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Cataract Surgery in the Small Adult Eye: A Review

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ABSTRACT

Modern cataract surgery continues to advance, yet intraocular lens (IOL) based surgery in the small adult eye remains challenging. Thorough preoperative assessment and surgical preparation optimise postoperative outcomes in these cases. Advances in IOL power calculation, including artificial intelligence-driven formulas, improve accuracy; however, careful consideration of biometry and IOL power selection is still necessary because inaccuracies can produce significant errors. Limited availability of high-powered IOLs to fully correct high refractive errors may necessitate further intervention. Surgical techniques have evolved to address the unique anatomical challenges of small eyes, improving safety and outcomes. Knowledge of the potential risks inherent in these cases can assist the surgeon in modifying the operative technique accordingly. This review discusses essential preoperative assessments, IOL power selection, surgical techniques, and potential complications, offering guidance for surgeons performing cataract surgery on small adult eyes.

1 | Introduction

Modern cataract surgery is one of the most common surgical procedures globally, with approximately 20 million surgeries conducted annually, [1] a number that is increasing at a compound annual rate of 3.1% [2]. Advances in biometry, intraocular lens (IOL) technology, and surgical techniques have led to consistently excellent visual outcomes, providing high levels of unaided postoperative vision and patient satisfaction. The increasing trend of cataract surgery being performed as a refractive procedure emphasises the critical importance of surgical precision in achieving optimal results [3, 4]. However, cataract surgery in small eyes presents unique challenges. Anatomical variations, including shorter axial lengths and shallower anterior chambers, complicate surgical procedures and refractive outcomes [5–7]. These anatomical features increase the risk of errors in IOL power calculations, as small shifts in effective lens position (ELP) can significantly affect refractive accuracy. Although advancements in biometry methodologies, including artificial intelligence, have improved outcomes for small eyes, accurate IOL power selection and surgical techniques remain critical in small eyes [8]. Small eyes are also associated with higher rates of intraoperative and postoperative complications [9] and often require more intensive and prolonged postoperative follow-up. This review provides an update on the literature regarding cataract surgery in the small eye, focusing on:

- The anatomical and refractive challenges associated with small eyes.
- Preoperative assessments and surgical planning.
- Biometry issues, formula and IOL power selection.
- Key surgical strategies.
- Potential intraoperative and postoperative complications.
- Surgery outcomes.

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This review aims to equip surgeons with the tools and strategies necessary to navigate the complexities of cataract surgery in small adult eyes.

2 | The Small Adult Eye

Short eyes include classifications such as simple or complex microphthalmos, nanophthalmos and relative anterior microphthalmos, each presenting with variations in clinical features. Simple microphthalmos is defined as an eye with an axial length more than two standard deviations smaller than age-matched normal eyes; however, historically, a range of axial lengths has been reported, including shorter than 20, 20.5 or 21 mm [10, 11]. Eyes with simple microphthalmos also have a normal anterior chamber depth and scleral thickness, with no other abnormalities. Complex microphthalmos refers to eyes with a short axial length and normal anterior chamber but exhibit coexisting abnormalities. Relative anterior microphthalmos is characterised by a normal axial length but a smaller anterior segment (< 2.2 mm) and a smaller cornea (< 11.0 mm) with no other abnormalities [5, 12]. Relative anterior microphthalmos has a prevalence of approximately 6% [13]. An extremely rare subtype of microphthalmos is posterior microphthalmos, where the anterior segment measurements are normal, but the posterior segment is shorter [11, 14].

Nanophthalmos is characterised by a short axial length, a smaller anterior chamber, and thickened choroid and sclera [10]. An anterior chamber of < 2.2 mm and a scleral and choroidal thickness of > 1.7 mm have been suggested in the definition of nanophthalmos [15]. There is no definitive axial length for nanophthalmos, with various studies suggesting a cut-off ranging from 17 to 20.5 mm [5, 10, 15–17]. The incidence of nanophthalmos varies between populations, with a prevalence of 0.0009% in the Asian population and up to 0.017% in the British population [15].

3 | Associated Comorbidities With Small Eyes

Complex microphthalmos is associated with anterior segment dysgenesis, retinal dysplasia and persistent fetal vasculature [10, 18]. Iris or retinochoroidal colobomas may also be present with microphthalmic eyes [11]. In nanophthalmos eyes, the sclera is often weakened despite being thicker and may impact the vortex venous drainage system [15]. The crystalline lens thickness can be normal or enlarged in nanophthalmic eyes. Yang et al. [10] outline that the lens-to-eyeball volume ratio can be significantly increased in small eyes, even in cases with a normal lens thickness. Microcornea is a finding that may present in microphthalmic or nanophthalmic eyes and is defined as a corneal diameter < 11 mm [10, 15, 19].

High hyperopia is inherently caused by the short axial length and increased lens-to-eyeball volume ratio characteristic of small eyes [20]. This results in the image being formed behind the retina, leading to high refractive errors in many cases. Consequently, a well-recognised comorbidity in short eyes is amblyopia [21]. A study [22] found that 64.3% of children with nanophthalmos had amblyopia, with another study reporting amblyopia as the leading cause of visual impairment (67%) in 75 children with nanophthalmos [23]. It is important to note the presence of amblyopia preoperatively to help surgeons select the appropriate IOL and to ensure proper counselling of patients regarding reduced visual acuity due to amblyopia and that reduced visual acuity will persist postoperatively [11]. Eyes with short axial lengths more commonly present with open or closed angle glaucoma [24–27]. Due to the shorter axial length, shallower anterior chamber, and normal crystalline lens size, the eye is more crowded, increasing the risk of angle closure glaucoma [28]. This risk increases further as the crystalline lens grows with age, causing the anterior chamber to become even shallower [20]. A study found that 67.7% of nanophthalmic eyes had angle-closure, and 35.7% had angle closure glaucoma [24]. Furthermore, pseudoexfoliation has been reported to be associated with smaller eyes and narrower anterior chambers, [29] which may further elevate the risk of glaucoma. Day et al. [30] reported a higher incidence of brunescent/white/mature cataracts in short eyes when compared to medium and long eyes, further increasing the risk of glaucoma. Additionally, the presence of synechiae has been reported to significantly increase the odds of developing glaucoma [24].

Fuchs' endothelial dystrophy may also be more common in small eyes [11]. The small anterior chamber often associated with these eyes can lead to a higher risk of endothelial cell loss. A study [31] comparing the endothelial cell loss in nanophthalmic eyes found that eyes with anterior chamber depth < 2.5 mm exhibited a significantly higher percentage of endothelial cell loss, highlighting the need for careful intraoperative management.

4 | Preoperative Assessment

Thorough preoperative assessment is crucial in cases involving small axial lengths [11, 15] as it helps identify co-existing comorbidities and determines more challenging cases with a higher risk of complication. Hoffman et al. [11] outline that assessment of refractive error and corrected visual acuity is essential for evaluating hyperopia, anisometropia and the presence of any amblyopia. This allows thorough discussion with the patient and management of postoperative visual expectations.

Assessment of the cornea, including the corneal endothelium, is warranted because eyes with small axial lengths are at increased risk of endothelial cell loss [11]. Additionally, anterior chamber measurement is required to detect potential angle closure. Gonioscopy or anterior OCT may be required if angle closure is suspected, and gonioscopy can also detect peripheral anterior synechiae [15]. Niazi et al. [13] outline the importance of assessment and documentation of intraocular pressure (IOP), along with evaluation of the anterior chamber depth and synechiae, as these can be indicators of anterior segment dysgenesis, which may subsequently lead to increased high IOPs and glaucoma.

Careful retinal examination to detect potential associated abnormalities that could impact postoperative visual acuity is required. Further scanning techniques such as B-scan ultrasound and enhanced depth imaging optical coherence tomography (EDI-OCT) are advisable if there is suspicion of choroidal effusion or choroidal folds [15, 32]. Ultrasound biomicroscopy can help detect thickened sclera, which is associated with nanophthalmos and a large crystalline lens [11, 19].

Elhusseiny and Sallam [15] outline that assessment of the pupil is important to assess for pseudoexfoliation syndrome and to ensure adequate pupil dilation. However, pupil dilation may not be advisable in cases at risk of angle closure and where the angle appears occludable on slit lamp examination. If the macula can be assessed through an undilated pupil, it may not be necessary to dilate the pupil. Additionally, further investigation of the retina can be achieved in these cases, with ultra-widefield (UWF) retinal imaging systems, such as the Optos (Optos Inc., Dunfermline, UK), EDI-OCT or B-scan ultrasound.

Furthermore, Hoffman et al. [11] outline that anterior chamber depth measurement is an important measurement for surgical planning. A shallower anterior chamber may present challenges during surgery by limiting space for surgical manoeuvres, highlighting the need for careful consideration in these cases. Anterior segment assessment can be enhanced by the use of detailed measurements utilising Scheimpflug imaging, such as the Pentacam (Oculus Optikgerate GmbH), where detailed imaging of the anterior chamber depth, volume and the crystalline lens can be achieved.

It is clear that comprehensive preoperative assessment is required for identifying comorbidities and managing the increased risk of complications in eyes with small axial lengths.

5 | Biometry

Modern biometry machines and IOL power calculation formulas produce high refractive accuracy across different IOL designs [33–35]. Biometry error more frequently occurs with short (< 22 mm) or long (> 26 mm) axial lengths, although accuracy in longer eyes has improved with adjustments to axial length measurements [36–38]. Accurate biometry assessment and IOL power selection are critical to optimise refractive accuracy in eyes with small axial lengths, especially with an increase in modern cataract surgery being utilised as a refractive procedure.

Two of the main sources of error in biometry are inaccuracies of axial length and keratometry measurements, as well as preoperative estimation of ELP [39]. In small eyes, these sources of error can significantly impact refractive outcomes and result in greater prediction errors. Gao et al. [40] summarise that eyes with short axial lengths have a higher likelihood of larger postoperative absolute errors compared to those with normal axial lengths (0.31 to 0.76 D compared to 0.24 to 0.46 D), and a lower percentage of eyes within ±0.50 D. The error caused by measurement inaccuracies in short eyes can be magnified due to both the anatomical and optical characteristics of hyperopic eyes, which make them distinct due to the compact nature of the anterior segment. Short eyes often have steeper corneas [41, 42], which can distort keratometry readings, and inconsistencies in axial length measurements can be caused due to deviation in retinal focus. Therefore, hyperopic eyes amplify the impact of measurement errors, and this poses challenges in achieving optimal postoperative refractive outcomes [43]. The estimation of the ELP, which is a critical determinant of postoperative refractive outcomes, is less accurate in shorter eyes due to the reliance on regression-based constants [44–46]. Therefore, predicting postoperative refractive outcomes is particularly challenging in small eyes due to the limitations of traditional IOL power calculation formulas, which may fail to accurately account for shorter axial lengths and altered anterior segment anatomy. Norrby [39] found that inaccurate prediction of ELP contributed to biometry error in 35% of cases, and inaccuracies in measurements contributed to 17%. It has been reported that a difference of 1 mm from the predicted ELP produces a 1.25 D shift in refractive error [26, 47]. Additionally, due to the high-powered IOLs often required for short eyes, a slight variation in postoperative IOL position from the estimated position can lead to significant refractive error, much greater than that produced in lower-powered IOLs [48]. Error in refractive outcomes may also be further influenced by inaccurate labelling of IOL powers, with a study reporting the actual power of an IOL may vary as much as ±1.0 D [49]. Thankfully, most IOL companies, however, claim that their accuracy in the delivered power is within 0.5D (personal discussions).

Numerous IOL power calculation formulas have been developed and are now being utilised in the clinical setting [50]. Newer formulas have evolved from vergence formulas to more complex theoretical mathematical derivations, artificial intelligence, modern regression models and ray tracing. Artificial intelligence is increasingly applied in ophthalmology and is expected to be incorporated more in the future. It is being utilised for screening and grading of various different ocular conditions, including keratoconus, glaucoma, age-related macular degeneration, diabetic retinopathy and retinopathy of prematurity [8, 51, 52] and its use is likely to continue to grow as algorithms advance and accuracy improves [8]. Artificial intelligence has now also been introduced into the calculation of IOL powers and is incorporated into the biometry formula. Artificial intelligence may help prediction accuracy in atypical eyes, such as eyes with smaller axial lengths or shallow anterior chambers [8]. Artificial intelligence-driven formulas, which employ further parameters including new biometry measurements as well as patients' anatomical, physiological and socio-demographics, could help improve accuracy for small eyes. Machine learning approaches are particularly promising, as they can account for the complex interplay of biometric variables and patient-specific factors. Such formulas include the Hill-radial basis function, which is a pure artificial intelligence formula; the Ladas Super formula; or the Kane formula, which are thin lens vergence formulas and also utilise artificial intelligence [53, 54]. Another advancement in biometry methodology is the use of ray tracing. Savini et al. [50] explain that ray tracing calculates the path of light rays based upon Snell's law at each interface and the refractive index of each dioptre. An example of a ray tracing formula is the Olsen formula [55].

Despite these advancements, no single formula has been universally accepted as the best for small eyes. Accurate IOL power calculation is crucial and therefore various studies have investigated the accuracy of different formulas in small eyes. Gao et al. [40] found the Kane formula to be the most accurate in eyes with axial lengths shorter than 22 mm. This is in agreement with a study by Darcy et al. [56] who found that the Kane formula had the lowest mean absolute prediction error in eyes with axial lengths ≤ 22 mm, followed by Hill-RBF and Olsen. Similarly, a study that compared formula accuracy in eyes implanted with an IOL power of 30 D or greater showed that the Kane formula had a statistically significantly lower prediction error compared to the other studied formulas, except for the EVO 2.0 formula [57]. This is further seen in a study which included eyes with an axial length ≤ 22 mm where the VRF-G, Haigis and Kane formulas performed with the highest accuracy [58]. The Kane formula appears to be a top performer and Gao et al. [40] advise in their recent article to use the Kane formula in short eyes. However, other studies show that different formulas are more accurate for short eyes. A review which conducted a meta-analysis of 14 studies to compare 13 formulas concluded that artificial intelligence and ray-tracing formulas are more accurate than vergence formulas, and the Pearl-DGS and Okulix formulas were the two most accurate formulas for short eyes (axial length ≤ 22 mm) [43]. Gokce et al. [59] also reported the lowest mean absolute prediction error with the Hill-RBF formula. A recent study found that the Zeiss-artificial intelligence formula was most accurate and performed better than the Kane formula [60]. It appears that there is no general consensus on which formulas perform best for short eyes, again highlighted by some studies displaying no statistically significant difference across biometry formula accuracy [61–63]. The recent study Gao et al. [40] previously mentioned also outlines that most biometry accuracy studies categorise eyes based upon either axial length or anterior chamber depth; however, eyes with short axial lengths may have a relatively deeper anterior chamber depth [41]. Therefore, their study assessed accuracy in eyes with short axial lengths and deeper anterior chamber depths and found Pearl-DGS to be the superior formula [40] Further investigation into different eye shapes is required.

Recent studies show variable conclusions regarding the best formula for small eyes, with studies reporting a significant difference and others no significant difference between formulae. It remains uncertain which formula clinicians should use. Furthermore, it is important to determine if the differences reported are clinically meaningful. Table 1 summarises the outcomes of some aforementioned biometry comparison studies and also presents the clinical relevance of the findings. Often, no measurable clinical difference is observed in biometry comparison studies (Table 1) and therefore the formulas which are presented as the top performers may not significantly improve clinical outcomes. The other aspect is that most studies eliminate the mean error in the studies and subsequently, this may also eliminate any demonstrable true 'clinical difference' between formulae.

In many biometry formula comparison studies, the optimised formula constants are utilised and the mean prediction error 'zeroed out' [66, 67]. The zeroing out of prediction error cannot be performed for machine learning formulas, and therefore machine learning formulas cannot be included in comparative studies across different categories of formulas. The authors of this current review also believe the zeroing out of prediction error does not provide real-life clinical outcomes [68]. The use of a training set to optimise formula constants, which is then applied to a test/study set, would produce more real-life clinical outcomes and, therefore, more meaningful analysis. This methodology, as used by Kane and Melles [57], offers more applicable insights into real-world outcomes. It is important to be aware of the methodology utilised in biometry studies to ensure a full understanding of the published results, which can then be appropriately applied to the clinical setting. The authors of this review believe that to achieve the most clinically relevant and meaningful comparisons, a training set should be used to optimise constants and then applied to a study set.

While most biometry accuracy studies enrol eyes with an axial length of ≤ 22 mm [58, 69] microphthalmos eyes are often reported to have an axial length < 21 mm. It is important to note the axial length inclusion criteria of published articles. A study [70] which did use a smaller axial length limit of < 20 mm for the nanophthalmos and relative anterior microphthalmos found that the Haigis formula was the most accurate.

Constant optimisation is crucial for improving refractive accuracy results and is of particular importance with extreme axial lengths. Third-generation formulas (HofferQ, Hollday 1 and SRK/T) have been observed to produce significant deviations from the mean IOL constant in extreme axial lengths [71] highlighting that consideration of constant estimation for a specific axial length group may be warranted. However, formulas such as Haigis overcome the potential error across axial lengths by having three IOL constants [71]. Sheard outlines that if a formula is to be utilised on eyes within a restricted axial length range, the formula should therefore be optimised on eyes that are also within this selected range [72]. This concept is similar to the MM formula, which has been created and devised by the authors [44] whereby multiple potential a-constants are created based upon particular ocular 'types' defined by the machine learning algorithm to predict ELP and are constantly automatically updated and optimised based upon ongoing refractive results per each IOL type. Accurate measurement of axial length is required, and the use of the most accurate biometry instruments is important. Modern biometry instruments, such as those using partial coherence interferometry, optical low coherence reflectometry and swept source optical coherence tomography, have been found to produce a high level of accuracy and agreement in axial length measurements [73–76].

In summary, there is no definitive consensus on which formula to use for small eyes, and surgeons should carefully consider the available evidence and recognise the potential advances of the latest generation biometry formulae. With the current biometry technology and formula, it appears one can reliably depend on the available formula to provide accurate refractive outcomes, and further improvements in refractive accuracy will be observed as formulas continue to advance. Further research is required to identify the most reliable formula for small eyes.

6 | Intraocular Lens Options

The use of two IOLs in the bag, sulcus or anterior chamber and secondary iris-claw lenses has been reported [13, 77, 78]. It is advisable to implant a single-piece hydrophobic acrylic IOL in small eyes due to the reduced space [11, 15]. The in-the-bag technique has further advantages such as IOL centration, IOL stability and posterior capsule opacification prevention [13]. When using a single IOL approach, a high powered IOL

TABLE 1 | Summary of studies on formula choice in short eyes.

Study	No. of eyes	AL (mm)	Formulas	Conclusion	Clinical relevance in MAE
Kato et al. 2024 [64]	44	≤22.0	BTAL, EVO and BUII	EVO and BTAL formulas showed higher accuracy than BU II	0.42 ± 0.29 D for BUII, 0.36 ± 0.24 D for BTAL, and for EVO 0.31 ± 0.22 D. No measurable clinically significant difference
Kenny et al. 2023 [60]	278	≤22.0	Zeiss AI, BUII, EVO, RBF, Hoffer QST, K6, Kane, Olsen, Pearl-DGS, Haigis, HofferQ, Holladay 1, Holladay 2 and SRK/T	ZEISS AI significantly outperformed BUII, Pearl-DGS, and Kane.	No clinically significant difference between MAE across formula
Taroni et al. 2023 [62]	75	<22.0	HofferQST, BUII, EVO, HofferQ, Kane and RBF	No significant difference in MAE	No statistically significant difference was found a across formula
Stopyra 2022 [65]	62	≤22.0	BUII, Haigis, HofferQ, Holladay 1 Holladay 2, SRK/T	HofferQ gave the lowest MAE with statistically significantly lower MAE than all other formula	Hoffer Q had the lowest (0.09 ± 0.08 D), and Holladay 1 the highest (0.26 ± 0.17 D) MAE. No measurable clinically significant difference between the best and worst
Kane et al. [54]	137	≤22.0	Hill-RBF, FullMonte method, Ladas Super Formula, Holladay 1 and BUII	Holladay had the lowest MAE and MedAE across the different formula for short eyes.	Holladay had the lowest (0.417) and FullMonte the highest (0.513) MAE representing no measurable clinically significant difference
Darcy et al. [56]	766	≤22.0	Kane, Hill-RBF 2.0, Holladay 2, BUII, Olsen, Haigis, Holladay 1, Hoffer Q and SRK/T	Kane formula had the lowest MAE, which was statistically significant compared with all other formulas.	Kane had MAE of 0.441 compared to the highest MAE of 0.493 (Barrett) which does not suggest a clinically significant difference.
Kane et al. [57]	182	Mean 20.82	Kane, EVO 2.0, Haigis, Olsen, Holladay 2, Holladay 1, SRK/T, Hill-RBF 2.0, BUII and Hoffer Q	Kane showed lowest prediction error (statistically significant except compared to EVO 2.0)	The lowest MAE was with Kane formula, however all but two (Barrett and HofferQ) of the formulas were within 0.25D of the MAE for Kane
Voytsekhivskyy et al. [58]	172	≤22.0	BUII, Haigis, Hoffer Q, Holladay 1, Holladay 2, Kane, SRK/T, T2, VRF and VRF-G	The VRF-G, Haigis and Kane were the most accurate	Range of 0.098 in MAE between best and worst performing formula, suggests no clinically significant difference across formula
Gökce et al. [59]	86	<22.1	BUII, Haigis, Hill-RBF, Hoffer Q, Holladay 1, Holladay 2 and Olsen	No statistically significant differences across the formula	Range of 0.10 in MAE between best and worst performing formula
Vilaltella et al. [61]	100	≤22.0	BUII, EVO 2.0, Haigis, Hill RBF 2.0, Hofer Q, Holladay 1 and 2, Kane, SRK/T and SuperLadas	Tendency of the EVO 2.0, the Kane and Hoffer Q formula, however no statistically significant difference was found	No statistically significant difference was found a across formula

Abbreviations: AL, axial length; BTAL, Barrett True AL; BU II, Barrett Universal II; EVO, emmetropia verifying optical; MAE, mean absolute error; MedAE, median absolute error; RBF, radial basis function.

is often required. There are high powered IOLs available up to + 40.0 D, and some manufacturers supply custom-made high powered IOLs. One case report showed good outcomes following bilateral implantation with a +56 D and +58 D IOL in extreme nanophthalmos eyes [79]. Alternatively, surgeons may aim to correct the maximum possible refractive error and then subsequently treat the residual refractive error with laser vision correction or advise spectacle use. Another option is a piggyback IOL, which can be implanted either in the capsular bag or the ciliary sulcus. Good visual outcomes can be achieved with a piggyback IOL [80]. Implantation of a piggyback IOL is recommended in the ciliary sulcus [11] because implantation in the bag can cause interlenticular membrane, hyperopic shifts and reduced visual acuity [81, 82]. In short eyes, the typical approach involves implanting a 1-piece monofocal IOL with a 3-piece monofocal in the ciliary sulcus. While both IOLs can be implanted in one surgery, the preferred methodology is to implant the 1-piece IOL in the bag and then do a second surgery later. This allows the surgeon to assess the outcome of the initial IOL implantation and more accurately calculate the power required for piggyback implantation. If required, it is safe to remove a piggyback IOL some years postoperatively in the presence of a visual issue or complication [13, 83].

7 | Planning for Surgery

Full preoperative discussion and consent are essential prior to any cataract surgery.

Subsequently, patient expectations should be managed carefully, including the potential for refractive surprise and a slower visual recovery. Preoperative counselling should be detailed and make the patient aware that having a small eye can complicate the surgery and produce more prediction errors. The surgeon should consider the type of anaesthesia and the surgical instruments potentially required, and the possible need for additional surgical manoeuvres [11, 15].

8 | Potential Complications

There is a higher risk of both intraoperative and postoperative complications in small eyes [15, 84]. Eyes with an axial length < 20 mm are associated with 15 times higher odds of complications, and eyes with axial length < 19 mm showed 21 times higher odds of any complication [85]. Day et al. reported a statistically significant increased rate of intraoperative complications in short eyes (< 21 mm) when compared to medium and long eyes [30]. A study of 71 eyes with an axial length < 21.0 mm undergoing cataract surgery showed that intraoperative or postoperative complications occurred in 25.4% of eyes [9]. Other previous studies have reported complication rates of 15.5% in nanophthalmos and microphthalmos eyes with a median axial length of 20.65 mm, [85] and 27.9% in 43 nanophthalmos eyes with an axial length ≤ 20.5 mm [86].

Yosar et al. [9] identified the most common complications in eyes with axial lengths < 21.0 mm as iris prolapse, corneal endothelial and/or Descemet membrane trauma, transient severe corneal oedema, and cystoid macular oedema. Nanophthalmic eyes have a higher rate of posterior capsular rupture, with a study reporting an incidence of 11.7% [5]. However, other studies report much lower incidences of 1.4% (1 out of 71 eyes) [9] or no incidence of posterior capsular rupture [85]. Day et al. [30] report little variation in the occurrence of posterior capsular rupture across different axial lengths, with small eyes (< 21 mm) showing a rate of 1.53%, 1.4% in medium eyes (21 to 28 mm), and 1.61% in long eyes (> 28 mm).

Endothelial cell loss is another potential complication, with small eyes being more prone due to the crowding of the small eye. A comparison of nanophthalmos, relative anterior microphthalmos eyes and a normal control group showed that corneal oedema is common, with a higher rate of oedema seen in nanophthalmos and relative anterior microphthalmos eyes [5]. The same study reported a greater rate of cell loss in nanophthalmos eyes compared to a normal control group; however, the difference was not statistically significant [5]. Nanophthalmic eyes with an anterior chamber depth of < 2.5 mm have shown a higher rate of cell loss [31]. Day et al. [30] reported significantly more corneal oedema in eyes with an axial length < 21 mm.

Uveitis is another common complication in small eyes. An extensive National Ophthalmology database study [30] found that 1.7% of eyes with an axial length < 21 mm experienced uveitis/synechiae, which is greater than that found with axial lengths of 21–28 and > 28 mm. However, another study found no statistically significant difference in anterior segment inflammation between nanophthalmos eyes, relative anterior microphthalmos eyes and normal eyes [5]. Day et al. report that 4 eyes of 103 nanophthalmic eyes had severe anterior uveitis [85] with all eyes resolving with topical steroid treatment.

There can be an increased likelihood of uveal effusion in small eyes [86, 87]. It is thought that impaired vortex venous drainage creates choroidal congestion leading to uveal effusion [88]. One study reported uveal effusion as the most common complication with an incidence of 9.3% in 43 nanophthalmic eyes [86]. However, the risk of uveal effusion appears to be low in modern cataract surgery, with another study reporting 3 out of 103 eyes having small uveal effusions only [85] and other studies reporting no incidence [5, 89].

Steijins et al. [86] report a rate of 4.7% for angle closure glaucoma after cataract surgery, and Jung et al. [5] reported significantly more cases of elevated IOP in nanophthalmic eyes when compared to normal eyes. However, no cases of acute angle-closure glaucoma have been reported in 71 nanophthalmos eyes with a preoperative axial length of < 21 mm [9]. A study of extreme microphthalmos found that 33% of eyes in a 30-eye study had glaucoma after cataract surgery, and the odds of glaucoma postoperatively were 6 times higher in eyes with an anterior chamber < 1.5 mm compared to eyes with an anterior chamber > 1.5 mm [78]. Hoffmann et al. [11] outline that a shallow or flat anterior chamber postoperatively could signify aqueous misdirection with the possibility of progression to malignant glaucoma. They also mention that ultrasound biometry can be used to differentiate between aqueous misdirection and secondary acute angle closure glaucoma caused by peripheral uveal effusions [11].

Other common reported complications are iris prolapse [9, 30] due to poor pupil dilation and proximity of iris to the cornea [9] and cystoid macular oedema [9, 26].

To aid the presentation of complications, the findings from some of the studies discussed are summarised in Table 2.

Despite the increased likelihood of complications, cataract surgery in small eyes has been shown to be safe, with low rates of complications. Carifi et al. [90] reported a retrospective case series of 47 short eyes with an axial length < 20.9 mm, where 90% of eyes encountered no complications. Similarly, a study of 71 eyes with an axial length < 21 mm found that 74.6% of eyes had no complications [9]. In a study by Cayatopa et al. [92] which evaluated the outcomes of central pars plana vitrectomy with phacoemulsification and IOL implantation in patients with small eyes, cataract and narrow anterior chambers. The study included eyes with an axial length < 22 mm and an anterior chamber depth < 2.0 mm and found only one complication in the 89 eyes included, demonstrating the safety and efficacy of the procedure.

TABLE 2 | Summary of complications found in short eyes in previous studies.

Study	No. of eyes	AL (mm)	Intraoperative complications	Eyes/cases
Day et al. [85]	103	< 21.0	– 1 broken IOL – 2 IOL exchange for ametropia – 2 zonular weakness only – 3 zonular dehiscence and aqueous misdirection – 4 severe postoperative uveitis – 3 aqueous misdirection – 1 aqueous misdirection and symptomatic choroidal effusion	16
Jung et al. [5]	17	< 20.5	– 2 posterior capsule rupture – 1 broken IOL – 3 severe postoperative uveitis – 2 elevated IOP – 1 severe corneal oedema at 2 months	9
Yosar et al. [9]	71	< 21.0	– Iris prolapse, corneal endothelial and/or descemet membrane trauma, transient severe corneal oedema and cystoid macular oedema (CMO) occurred in 15 eyes – 3 additional surgical interventions due to complications	18
Lai et al. [88]	14	≤ 20.5	– None reported	—
Steijin et al. [86]	43	≤ 20.5	– 2 capsular defect without loss of lens fragments – 1 capsular defect with loss of lens fragments – 2 angle-closure glaucoma – 2 retained lens material – 1 severe iritis – 2 corneal decompensation – 2 anterior capsular phimosis – 3 uveal effusion without serous retinal detachment – 1 uveal effusion with serous retinal detachment – 3 CMO	19
Carifi et al. [90]	39	< 20.9	– 1 iris prolapse with iris trauma – 1 endothelial corneal touch – 1 retinal detachment – 2 marked postoperative inflammation – 1 chronic cystoid macular oedema	6
Rajendrababu et al. [91]	31	< 20.5	– 1 iridodialysis – 3 posterior capsular tear – 1 rhexis extension – 1 zonular dialysis – 1 persistent corneal edema – 1 anterior capsular phimosis – 1 aqueous misdirection – 4 choroidal effusion – 1 fibrin membrane	14

Thus, while cataract surgery in small eyes is challenging, it can be performed safely with low intraoperative and postoperative complication rates.

9 | Surgical Considerations

Operating on a small eye can create difficulties at every step of the surgical procedure and therefore needs to be carefully planned [92]. The crowded eye and often deeper-set eye can increase the difficulty of surgery. Strategies and surgical techniques to improve access can help overcome these challenges [15]. Access can be optimised using peribulbar or retrobulbar anaesthesia, which pushes forward the globe. Additionally, operating temporal to the patient and placing the incision near the limbus can further enhance access [11, 15]. Vitreous tap using needle aspiration has been reported to be a safe technique for managing narrow anterior chambers during cataract surgery, with no associated complications reported [93].

A study has outlined that the risk of uveal effusion can be reduced by sclerostomy prior to surgery or intraoperatively [91]. Furthermore, IOP control can prevent uveal effusion and suprachoroidal bleeding [13, 24] Niazi et al. [13] outline that effusion should be suspected if there is an increase in IOP and a sudden decrease in anterior chamber depth, and inferior sclerectomies can be performed at the end of the surgery. Alternatively, the wounds should be closed and surgery deferred.

It is recommended to protect the corneal endothelium to minimise significant cell loss. Ophthalmic viscoelastic devices (OVD) with higher viscosity can be used to push back the lens–iris diaphragm, creating more operating space. Additionally, preoperative 20% mannitol can be utilised 30 min prior to surgery to reduce vitreous volume in more severe cases [11, 15, 86].

The softshell technique utilises both dispersive and cohesive OVD to protect the endothelium and increase anterior chamber depth [94, 95]. Chia-Wen Hsiao et al. [96] recently published a systematic review and meta-analysis which concluded that OVDs composed of chondroitin sulfate–hyaluronic result in less endothelial cell loss and may offer better protection to the corneal endothelium during cataract surgery compared to other OVDs.

Due to the higher risk of residual refractive error and the potential requirement for a piggyback IOL, careful surgery to ensure initial IOL implantation into the bag is important. Care is required to ensure that the IOL fully enters the bag with both haptics because it is easy to inadvertently have one haptic inside the bag and another outside in such a small anterior chamber space.

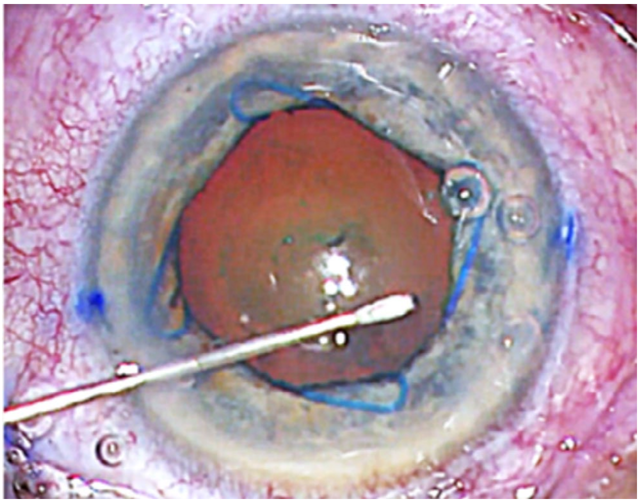

FIGURE 1 | Malyugin ring.

The authors of this review article suggest that preoperative 20% mannitol, OVD, use of the Malyugin ring (Figure 1) or iris hooks, and low flow settings will in the vast majority of cases allow safe cataract surgery to be completed on the small eye, without the need for more invasive sclerotomy or pars plana vitrectomy. In the small eye, entering the vitreous through the pars plana to perform an anterior vitrectomy can result in complications due to potential anomalous positioning of traditional external anatomical landmarks compared to internal positions of both the posterior crystalline lens and the anterior extremity of the retina, particularly in very short eyes.

General tips for managing these cases:

- Potential preoperative mannitol.
- A slightly longer corneal incision to prevent iris prolapse; if iris prolapse starts to occur, be prepared to change the incision site and make a longer, more anterior section.
- Judicious use of intracameral phenylephrine.
- Softshell viscoelastic approach.
- Use a Malyugin ring with a smaller diameter if possible, or if this is not possible, use iris hooks.
- Lower flow phacoemulsification and irrigation & aspiration.

10 | Visual and Refractive Outcomes

Biometry accuracy in modern lens-based surgery is generally high; however, residual refractive error occurs more frequently in small eyes compared to eyes of normal length. Despite higher complication rates and biometry inaccuracies, many small eyes have cataract surgery safely, resulting in significant visual improvements [90]. A study reported that 74.6% (43 of 71 eyes) of eyes experienced improved vision, with only 3 eyes losing ≥3 Snellen lines [9]. The cause of visual acuity loss was unknown in 2 eyes, while the other eye was left aphakic due to intraoperative zonular dehiscence. Another study assessing 21 eyes with axial lengths ranging from 15.7 to 18 mm showed a statistically significant improvement in mean postoperative spherical equivalent refraction and unaided distance visual acuity [97]. Carifi et al. [90] found that 62% of eyes with a preoperative axial length of <20.9 mm had a postoperative corrected distance visual acuity (CDVA) of 0.3 logMAR or better.

However, it is well established that smaller eyes with short axial lengths have poorer outcomes when compared to eyes with longer axial lengths. Mohammadi et al. [98] retrospectively reviewed hospital records of patients (405 eyes) and categorised eyes as short (<22 mm), normal (22–24.5 mm) or long (>24.5 mm). The study found a significantly lower CDVA of 0.34 logMAR in short eyes compared to 0.17 logMAR in long eyes, highlighting less satisfactory outcomes in short eyes [98]. Another retrospective study showed worse refractive outcomes in eyes with axial length < 22 mm, with a mean refractive error of −0.95 ± 1.91 D in this group, compared to −0.36 ± 0.88 and 0.23 ± 1.15 D in the axial lengths of 22–25 and > 25 mm groups respectively [99].

These findings suggest that while cataract surgery in small eyes is safe and effective, the results may not be as good as in eyes with normal or longer axial lengths.

11 | Refractive Lens Exchange

Refractive lens exchange (RLE) has also demonstrated good efficacy and safety in short eyes. Alió et al. [100] outline that RLE can be considered in hyperopic eyes when patients have presbyopia, increased higher order aberrations or congenital cases who are unable to wear glasses or contact lens correction. To ensure optimal outcomes, an accurate axial length measurement is critical [101].

Preetha et al. [25] studied 20 eyes undergoing RLE with a mean axial length of 20.98 mm (range 18.4 to 22.2 mm) and found that 60% of eyes achieved CDVA better than 0.3 logMAR and 90% were ± 1.00D of the refractive target.

The correction of high hyperopia with multifocal IOLs was shown to provide a comparable range of vision to eyes with low to moderate hyperopia [102]. High hyperopia was defined as eyes implanted with IOL powers between 25 and 36 D, and was compared to eyes receiving IOL powers between 21 and 24.5 D.

In patients receiving bilateral implantation of a diffractive multifocal IOL, distance and near contrast sensitivity were reported to be good and comparable to that found preoperatively with the natural lens. This was a small study of 15 patients implanted bilaterally, and the axial lengths were between20.61 and 23.90 mm [103].

Patients with high hyperopia have also reported high levels of satisfaction after multifocal IOL implantation, with one study reporting that 84% of patients were satisfied and would recommend the procedure to others [104].

RLE to correct hyperopia has been found to minimise HOAs more effectively than LASIK [105]. RLE can be utilised to treat high hyperopia in cases of congenital systemic syndromes and in those who do not tolerate refractive correction through glasses or contact lenses [106].

12 | Conclusion

Cataract surgery in small eyes presents unique challenges but can be performed safely and effectively. Thorough preoperative assessment and planning are required to increase the likelihood of a successful surgery. Surgeons should have an awareness of the comorbidities and potential complications associated with small eyes, and subsequently, knowledge of surgical techniques that may help negate the occurrence of complications and optimise visual outcomes. Advancements in surgical techniques, equipment and IOL power calculations allow excellent postoperative outcomes in small eyes, but careful consideration must still be given to these patients.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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