Ophthalmol Ther (2023) 12:1813–1826
https://doi.org/10.1007/s40123-023-00721-0

REVIEW

Supplemental Toric Intraocular Lenses in the Ciliary Sulcus for Correction of Residual Refractive Astigmatism: A Review

Carlos Rocha-de-Lossada · María García-Lorente · Diego Zamora-de La Cruz · Marina Rodríguez-Calvo-de-Mora · Joaquín Fernández

Received: March 30, 2023 / Accepted: April 17, 2023 / Published online: May 5, 2023

ABSTRACT

Purpose: This study conducted a critical review of the peer-reviewed literature on the use of supplemental toric intraocular lenses (STIOL) in the ciliary sulcus to correct residual refractive astigmatism.

Methods: This review used PubMed as a database from 1 January 2010 to 13 March 2023. According to the inclusion and exclusion criteria defined, 14 articles were selected for the current review.

Results: The data of 155 eyes were analyzed. Most of the studies reviewed had a short follow-up and poor or limited design, including case reports, case series, and retrospective cohorts. The follow-up period ranged from 43 days to 4.5 years. STIOL rotation was the most frequently described complication in the literature, with a mean rotation of 30.48 ± 19.90°. These patients required repositioning in 50 of 155 eyes (32.25%). Moreover, four eyes (2.58%) required scleral fixation sutures and two eyes (1.29%) iris fixation. Other complications were high intraocular pressure (3 eyes, 1.93%), transient corneal edema (2 eyes, 1.29%), corneal decompensation (2 eyes, 1.29%), and pigment dispersion (1 eye, 0.64%). From the total, 57.41% of eyes (89 eyes from 155) achieved within ± 0.50D of target refractive astigmatism. It is important to highlight that at least 52 eyes out of the 155 (33.54%) had an abnormal cornea with irregular astigmatism.

Conclusion: STIOL seem to offer good visual and refractive outcomes. However, STIOL

C. Rocha-de-Lossada (✉) · M. Rodríguez-Calvo-de-Mora · J. Fernández
Ophthalmology Department, Clínica QVision, Vithas Almería, Almería, Spain
e-mail: carlosrochadelossada5@gmail.com

C. Rocha-de-Lossada · M. Rodríguez-Calvo-de-Mora
Ophthalmology Department, Vithas Málaga, Malaga, Spain

C. Rocha-de-Lossada · M. Rodríguez-Calvo-de-Mora
Ophthalmology Department, Hospital Regional Universitario Málaga, Malaga, Spain

C. Rocha-de-Lossada
Departamento de Cirugía, Área de Oftalmología, Universidad de Sevilla, Seville, Spain

M. García-Lorente
Asociación para Evitar la Ceguera en Mexico, Mexico City, Mexico

D. Z. La Cruz
Anterior Segment Department, Instituto de Oftalmología Fundación Conde de Valenciana, Mexico City, Mexico

D. Z. La Cruz
Anterior Segment Department, Hospital Mexiquense de Salud Visual, ISEM, Naucalpan de Juárez, Mexico

showed variable rotational stability, especially in some platforms. Further studies with a more robust design, methodology, and standardized analysis methods are needed to confirm these trends.

Keywords: Astigmatism; Supplemental toric IOL; Piggyback toric IOL; Complementary toric sulcus IOL

Key Summary Points
Supplemental toric intraocular lenses (STIOL) seem to offer good visual acuity and refractive outcomes, decreasing residual refractive astigmatism
STIOL rotation was the most frequently described complication in the literature, with a mean rotation of 30.48 ± 19.90°
STIOL showed variable rotational stability, especially in some platforms
Further studies with a more robust design, methodology, and standardized analysis methods are needed to confirm these trends

INTRODUCTION

Cataract surgery is a cost-effective procedure [1], and nowadays could be considered a refractive surgery with an emmetropic objective [2], especially when it comes to implanting multifocal intraocular lenses (MIOL) [3, 4]. On the one hand, it is well known that the presence of low-to-moderate corneal astigmatism is very common in the population, since two-thirds of candidates for cataract or presbyopia surgery could present with some level of corneal astigmatism, normally between 0.50 D and 1.50 D [5]. This fact has recently been corroborated in a systematic review in which the authors show that the prevalence of astigmatism between 0.50 D and 1.50 D could reach 68%, especially in patients older than 70 years old [6]. On the other hand, it is also known that residual levels of refractive astigmatism can influence postoperative visual acuity (VA) [7], decrease patients' vision-related quality of life, and even hinder productivity among working-age adults, thus posing an economic burden. Therefore, it is worth mentioning that astigmatism correction improves patient's VA and vision-related quality of life [8, 9]. One way to correct astigmatism could be corneal incisions, either through clear corneal incisions, opposite clear corneal incisions, limbal relaxing incisions (LRI), or arcuate keratectomy, either manually or using a femtosecond laser [10]. These techniques have been shown to be safe and moderately effective in corneal astigmatism correction during cataract surgery. Therefore, it is plausible that their use could be effective in patients with residual refractive astigmatism. Nevertheless, toric intraocular lenses (TIOL) have been proven to be the best method of correcting astigmatism during cataract surgery [11, 12]. However, the correction of residual astigmatism in patients who have already undergone surgery with non-toric intraocularf lenses (IOLs) by explanting the IOL and replacing it with a TIOL is a complex procedure not without risk [10]. Another option when it comes to correcting residual refractive astigmatism could be the use of the corneal laser refractive surgery, traditionally called laser corneal enhancement or the insertion of a supplementary toric IOL (STIOL) in the ciliary sulcus. The former option has been shown to achieve satisfactory results [13, 14]. However, this procedure may not be possible in certain circumstances, such as in patients with corneas suspected of developing post-laser ectasia[15] or in certain departments, such as those of some public health systems, that may not have this technology available. It is in this situation that supplementary intraocular lenses could be an ideal option. In fact, supplementary intraocular lenses have been shown to significantly reduce the risk of intraoperative complications compared with IOL replacement within the capsular bag [16].

Previously, our group published a systematic review regarding visual and refractive results, patient satisfaction, and complications of patients operated on with supplementary

multifocal IOLs (SMIOLs), highlighting that SMIOLs could be a valid option in offering good results in terms of VA in different focuses, giving spectacle independence in most patients and generating their satisfaction with generally few complications, as positive dysphotopsias is the complaint most referred to by patients, and pigmentary dispersion, especially in a specific platform, the most described complication [17]. However, little is known about STIOL for the correction of astigmatism, either as a primary or secondary surgical option to achieve emmetropia due to an astigmatic residual refractive error. Although there is a narrative review about the different supplemental intraocular lenses on the market, in which the authors explained their technology (from monofocal to multifocal), different platforms, surgical technique, and limitations [17], to the best of our knowledge, there is no review in the literature that specifically addresses this particular topic; the utility of the STIOL in depth.

The purpose of this article is to review and report the outcomes from the available scientific literature on STIOL, summarizing the data reported regarding the design of the studies included, VA, and complications related to this technology.

METHODS

This review was performed using PubMed as a database from 1 January 2010 to 13 March 2023. An initial search was carried out with the objective of finding case series studies and/or clinical trials that reported refractive and visual results and complications of combined STIOL, whether in multifocal or monofocal version. The data search strategy with Boolean operators was as follows: Complementary toric sulcus intraocular lens OR Secondary toric piggyback OR supplementary toric sulcus IOL OR supplementary toric sulcus intraocular lens OR complementary toric sulcus IOL OR supplementary toric sulcus IOL OR toric add-on IOL OR toric add on intraocular lens OR toric sulcus IOL OR toric sulcus intraocular lens OR toric piggy back IOLS OR toric piggyback intraocular lens OR toric add on IOL OR toric sulcoflex IOL OR toric Supplementary Add-on Intraocular Lens OR toric Supplementary Intraocular Lens NOT multifocal add-on. In total, 14 articles were selected for the current review. The process of this review was summarized in a flowchart diagram in Fig. 1. Inclusion criteria were original articles, clinical trials, case reports, and case series studies including a spherical IOL or MIOL in the capsular bag and a STIOL, monofocal or multifocal. Exclusion criteria were: (1) narrative reviews; (2) artificial eye studies; (3) non-English publications except those in Spanish; (4) animal eye studies; (5) studies that included toric IOL and monofocal IOL implantation as piggyback but with both IOLs in the capsular bag; (6) supplementary non-toric IOL or a STIOL in patients with previous TIOL in the capsular bag since the objective of this study is to evaluate the possible improvement of residual refractive astigmatism in eyes without previously implanted TIOL.; and (7) IOLs implanted in the sulcus not specifically designed for piggyback placement in previously pseudophakic patients.

Articles were selected, reviewed, and discussed by two of the authors (C.R.L. and M.G.L.). Disagreements between C.R.L. and M.G.L. were addressed by a third author (D.Z.C.).

This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

RESULTS

The data of 155 eyes were analyzed. Most of the studies reviewed had a short follow-up and poor or limited design, including case reports, case series, and retrospective cohorts. Demographic patient characteristics, follow-up times, type of STIOL, and time to implantation are reported in Table 1. The follow-up period ranged from 43 days to 4.5 years. The evaluation of rotational stability, VA, refractive outcomes, and complications after implantation of STIOL are presented in Table 2. STIOL rotation was the most frequently described complication in the literature, with mean lens rotation averaging

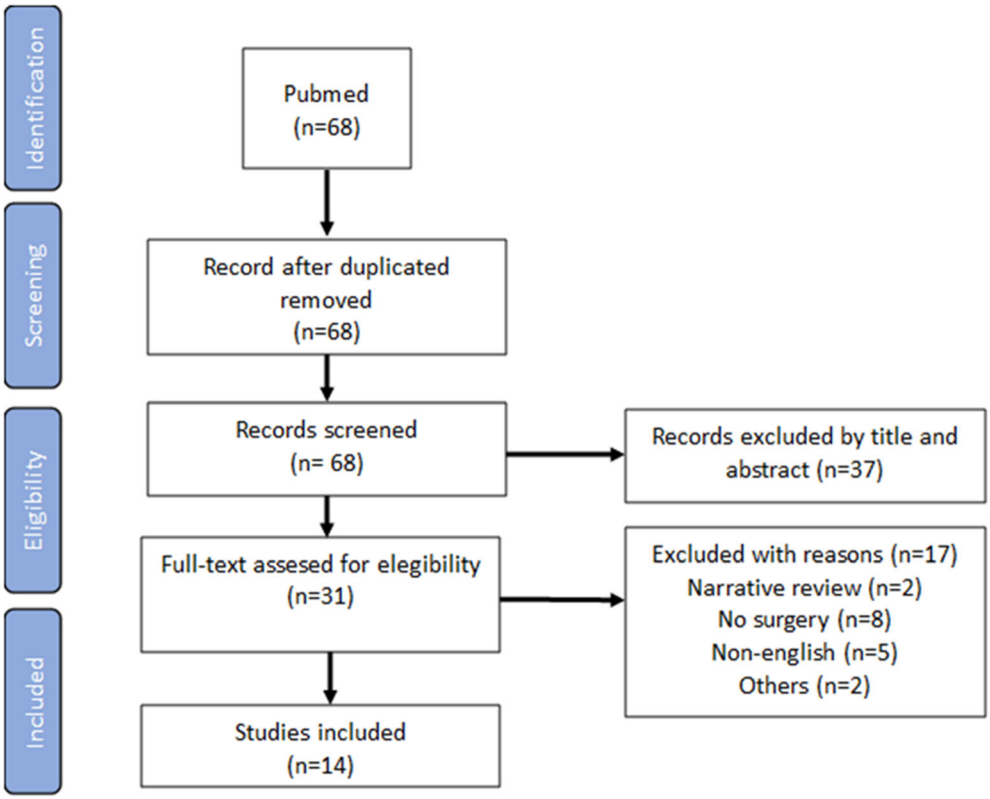

Fig. 1 Flowchart of the narrative review performed

30.48 ± 19.90°. These patients required repositioning in 50 of 155 eyes (32.25%). Moreover, four eyes (2.58%) required scleral fixation sutures and two eyes (1.29%) iris fixation. Other complications were high intraocular pressure (IOP) in three eyes (1.93%), transient corneal edema in two eyes (1.29%), corneal decompensation in two eyes (1.29%), and pigment dispersion in one eye (0.64%). A ±0.5 D target astigmatism was achieved by 57.41% of eyes (89 eyes from 155 patients). At least 52 eyes from a total of 155 (33.54%) had an abnormal cornea with irregular astigmatism.

DISCUSSION

Currently, patients demand independence from glasses, and emmetropia is generally the surgical target in cataract and presbyopia surgery. Residual refractive astigmatism is one of the most important causes of suboptimum visual function and patient dissatisfaction, decreasing the VA and patients' vision-related quality of life [7]. In this study, we reviewed the benefits and complications of STIOL in the 155 eyes described in the literature. Most of the studies use this technology in a second surgical time, between 3 months and 72 months postoperative, something that was previously described with the use of SMIOL [17]. This makes sense, since most ophthalmologists use TIOL when correcting preoperative corneal astigmatism in the case of cataract or presbyopia surgery. In general, the results obtained from this review show that this approach is effective in correcting residual refractive astigmatism, improving final uncorrected and best-corrected distance VA (UCDVA/CDVA) with few complications described. It is of note that 57.41% of eyes (89 eyes from 155) achieved a residual refractive astigmatism ±0.50 D, improving the final uncorrected distance visual acuity of most patients from the articles included in this review. The concept of safety in refractive surgery is defined as the loss of two lines of CDVA

Table 1 Study characteristics

Author (date)	Design	Mean follow-up (months)	No. Patients	No. eyes	Age (mean years old)	Gender (M/F)	Type of IOL in sulcus	Design and material	Time to implantation (months)
Jin et al. (2010) [48]	CR	8	1	1	72	1/0	MicroSil MS 614 TPB (HumanOptics/Dr. Schmidt Intraocularlinsen, Erlangen, Germany)	3-piece foldable IOLs; Silicon(optic); PMMA (haptic); MS 614 TPB has smooth C-haptics	24
Khan & Muhtaseb (2011) [49]	CS	2.5	1	1	76	0/1	Sulcoflex Toric (Rayner Intraocular Lenses Ltd, East Sussex, UK)	Single piece; hydrophilic acrylic with open C-shaped haptics	NR
Rabsilber et al. (2012) [39]	CR	9	1	2	41	NR	Toric Multifocal Add-On (HumanOptics, Erlangen, Germany)	Toric-diffractive Add-On IOL 3-piece foldable IOL; silicon; two C-shaped haptics of polymethylacrylate (PMMA) Near addition: +3.5 D	72
Thomas et al. (2013) [20]	CS	8	20	21	69	9/11	MicroSil MS 614 TPB (n = 4) and MS 714 TPB (n = 17) (HumanOptics/Dr. Schmidt Intraocularlinsen, Erlangen, Germany)	3-piece foldable IOLs; Silicon(optic); PMMA (haptic); MS 614 TPB has smooth C haptics and the MS 714 TPB has undulated C haptics	NR
Žiak et al. (2013) [50]	CR	3	1	1	30	0/1	Sulcoflex Toric (Rayner Intraocular Lenses Ltd, East Sussex, UK)	Single piece; hydrophilic acrylic with open C-shaped haptics	NR
Ferreira et Pinheiro (2015) [51]	CS	7	10	10	56	NR	Sulcoflex Toric (Rayner Intraocular Lenses Ltd, East Sussex, UK)	Single piece; hydrophilic acrylic with open C-shaped haptics	40 (mean) 4 (min)
Meyer et al. (2015) [22]	CS	12	8 toric/ 10 total	8 toric/ 10 total	67	6/4	Sulcoflex Toric (Rayner Intraocular Lenses Ltd, East Sussex, UK)	Single piece; hydrophilic acrylic with open C-shaped haptics	66 (mean)
Gundersen et al. (2017) [52]	RC	3	NR	10 toric/ 46 total	NR	NR	1stQ AddOn toric monofocal IOL (GmbH, Mannheim, Germany)	Single piece with four closed haptics; hydrophilic; Toric monofocal	9 (median)
Meyer et al. (2017) [32]	CS	16	7	7	67	5/2	Sulcoflex Toric (Rayner Intraocular Lenses Ltd, East Sussex, UK)	Single piece; hydrophilic acrylic with open C-shaped haptics	NR
McLintock et al. (2019) [21]	RC	3 (min)	44	51	67	26/25 (eyes)	Sulcoflex Toric (Rayner Intraocular Lenses Ltd, East Sussex, UK)	Single piece; hydrophilic acrylic with open C-shaped haptics	3 (min)
Gundersen et al. (2020) [53]	RC	NR (ranged from 43 days to 4.5 years)	NR	18	NR	NR	1stQ AddOn toric monofocal IOL (GmbH, Mannheim, Germany)	Single piece with four closed haptics; hydrophilic; Toric monofocal	NR
Boutillier et al. (2021) [34]	CR	NR	2	2	65	2/0	Add-On (HumanOptics, Erlangen, Germany)	3-piece foldable IOL; silicon; two C-shaped haptics of polymethylacrylate (PMMA)	NR
McLintock et al. (2022) [36]	RC	3 (min)	17	22	65	12/10 (eyes)	1stQ AddOn toric monofocal IOL (GmbH, Mannheim, Germany)	Single piece with four closed haptics; hydrophilic; Toric monofocal	NR
Franco et al. (2023) [25]	CR	12	1	1	71	1/0	Cammelens II FIL 622–2 Toric IOL (Soleko Rome, Italy)	Single piece; hydrophilic; toric monofocal	NR

RC, retrospective cohort; CS, case series; CR, case report; NR, not reported; min, minimum

Table 2 Evaluation of rotational stability, visual acuity, refractive outcomes and complications after sulcus implantation of a STIOL

Author (date)	Corneal alteration	UCVA (logMAR)		CDVA (logMAR)		SE (D)		AST refractive (D)	
		Preop	Postop	Preop	Postop	Preop	Postop	Preop	Postop
Jin et al. (2010) [48] (CR)	No	0.70	0.55	0.20	0.10	-0.25	+ 1.62	- 5.00	− 0.75
Khan & Muhtaseb (2011) [49] (CR)	No	0.78	0.17	0.17	0.10	+ 0.37	–	− 2.75	− 1.00
Rabsilber et al. (2012) [39]	No	0.20	0.10	0.10	0.00	0.12	0.12	− 1.75	− 0.25
(CR)	No	0.30	0.10	0.10	0.10	0.12	0.00	− 1.25	0.00
Thomas et al. (2013) [20] (SC)	Yes (15/21)	1.18	0.60	0.30	0.30	-0.13	-0.25	3.19	0.94
Ziak et al. (2013) [50] (CR)	Yes (1/1)	1.00	0.10	0.20	0.00	0.375	0.75	− 5.75	− 3.50
Ferreira& Pinheiro (2015) [51] (SC)	Yes (3/10)	–	0.10 ± 0.12	–	0.07 ± 0.12	− 1.77 ± 2.64	− 0.30 ± 0.56	− 2.96 ± 0.84	− 0.89 ± 0.46
Meyer et al. (2015) [22] (SC)	Yes(8/8)	–	–	–	–	–	–	5.70	0.90
Gundersen & Potvin (2017) [52] (SC)	No	–	–	–	–	–	–	1.35 ± 0.36	0.42 ± 0.47
Meyer et al. (2017) [32]	Yes	0.60	0.30	0.30	–	+ 2.75	–	-2.50	-
(SC)	Yes	0.30	0.00	0.00	–	-0.50	–	-3.00	-
	Yes	1.00	0.48	0.30	–	+ 4.00	–	-6.00	-
	Yes	1.3	0.54	–	–	–	–	–	–
	Yes	–	–	0.10	0.10	− 2.00	− 1.50	− 9.00	− 3.00
	Yes	0.60	0.30	0.18	0.18	− 2.25	− 0.62	− 3.50	− 1.25
	Yes	0.90	0.48	0.30	–	− 1.25	–	− 8.50	–
McLintock et al. (2019) [21] (RC)	No (32/51) Yes (19/51)	0.34	0.23	0.14	0.20	1.73 ± 1.85	0.56 ± 0.77	2.51 ± 2.08	1.32 ± 1.56
Gundersen et al. (2020) [53] (RC)	No	–	0.00 ± 0.03	–	− 0.05 ± 0.03	− 0.18 ± 0.88	− 0.15 ± 0.44	− 1.66 ± 0.93	− 0.32 ± 0.25
Boutillier et al. (2021) [34]	Yes	–	–	–	0.20	+ 0.50	0.00	− 9.00	− 2.00
(CR)	No	–	–	–	–	− 1.62	–	-3.25	–
McLintock et al. (2022) [36] (RC)	No	0.27 ± 0.03	0.04 ± 0.04	–	–	+ 0.71	+ 0.21	–	–
Franco et al. (2023) [25] (CR)	Yes (1/1)	1.00	0.30	0.40	–	+ 1.75	0.00	− 4.50	0.00

Table 2 continued

% Post AST ± 0.50D (%)	% Post AST ± 1.00 D (%)	IOL rotation (%)	IOL Rotation Less than 10° (%)	Mean Toric IOL rotation degree (°)	IOL Repositioning (%)	Loss ≥ 1 line CDVA (%)	Complication
–	100.00% (1/1)	0.00% (0/1)	–	–	–	0.00% (0/1)	None
–	100.00% (1/1)	–	–	–	–	0.00% (0/1)	None
100.00% (1/1)	–	0.00% (0/1)	–	–	0.00% (0/1)	0.00% (0/1)	None
100.00% (1/1)		0.00% (0/1)	–	–	0.00% (0/1)	0.00% (0/1)	None
50.00% (10/21)	70.00% (15/21)	28.50% (6/21)	–	–	23.00% (5/21)	4.00% (1/21)	Transient high IOP (2), transient corneal edema (2) Pigment dispersion (1) Corneal descompensation (2)
–	–	–	100.00% (1/1)	3.00°	0.00% (0/1)	0.00% (0/1)	None
50.00% (5/10)	80.00% (8/10)	–	100.00% (10/10)	3.00° ± 2.45°	0.00% (0/10)	0.00% (0/10)	None
87.50% (7/8)	–	12.50% (1/8)	–	–	12.50% (1/8)	0.00% (0/8)	High IOP (1)
70.00% (7/10)	–	10.00% (1/10)	–	–	10.00% (1/10)	–	Unsuccessfully Realignment
-	-	100.00% (1/1)	–	50.00°	100.00% (1/1)	–	2 realignments
-	-	100.00% (1/1)	–	44.00°	100.00% (1/1)	–	2 realignments + 1 suture fixation
-	-	100.00% (1/1)	–	25.00°	100.00% (1/1)	–	1 realignment
–	–	100.00% (1/1)	–	52.00°	100.00% (1/1)	–	Awaiting surgery
–	–	100.00% (1/1)	–	45.00°	100.00% (1/1)	0.00% (0/1)	1 realignment
–	–	100.00% (1/1)	–	40.00°	100.00% (1/1)	0.00% (0/1)	Awaiting surgery
–	–	100.00% (1/1)	–	45.00°	100.00% (1/1)	–	1 suture fixation

Table 2 continued

%Post AST ± 0.50D (%)	%Post AST ± 1.00 D (%)	IOL rotation (%)	IOL RotationLess than 10° (%)	Mean Toric IOL rotation degree (°)	IOL Repositioning (%)	Loss ≥ 1 line CDVA(%)	Complication
73.00%	–	62.00%	–	17.63°	62.00%	15.00%	Scleral
(23/32)		(32/51)			(32/51)	(5/32)	fixation (2)
0.00%						39.00%	
(0/19)						(7/19)	
89.00%	10.000%	–	89.00%	4.90° ± 3.70°	0.00%	–	None
(16/18)	(18/18)		(16/18)		(0/18)		
–	–	100.00% (1/1)	–	45.00°	100.00% (1/1)	–	2 IOL fixed by suture to the iris
–	–	100.00% (1/1)	–	49.00°	100.00% (1/1)	–	
82.00%	100.00%	–	86.40%	3.20° ± 3.30°	9.10%	13.60%(3/22)	None
(18/22)	(22/22)		(19/22)		(2/22)		
100.00%	–	–	–	–	0.00%	–	None
(1/1)					(0/1)		

RC, retrospective cohort; SC, serie of cases; CR, case report; UDVA, uncorrected distance visual acuity; CDVA, corrected distance visual acuity; Preop, preoperative; Postop, postoperative; SE, spherical equivalent; D, diopters; AST, astigmatism; IOL, intraocular lens; IOP, intraocular pressure

with respect to the preoperative period after any given procedure. In this review, loss of CDVA in the postoperative period, respecting preoperative values, was analyzed only in 119 eyes. From these eyes, 2.52% (3 eyes out of 119) lost two lines of CDVA and 13.44% (16 eyes out of 119) lost one line of CDVA. These outcomes, combined with few intraoperative or postoperative complications, suggest a good safety profile for STIOLs.

Although the results of this approach may not be as reliable and effective compared with naïve eyes, STIOL may also be useful in borderline cases or in abnormal corneas such as post corneal transplantation or corneal ectasias as reported in this review. In fact, the use of TIOL in these patients has recently been described and reviewed in the literature, obtaining satisfactory results regarding the improvement of VA and the reduction of anisometropia [18]. It is suggested to remove keratoplasty corneal sutures prior to TIOL implantation, as these cases can present with largely orthogonal and symmetrical residual astigmatism after the complete removal of the sutures [19]. These suggestions should also apply in the case of a STIOL implant. Thomas et al., in an article in which the majority of patients presented with astigmatism related to corneal transplantation, demonstrated that although the refractive target did not reach emmetropia, the residual refractive astigmatism was considerably reduced compared with preoperative values with the use of STIOL [20]. McLintock et al. [21] showed that, even if the outcomes were worse in the post-corneal transplant group, 34.00% of the eyes with STIOL achieved an objective within ±0.50 D of the spherical equivalent target. Similar results are reported by Meyer et al., who found a decrease in mean refractive astigmatism of 84.00%, from 5.70 D (range, 4.00–9.00 D) to 0.90 D (range, 0.20–3.00 D) [22]. Therefore, the use of STIOL could be useful in post-corneal transplant patients if they meet these proposed criteria. Other refractive options to correct residual refractive astigmatism for these patients can be found in these detailed reviews [23, 24]. Moreover, STIOL seems to be a plausible option for patients with some component of irregular astigmatism as well, as shown by Franco et al. [25] A similar approach has also been described in patients with TIOL [26].

The risk factors reported in the literature regarding TIOL rotation are large axial lengths (greater than 25 mm) [27], large anterior segment lengths [28], with rule astigmatism [27], inadequate size and shape of the capsulorhexis [29], postoperative hypotonia [30], zonular instability, or leaving viscoelastic within the eye after completing the surgical procedure [29, 30] (Table 3). However, STIOL, unlike TIOL, are lenses that are placed in the ciliary sulcus, with the consequent anatomical difference that this entails. Therefore, the risk factors for rotation may in some cases be similar to TIOL, and in others, inherent to the sulcus placement of the STIOL. Among risk factors for STIOL rotation reported in the literature are patients who are myopic, as it is known that these large eyes tend to have a larger ciliary sulcus diameter, which could facilitate STIOL rotation [31]. Meyer et al. [32] showed in their series that all the eyes with STIOL rotation were myopic, three of them (3/7) having more than 25.00 mm of axial length. It has been reported that the ciliary sulcus

Table 3 Risk factors for rotation of STIOL reported in the literature

Anatomic features
1. Large axial length
2. Large anterior segment length
3. Large ciliary sulcus diameter
4. Zonular instability
5. With rule corneal astigmatism (STIOL place vertical)
Intraoperative risk factors
6. STIOL with a C-loop design
7. Incomplete removal of the ophthalmic viscosurgical device
Postoperative risk factors
8. Postoperative hypotonia (incision leakage)

becomes smaller in older people [33]. Following this suggestion, Meyer et al. [32] proposed that younger patients could have greater risk of SIOL rotation. Other rotation risk factors proposed by Meyer et al. [32] are a deep anterior chamber, since it would be expected to allow more space within the iridociliary angle for STIOL rotation. Currently, STIOL, unlike TIOL, are implanted in an "open space" without the support of capsulorhexis, therefore, they can potentially rotate immediately after the surgery, or even later [34]. Similar to the possibility of rotation of a TIOL placed vertically [27], a STIOL placed vertically may have a greater risk of rotation because the ciliary sulcus is larger in the vertical meridian than in the horizontal meridian [32, 33, 35].

According to the outcomes of this review, it seems that STIOL with a C-loop design has a higher risk of rotation, either single piece or three pieces, unlike those with four closed haptics as has the 1stQ AddOn. In this line, McLintock et al. reported that 86.40% of the eyes showed less than 10° of rotation, needing repositioning in only two eyes [36]. However, it is fair to mention that there are only 50 eyes reported in the literature with this platform, from which only three cases needed repositioning. In contrast, the same author, using a C-loop platform, showed repositioning rates of up to 62.00% (32/51). [21] Therefore, we recommend that the scientific community report their results, so that, with a greater number of eyes, more robust conclusions can be reached regarding which haptic design is better when it comes to guaranteeing the rotational stability of STIOLs.

Although it has been suggested that the repositioning of the TIOL in case of rotation be carried out between 1 week and 3 weeks after the primary surgery [37], little is known regarding when the best moment is to reposition a STIOL. Some authors have repositioned the STIOL by rotation over a long period of time, such as Thomas et al., who repositioned some STIOLs 1 week after surgery, others 3 weeks after surgery, or even 10 months after the procedure, with satisfactory results [20]. In the study by McLintock et al. [21], in 31.00% of cases, IOL repositioning was required 3 months or later in the postoperative period. In the rest of the available literature, the authors do not specify when the repositioning was performed. Therefore, future studies should evaluate the best moment to reposition a STIOL in case of rotation that affects the CDVA. In other studies, the STIOL was still not properly oriented after being repositioned several times, thus requiring suturing the lens to the sclera or the iris [21, 32, 34]. Nevertheless, these techniques had to be performed in very few cases. This approach might be beneficial in cases of recurrent rotations; however, limited information is currently available regarding its advantages and side effects.

Another complication reported in this review is pigment dispersion. Interestingly, this was one of the most frequently described complications in the SMIOL review [17]. Most of the cases were reported in the same study and with the same platform [38]. Unlike in the previous review, in the study by Thomas et al. just one eye with a three-piece STIOL implanted showed persistent pigment dispersion [20]. Other infrequently reported complications are high IOP in three eyes, corneal edema in three eyes (one needed a corneal transplantation), and two corneal graft failures [20].

Although it has not been the primary objective of this study, it is important to note that STIOL could be used in patients who have a refractive residual astigmatism and who would also prefer to have it resolved with a multifocal technology, since there are currently platforms on the market that incorporate diffractive rings to improve the depth of focus with the toric version, as shown in a case report by Rabsilber et al. [39]. In addition, it is worth noting that, although this technology did not meet our inclusion criteria, the off-label use as piggyback of the Visian implantable collamer lens (ICL), both for the correction of the spherical and astigmatic components, has also been recently described with satisfactory results [40, 41]. Therefore, this technology could also be taken into consideration, although more long-term studies focused on safety are still necessary.

Among the limitations of this review, it should be noted that, as previously shown in the review on SMIOL [17], most of the studies collected are case series, with the biases that this

entails. Likewise, it is important to highlight the short follow-up of the most of the studies. Since this is a narrative and not a systematic review with meta-analysis, some biases could also be found in the article selection process. However, as previously mentioned, the design of the articles included and the heterogeneity of their outcomes make it difficult to carry out a study with such characteristics. Moreover, it is worth mentioning that several studies mix patients with regular and irregular astigmatisms without subdividing them by groups in their results. Although the outcomes of this review show that in general, STIOLs are effective in reducing the total amount of residual refractive astigmatism, not dividing patients with regular and irregular astigmatisms by subgroups could affect the final results, since it is plausible that the former perform better than the latter. Future studies should perform subgroup analysis in such cases. Similarly, some studies were discarded because, although they included STIOL, they also included supplementary spherical lenses in the sulcus without a toric component and without analyzing the results obtained by subgroups [42, 43]. It is equally important to note that some of the STIOLs reported in this study are not currently used widely, especially the three-piece platforms. Similarly, some studies use both eyes when evaluating the results. It is well known that without proper statistical adjustment, this fact could equally affect the results, since both eyes are usually correlated [44]. In addition, many studies use non-standardized methods when reporting refractive results regarding astigmatism analysis [45]. In the same line, most of the studies do not follow standardized criteria[46] when carrying out collection or reporting refractive results with respect to IOLs. We encourage the scientific community to try to follow these criteria, which have recently been collected and summarized [47].

In conclusion, STIOLs seem to offer optimal visual and refractive results regarding the correction of residual refractive astigmatism. We believe that STIOLs can be a very useful option, especially in those cases where other techniques, such as corneal laser refractive surgery, may be contraindicated or not available. However, it is important to note that rotational stability may not be optimal in certain situations, especially in some platforms, and may require postoperative repositioning. More robust studies are still needed to confirm satisfactory outcomes for STIOL.

ACKNOWLEDGEMENTS

Funding. No funding or sponsorship was received for this this article.

Authors Contributions. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Carlos Rocha-de-Lossada, María García-Lorente and Diego Zamora-de La Cruz The first draft of the manuscript was written by Carlos Rocha-de-Lossada and María García-Lorente. All authors reviewed the first draft version and contributed to the final manuscript.

Disclosures. All the authors have nothing to declare.

Compliance with Ethics Guidelines. This review is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

Data Availability. All data generated or analyzed during this study are included in this published article/as supplementary information files.

REFERENCES

1. Ginel J, Burguera N, Rocha-de-Lossada C, Piñero D, Sáez-Martín A, Fernández J. Economic evaluation of cataract: a systematic mapping review. Ophthalmol Ther. 2023. https://doi.org/10.1007/s40123-023-00678-0.

2. Aristodemou P, Sparrow JM, Kaye S. Evaluating refractive outcomes after cataract surgery. Ophthalmology. 2019;126(1):13–8. https://doi.org/10.1016/j.ophtha.2018.07.009.

3. Hayashi K, Manabe SI, Yoshida M, Hayashi H. Effect of astigmatism on visual acuity in eyes with a diffractive multifocal intraocular lens. J Cataract Refract Surg. 2010;36(8):1323–9. https://doi.org/10.1016/j.jcrs.2010.02.016.

4. Rocha-de-Lossada C, et al. Intraocular lens power calculation formula accuracy: comparison of 12 formulas for a trifocal hydrophilic intraocular lens. Eur J Ophthalmol. 2021;31(6):2981–8. https://doi.org/10.1177/1120672120980690.

5. Hoffmann PC, Hütz WW. Analysis of biometry and prevalence data for corneal astigmatism in 23,239 eyes. J Cataract Refract Surg. 2010;36(9):1479–85.

6. Zhang J, Wu Y, Sharma B, Gupta R, Jawla S, Bullimore MA. Epidemiology and burden of astigmatism: a systematic literature review. Optom Vis Sci Off Publ Am Acad Optom. 2023. https://doi.org/10.1097/OPX.0000000000001998.

7. Hasegawa Y, Honbo M, Miyata K, Oshika T. Type of residual astigmatism and uncorrected visual acuity in pseudophakic eyes. Sci Rep. 2022;12(1):1225.

8. Ahmed IIK, et al. Visual function and patient experience after bilateral implantation of toric intraocular lenses. J Cataract Refract Surg. 2010;36(4):609–16. https://doi.org/10.1016/j.jcrs.2009.10.044.

9. Tan Q-Q, Wen B-W, Liao X, Tian J, Lin J, Lan C-J. Optical quality in low astigmatic eyes with or without cylindrical correction. Graefe's Arch Clin Exp Ophthalmol. 2020;258(2):451–8. https://doi.org/10.1007/s00417-019-04501-0.

10. Kahraman G, Dragostinoff N, Brezna W, Bernhart C, Amon M. Visual outcomes and patient satisfaction after bilateral sequential implantation of a capsular Bag IOL and a supplementary sulcus-fixated trifocal IOL. J Refract Surg. 2021;37(2):105–11. https://doi.org/10.3928/1081597X-20201215-01.

11. Kessel L, Andresen J, Tendal B, Erngaard D, Flesner P, Hjortdal J. Toric intraocular lenses in the correction of astigmatism during cataract surgery: a systematic review and meta-analysis. Ophthalmology. 2016;123(2):275–86. https://doi.org/10.1016/j.ophtha.2015.10.002.

12. Lake JC, Victor G, Clare G, Porfírio GJ, Kernohan A, Evans JR. Toric intraocular lens versus limbal relaxing incisions for corneal astigmatism after phacoemulsification. Cochrane database Syst Rev. 2019;12(12):CD012801. https://doi.org/10.1002/14651858.CD012801.pub2.

13. Alio JL, Abdelghany AA, Fernández-Buenaga R. Enhancements after cataract surgery. Curr Opin Ophthalmol. 2015;26(1):50–5. https://doi.org/10.1097/ICU.0000000000000111.

14. Mayordomo-Cerdá F, et al. Laser corneal enhancement after trifocal intraocular lens implantation in eyes that previously had photoablative corneal refractive surgery. J Cataract Refract Surg. 2022;48(7):790–8. https://doi.org/10.1097/j.jcrs.0000000000000847.

15. Moshirfar M, et al. Ectasia after corneal refractive surgery: a systematic review. Ophthalmol Ther. 2021;10(4):753–76. https://doi.org/10.1007/s40123-021-00383-w.

16. Manzouri B, Dari ML, Claoué C. Supplementary IOLs: monofocal and multifocal, their applications and limitations. Asia-Pac J Ophthalmol. 2017;6(4):358–63. https://doi.org/10.22608/APO.2017110.

17. Rocha-De-Lossada C, Zamorano-Martín F, Piñero DP, Rodríguez-Vallejo M, Fernández J. Systematic review of the use of supplemental multifocal intraocular lenses in the ciliary sulcus for presbyopia correction. J Refract Surg. 2021;37(12):830–5. https://doi.org/10.3928/1081597X-20210920-01.

18. Wan KH, Chang JSM, Jhanji V. Toric intraocular lenses for astigmatism correction after keratoplasty in phakic and pseudophakic eyes. J Cataract Refract Surg. 2022;48(9):1078–87. https://doi.org/10.1097/j.jcrs.0000000000000907.

19. Wade M, Steinert RF, Garg S, Farid M, Gaster R. Results of toric intraocular lenses for post-penetrating keratoplasty astigmatism. Ophthalmology.

2014;121(3):771–7. https://doi.org/10.1016/j.ophtha.2013.10.011.

20. Thomas BC, Auffarth GU, Reiter J, Holzer MP, Rabsilber TM. Implantation of three-piece silicone toric additive IOLs in challenging clinical cases with high astigmatism. J Refract Surg. 2013;29(3):187–93. https://doi.org/10.3928/1081597X-20130212-01.

21. McLintock CA, McKelvie J, Gatzioufas Z, Wilson JJ, Stephensen DC, Apel AJG. Outcomes of toric supplementary intraocular lenses for residual astigmatic refractive error in pseudophakic eyes. Int Ophthalmol. 2019;39(9):1965–72. https://doi.org/10.1007/s10792-018-1027-7.

22. Meyer JJ, McGhee CNJ. Supplementary, sulcus-fixated intraocular lens in the treatment of spherical and astigmatic refractive errors in pseudophakic eyes after keratoplasty. Cornea. 2015;34(9):1052–6. https://doi.org/10.1097/ICO.0000000000000506.

23. Deshmukh R, et al. Post-penetrating keratoplasty astigmatism. Surv Ophthalmol. 2022;67(4):1200–28. https://doi.org/10.1016/j.survophthal.2021.11.005.

24. Alfonso-Bartolozzi B, Martínez-Alberquilla I, Baamonde B, Fernández-Vega-Cueto L, Alfonso JF, Madrid-Costa D. Refractive surgery after deep anterior lamellar keratoplasty: a review of the literature. Int Ophthalmol. 2022. https://doi.org/10.1007/s10792-022-02507-y.

25. Franco FGS, Nicolosi C, Vicini G, Grasso-Cannizzo P, Virgili G, Giansanti F. Combining primary and sulcus piggyback IOLs for the correction of a spherical-cylindrical defect in an eye with abnormal cornea. Eur J Ophthalmol. 2023;33(1):NP64–8. https://doi.org/10.1177/11206721211037824.

26. Gao Y, Ye Z, Chen W, Li J, Yan X, Li Z. Management of cataract in patients with irregular astigmatism with regular central component by phacoemulsification combined with toric intraocular lens implantation. J Ophthalmol. 2020;2020:3520856. https://doi.org/10.1155/2020/3520856.

27. Miyake T, Kamiya K, Amano R, Iida Y, Tsunehiro S, Shimizu K. Long-term clinical outcomes of toric intraocular lens implantation in cataract cases with preexisting astigmatism. J Cataract Refract Surg. 2014;40(10):1654–60. https://doi.org/10.1016/j.jcrs.2014.01.044.

28. Yao Y, et al. Associations between anterior segment parameters and rotational stability of a plate-haptic toric intraocular lens. J Cataract Refract Surg. 2021;47(11):1436–40. https://doi.org/10.1097/j.jcrs.0000000000000653.

29. Núñez MX, et al. Consensus on the management of astigmatism in cataract surgery. Clin Ophthalmol. 2019;13:311–24. https://doi.org/10.2147/OPTH.S178277.

30. Kodavoor SK, Divya J, Dandapani R, Ramamurthy C, Ramamurthy S, Sachdev G. Randomized trial comparing visual outcomes of toric intraocular lens implantation using manual and digital marker. Indian J Ophthalmol. 2020;68(12):3020–4. https://doi.org/10.4103/ijo.IJO_465_20.

31. Vass C, Menapace R, Schmetterer K, Findl O, Rainer G, Steineck I. Prediction of pseudophakic capsular bag diameter based on biometric variables. J Cataract Refract Surg. 1999;25(10):1376–81. https://doi.org/10.1016/s0886-3350(99)00204-7.

32. Meyer JJ, Kim BZ, Ziaei M, McGhee CNJ. Postoperative rotation of supplementary sulcus-supported toric intraocular lenses. J Cataract Refract Surg. 2017;43(2):285–8. https://doi.org/10.1016/j.jcrs.2016.12.014.

33. Blum M, Tetz MR, Faller U, Völcker HE. Age-related changes of the ciliary sulcus: implications for implanting sulcus-fixated lenses. J Cataract Refract Surg. 1997;23(1):91–6. https://doi.org/10.1016/s0886-3350(97)80157-5.

34. Boutillier G, Gueudry J, Aouidid S, Muraine M. Sudden rotation and technique for repositioning Add-On® piggy-back sulcus toric intraocular lenses. J Fr Ophtalmol. 2021;44(5):e287–90. https://doi.org/10.1016/j.jfo.2020.07.015.

35. Biermann J, Bredow L, Boehringer D, Reinhard T. Evaluation of ciliary sulcus diameter using ultrasound biomicroscopy in emmetropic eyes and myopic eyes. J Cataract Refract Surg. 2011;37(9):1686–93. https://doi.org/10.1016/j.jcrs.2011.03.048.

36. McLintock CA, McKelvie J, Niyazmand H, Apel AJG. Outcomes of a toric monofocal piggyback intraocular lens for residual astigmatic refractive error in pseudophakic eyes. Curr Eye Res. 2022;47(3):443–9. https://doi.org/10.1080/02713683.2021.2007534.

37. Oshika T, et al. Incidence and outcomes of repositioning surgery to correct misalignment of toric intraocular lenses. Ophthalmology. 2018;125(1):31–5. https://doi.org/10.1016/j.ophtha.2017.07.004.

38. Verdonck T, Werner L, Ní Dhubhghaill S, Tassignon M-J. Clinical and surgical outcome of a supplementary multifocal intraocular lens implanted with a bag-in-the-lens intraocular lens: 5-year follow-up. Ophthalmic Res. 2021;64(3):503–511. https://doi.org/10.1159/000513790. LK, http://xv9lx6cm3j.search.serialssolutions.com/?sid=EMBASE&issn=

14230259&id=doi:10.1159%2F000513790&atitle=Clinical+and+Surgical+Outcome+of+a+Supplementary+Multifocal+Intraocular+Lens+Implanted+with+a+Bag-In-the-Lens+Intraocular+Lens%3A+5-Year+Follow-Up&stitle=Ophthalmic+Res.&title=Ophthalmic+Research&volume=64&issue=3&spage=503&epage=511&aulast=Verdonck&aufirst=Thomas&auinit=T.&aufull=Verdonck+T.&coden=OPRSA&isbn=&pages=503-511&date=2021&auinit1=T&auinitm=.

39. Rabsilber TM, Kretz FTA, Holzer MP, Fitting A, Sanchez MJ, Auffarth GU. Bilateral implantation of toric multifocal additive intraocular lenses in pseudophakic eyes. J Cataract Refract Surg. 2012;38(8):1495–8. https://doi.org/10.1016/j.jcrs.2012.06.014.

40. Eissa SA. Management of pseudophakic myopic anisometropic amblyopia with piggyback Visian® implantable collamer lens. Acta Ophthalmol. 2017;95(2):188–93. https://doi.org/10.1111/aos.13203.

41. Duncker GIW, Sasse AC, Duncker T. A prospective pilot study using a low power piggy-back toric implantable Collamer lens to correct residual refractive error after multifocal IOL implantation. Clin Ophthalmol. 2019;13:1689–702. https://doi.org/10.2147/OPTH.S219738.

42. Falzon K, Stewart OG. Correction of undesirable pseudophakic refractive error with the sulcoflex intraocular lens. J Refract Surg. 2012;28(9):614–9. https://doi.org/10.3928/1081597X-20120809-01.

43. Levinger E, Mimouni M, Finkelman Y, Yatziv Y, Shahar J, Trivizki O. Outcomes of refractive error correction in pseudophakic patients using a sulcus piggyback intraocular lens. Eur J Ophthalmol. 2021;31(2):422–6. https://doi.org/10.1177/1120672120903560.

44. Karakosta A, Vassilaki M, Plainis S, Elfadl NH, Tsilimbaris M, Moschandreas J. Choice of analytic approach for eye-specific outcomes: one eye or two? Am J Ophthalmol. 2012;153(3):571-579.e1. https://doi.org/10.1016/j.ajo.2011.08.032.

45. Koch DD, Wang L, Abulafia A, Holladay JT, Hill W. Rethinking the optimal methods for vector analysis of astigmatism. J Cataract Refract Surg. 2021;47(1):100–5. https://doi.org/10.1097/j.jcrs.0000000000000428.

46. Rocha-de-Lossada C, Sánchez-González JM, Borroni D, Peraza-Nieves J. Standardisation in the methodology and interpretation of the defocus curves and contrast sensitivity in the evaluation of intraocular lenses. Arch Soc Esp Oftalmol. 2020;95(7):313–4. https://doi.org/10.1016/j.oftal.2020.03.001.

47. Fernández J, et al. Standard for collecting and reporting outcomes of IOL-based refractive surgery: update for enhanced monofocal, EDOF, and multifocal IOLs. J Cataract Refract Surg. 2022;48:11. https://doi.org/10.1097/j.jcrs.0000000000001013.

48. Jin H, Limberger IJ, Borkenstein AFM, Ehmer A, Guo H, Auffarth GU. Pseudophakic eye with obliquely crossed piggyback toric intraocular lenses. J Cataract Refract Surg. 2010;36(3):497–502. https://doi.org/10.1016/j.jcrs.2009.07.054.

49. Khan MI, Muhtaseb M. Performance of the sulcoflex piggyback intraocular lens in pseudophakic patients. J Refract Surg. 2011;27(9):693–6. https://doi.org/10.3928/1081597X-20110512-01.

50. Žiak P, Šesták M, Mojžiš P, Piñero DP. Piggyback with toric intraocular lens after corneal melting in autoimmune necrotizing vasculitis. Can J Ophthalmol. 2013;48(3):48–50. https://doi.org/10.1016/j.jcjo.2012.12.007.

51. Ferreira TB, Pinheiro J. Clinical results with a supplementary toric intraocular lens for the correction of astigmatism in pseudophakic patients. Eur J Ophthalmol. 2015;25(4):302–8. https://doi.org/10.5301/ejo.5000564.

52. Gundersen KG, Potvin R. A review of results after implantation of a secondary intraocular lens to correct residual refractive error after cataract surgery. Clin Ophthalmol. 2017;11:1791–6. https://doi.org/10.2147/OPTH.S144675.

53. Gundersen KG, Potvin R. Refractive and visual outcomes after implantation of a secondary Toric Sulcus intraocular lenses. Clin Ophthalmol. 2020;14:1337–42. https://doi.org/10.2147/OPTH.S255725.