), children have numerous congenital eye diseases such as glaucoma, congenital cataract, and strabismus, which require surgical intervention; young patients cannot adequately cooperate with local anesthesia, so they are almost always operated under general anesthesia [31; 18; 25;]. The narrowness of the surgeon's field of view, the delicacy of the pediatric ocular apparatus, and the rapid variability of physiological parameters specific to this group demand high anesthesia stability [12; 33;].

Surgical stimulation in children often provokes sudden cardiovascular reactions. Their airways are narrower and prone to collapse, increasing the risk of obstruction during induction and emergence phases. Due to the elevated metabolic rate, tolerance to apnea and hypoventilation is reduced, particularly during periods of fluctuating anesthesia depth. These physiological features impact intraocular pressure, as IOP is sensitive to changes in venous pressure, carbon dioxide levels, and sympathetic stimulation [48; 15;]. Manipulation of the eyeball, activation of the oculocardiac reflex, and unanticipated changes in anesthesia depth create the risk of a sharp IOP increase. Prospective studies have noted that induction, laryngoscopy, and insufficient anesthesia depth can significantly elevate IOP, compromising the quality of delicate intraocular surgery [35; 14; 8;].

There are also complexities related to behavioral factors. Sympathetic tone, arterial pressure, and IOP often rise in the pre-anesthetic period because anxiety intensifies in young children during separation from caregivers, with crying or restlessness further exacerbating these changes. Emergence agitation is particularly common after strabismus surgeries and following volatile anesthesia. Chen and co-authors explained that the risk of agitation in this group is substantially higher, attributing this condition to ocular pain and the effects of the anesthetic combination [29; 28; 34;]. This evidence underscores the importance of approaches that ensure anesthesia stability throughout the perioperative process. The interplay of anatomical, physiological, and emotional reactivity factors creates a clinical environment requiring cautious and patient-specific anesthesia planning for every pediatric ophthalmic surgery [42; 39;]. The selection of anesthesia type is a clinically significant issue in pediatric ophthalmic surgery, as different agents exert markedly varied effects on intraocular pressure, airways, cardiovascular physiology, and postoperative behavior [42; 48;]. Children are more sensitive to anesthetic agents, resulting in heightened probabilities of both beneficial and adverse effects [19; 46;]. Consequently, the chosen anesthesia method directly influences operative conditions, surgical efficacy, and recovery quality [38; 41;].

Sevoflurane and other volatile anesthetics remain popular in pediatrics due to the ease of inhalation induction and rapid adjustment of anesthesia depth [27; 45;]. However, volatile agents can elevate intraocular pressure, especially during induction, and increase instances of emergence agitation following ocular surgeries [29; 28; 34;]. This trend is also observed in strabismus surgeries, as stimulation of extraocular muscles triggers strong oculocardiac and oculo-sympathetic reflexes [43; 9;]. Children undergoing inhalation anesthesia for strabismus correction often emerge abruptly, exhibiting disorientation, crying, or restless movements, which complicates postoperative monitoring [49;]. Intravenous sedatives offer other advantages.

Propofol reliably reduces intraocular pressure and provides smooth, rapid induction and clearance, though it may cause arterial pressure decrease in some patients [32; 22;]. Ketamine preserves airway reflexes and cardiovascular stability but may excessively increase IOP in certain scenarios, making it less suitable for some ophthalmic surgeries [40;]. Dexmedetomidine has proven effective as an adjunct due to its properties of reducing sympathetic tone, lowering IOP, providing cooperative sedation, and minimizing agitation during recovery [18; 37;]. Reviews on pediatric ophthalmic anesthesia emphasize that dexmedetomidine-based methods in multimodal approaches improve hemodynamic stability and postoperative behavior [44;]. Hybrid anesthesia methods combining intravenous and inhalation agents are increasingly employed [13; 21;]. Ducloyer and colleagues determined that dexmedetomidine-supported inhalation or intravenous anesthesia maintains cardiovascular parameters more stably than volatile agents alone and creates better working conditions for surgery [35;]. These methods reduce opioid usage, aligning with pediatric practices aimed at limiting exposure to opioid analgesics [19;]. Systematic reviews demonstrate strong evidence for the efficacy of opioid-sparing techniques in the pediatric surgical population, with paracetamol, NSAIDs, and adjunct sedatives reducing opioid requirements [13;]. The choice of anesthesia influences multiple aspects of intraoperative events. Balanced anesthesia or dexmedetomidine-enriched regimens mitigate issues during the emergence period, accelerate recovery, enhance airway reflex predictability, and reduce instances of nausea, vomiting, and agitation [50; 42;]. Smith and Pettigrew found that optimal anesthesia selection significantly contributes to improving the overall perioperative experience for pediatric patients and their families, while also enhancing safety in non-surgical ophthalmic units [18;].

Overall, the literature unequivocally demonstrates that the anesthesia decision is a key factor in the quality of perioperative care in pediatric ophthalmic surgery [31; 15;]. The selected method directly affects IOP stability, reliable airway management, predictability of postoperative behavior, and comfort for the patient and family [32; 16;]. These factors support the need for in-depth investigation of the physiological and clinical outcomes of anesthesia modalities in children undergoing ocular surgeries [12;]. Intraocular pressure is linked to a complex physiological mechanism involving the musculoskeletal system, brain, and central nervous system [48;]. Intraocular pressure serves fundamental physiological functions, such as maintaining eye shape, supporting the optical apparatus, and ensuring optimal perfusion of the optic nerve head [48;]. IOP is determined by the balance between aqueous humor production and drainage, venous pressure, and extraocular muscle tone [20;]. This ocular system is more reactive in children, with scleral tissues being more elastic than in adults and autonomic responses manifesting more acutely [25;]. Consequently, children's eyes respond more strongly to ventilation changes, airway manipulations, and variations in anesthesia depth [24;]. These responses hold clinical significance in ophthalmic surgery, as even minor IOP fluctuations can deform the surgical field or damage delicate intraocular structures [20;].

Several events known to influence IOP occur in the perioperative period. Mask induction, crying, anxiety, and laryngoscopy heighten sympathetic activity and elevate IOP [27; 17;]. The intubation response is particularly acute, with supraglottic stimulation having systemic effects: increased heart rate and arterial pressure directly raise orbital venous pressure [14;]. Existing pediatric anesthesia literature indicates that volatile anesthetics, particularly sevoflurane, can cause transient IOP elevation during initial induction, whereas intravenous agents, including propofol and dexmedetomidine, reduce IOP by lowering sympathetic activity and venous pressure [16; 12;]. Additionally, during strabismus surgery, traction on extraocular muscles activates the oculocardiac reflex, leading to bradycardia and perfusion pattern changes that also affect IOP [9]. Chen and co-authors emphasize that rapid and notable changes in IOP and autonomic tone are observed during anesthesia in children undergoing strabismus correction [29]. Understanding IOP physiology is crucial for anesthesia planning, as uncontrolled pressure surges can disrupt glaucoma surgeries, cataract extraction, and retinal procedures [31; 4;]. The high reactivity of ocular tissues in children makes stable hemodynamics and adequate anesthesia depth the primary objective in any pediatric ophthalmic case [50; 39;].

Surgical and anesthetic stress during the procedure elicits a stronger and more uneven neuroendocrine response in children compared to adults [42; 19;]. Anxiety, caregiver absence, mask application, or airway manipulations rapidly activate their sympathetic nervous system, leading to elevated blood catecholamine levels, increased heart rate and arterial pressure, and indirect IOP elevation [48]. Becke also noted that children with mild upper respiratory infections or sensitive airways are highly responsive to anesthetic stimulation and prone to respiratory complications during induction [24]. Such physiological predispositions necessitate carefully balanced administration of anesthetic agents to suppress stress responses without jeopardizing airway safety [43]. Airway management is challenging, as children's airways are smaller and more prone to collapse during sedation [39; 41;]. In a study involving over five thousand children undergoing general anesthesia without intravenous access, Hung and co-authors found a significantly higher frequency of airway complications compared to cases with pre-anesthesia intravenous access [43]. Laryngospasm, desaturation, or coughing endanger ventilation and cause immediate IOP changes [34]. These conditions highlight the need for gradual induction and low stimulation levels in pediatric ophthalmic surgery [50]. Children display various postoperative behavioral patterns directly linked to the anesthetic regimen. In young children, particularly after sevoflurane anesthesia, the likelihood of emergence agitation is higher [28]. Chen and co-authors demonstrated that agitation frequency is elevated in children undergoing strabismus surgery when volatile anesthetics are the primary method [29]. This state complicates recovery and heightens risks of accidental eye trauma, IOP increase, and inadvertent suture removal [44]. The MASK study also indicated that repeated or prolonged general anesthesia exposure may have non-clinical effects on neurocognitive development in early childhood, supporting the use of stable and effective anesthetic regimens that minimize overall anesthesia exposure [46]. These behavioral and physiological features form a complex anesthetic landscape [50]. Thus, pediatric ophthalmic surgery requires control of stable anesthesia depth with minimal stress response, airway dynamics, and hemodynamic variability [48]. The field of pediatric anesthesia demands a profound understanding of children's unique physiological characteristics and how these influence the pharmacokinetics and pharmacodynamics of anesthetic agents [33; 39;]. From an anesthesia perspective, children are not merely small adults; their respiratory, cardiovascular, and metabolic systems exhibit high variability and low physiological reserves [19]. These differences impact every stage of anesthesia, from induction to emergence [37]. Key sources in this area emphasize that the immaturity of structures in infants and young children poses specific challenges in anesthesia, requiring approaches that anticipate rapid changes in ventilation, hemodynamics, and drug effects [33; 39;]. Research on modern anesthesia in pediatric settings highlights the need to account for the patient's developmental stage when devising drug dosages and monitoring plans, noting that simply scaling adult models by weight is insufficient [19]. Comprehending these theoretical foundations establishes the groundwork for safe and effective anesthesia management in pediatric ophthalmic surgery [48]. In preterm infants, respiratory, cardiovascular, and metabolic characteristics differ from those of full-term infants [25]. Children's anatomical and physiological traits predispose them to sudden and severe respiratory changes during anesthesia [24]. Their airways are smaller and less flexible, with the tongue and occiput occupying a larger proportion relative to head and neck size [33]. These features increase the risk of airway obstruction during sedation and induction [43]. According to Cote and co-authors (2018), the larynx in children is positioned higher and more anteriorly, complicating laryngoscopy and elevating desaturation risk during airway manipulation [33]. In infants, diaphragmatic breathing is the primary mechanism, and respiratory center disruption can lead to hypoventilation or apnea [39]. Young children have higher oxygen consumption and lower functional residual capacity, resulting in faster desaturation than adults under anesthesia [24]. Children's cardiovascular physiology markedly differs from adults...[truncated 4215 characters]... These safety advantages are particularly important in pediatric ophthalmic surgery, where managing anesthesia depth and recovery stability are key factors [42].

The aforementioned findings indicate that pediatric anesthesia safety cannot be achieved merely by applying adult standards. It relies on integrating developmental physiology, vigilant monitoring, tailored pharmacological interventions, and sensitivity to social and cognitive risk factors [41; 42;]. The application of these principles forms the foundation for safe anesthesia practices in children undergoing pediatric ophthalmic surgery [48]. Children's heightened pharmacodynamic sensitivity to many anesthetic agents is explained by central nervous system immaturity, differences in receptor density, and alterations in neurotransmitter systems [19; 46;]. In pediatric patients, lower doses of volatile anesthetics are typically required to achieve equivalent anesthesia depth, yet children are more susceptible to emergence agitation and hemodynamic lability [28; 44;]. Chidambaran and colleagues (2023) note that propofol serves as a stable induction agent due to its rapid onset and recovery in children, but it may induce deeper cardiovascular depression in young patients [32]. These observations confirm that pharmacodynamic responses vary by developmental stage [19]. Children's pharmacokinetic profiles significantly differ from those of adults. According to Anderson and colleagues (2020), clearance and distribution volume change rapidly in early life, affecting drug onset and offset [19]. Clearance of agents like propofol is higher in infants due to elevated hepatic blood flow, whereas clearance of other drugs is lower owing to immature metabolic pathways [32]. This situation compels anesthesiologists to employ age-specific dosing regimens and dynamic titration beyond weight-based calculations [48]. Kaye and colleagues (2017, 2020) provide a detailed description of pediatric anesthetic pharmacological behaviors, emphasizing that minor dose variations can produce significant effects [46; 47;]. Local anesthetics also exhibit different effects in children. According to Oda (2024), the absorption rate of local anesthetics in children differs from adults, and due to variations in protein binding and systemic distribution, there is a higher likelihood of rapidly reaching toxic plasma concentrations [40]. This risk heightens the need for strict dose monitoring and close surveillance of systemic toxicity [11]. In general, pharmacological literature demonstrates children's particular vulnerability to anesthetic agents due to physiological developmental features and age-specific pharmacokinetic profiles [42; 46;]. All these changes underscore the necessity for cautious dosing approaches, customized drug selection, and ongoing adaptation of anesthesia practices to developmental stages [37].

Pediatric anesthesia relies on rigorous assessment, age-appropriate monitoring, and evidence-based standards for perioperative evaluation [45]. The American Society of Anesthesiologists (ASA) physical status classification is a useful baseline risk assessment tool, but in children, deeper consideration of developmental, congenital, and airway-related conditions is essential [33]. According to Cote and colleagues (2024), preoperative evaluations for many pediatric patients should be more detailed than those for adults, as certain minor physiological changes hold high significance from an anesthesia perspective [34]. The primary means of enhancing pediatric anesthesia safety is continuous monitoring. Standard monitoring includes pulse oximetry, capnography, electrocardiography, and non-invasive blood pressure measurement, but given the high physiological variability in children, more sensitive monitoring of respiration and hemodynamics is required [37]. As Veyckemans (2023) emphasizes, extubation is a stage demanding special attention in children, where failure to pre-assess airway swelling, secretions, or reflexes can result in serious complications [33]. Ophthalmic surgery amplifies these risks, as manipulations of ocular structures can trigger reflexes affecting airway stability [43]. Global safety programs demand systemic changes in pediatric anesthesia practice. Warner and colleagues (2022) highlight the priority of perioperative safety, noting that children's physiology is intolerant to errors and that deficiencies in specialized equipment and preparation elevate risks for them [47]. Baetzel and colleagues (2019) demonstrate that the "adultification" of Black children in pediatric anesthesia clinics is a factor impacting safety, with implicit bias leading clinicians to overlook child-specific vulnerabilities in risk assessment despite older age [21]. This confirms the need for objective assessments aligned with physiological and developmental stages rather than subjective criteria [19].

The aforementioned results indicate that pediatric anesthesia safety cannot be achieved merely by applying adult standards. It relies on integrating developmental physiology, vigilant monitoring, tailored pharmacological interventions, and sensitivity to social and cognitive risk factors [41; 42;]. The application of these principles forms the foundation for safe anesthesia practices in children undergoing pediatric ophthalmic surgery [48]. The analysis also uncovers significant gaps in the existing literature [21]. While many studies have examined general physiological responses in children, research on the impact of specific anesthesia agent combinations on IOP dynamics in ophthalmic surgery is highly limited [14]. Most existing works are confined to individual agents, short procedures, or even non-ophthalmic populations, narrowing the scope for broad application of their findings [41]. Furthermore, clinical data comparing dexmedetomidine-enriched anesthesia regimens with traditional inhalation or intravenous approaches in children with congenital eye pathologies are insufficient [42]. Another gap relates to the scarcity of studies examining stress hormone responses during induction, airway manipulations, and the emergence period in conjunction with IOP changes [44]. These gaps indicate that numerous issues remain to be explored in the field of pediatric ophthalmic anesthesia [35].

There is a need to address these gaps [37]. Systematic investigation of hemodynamic reactions, IOP changes, and stress hormone indicators in children undergoing ophthalmic surgery fills the missing clinical foundation in the literature [38]. Such studies provide clinically relevant information for anesthesiologists and ophthalmologists dealing with congenital eye diseases. This information aids in developing evidence-based guidelines for practical application, enhances procedural safety, reduces perioperative complications, and improves surgical outcomes [48]. Thus, this review establishes a robust scientific basis for prospective controlled studies examining the impact of various anesthesia methods—including dexmedetomidine-enhanced approaches—on intraoperative and postoperative physiology in pediatric ophthalmic surgery [50].

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