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REVIEW ARTICLE

Cataract surgery astigmatism incisional management. Manual relaxing incision versus femtosecond laser-assisted arcuate keratotomy. A systematic review

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Abstract

Purpose This systematic review aims to compare corneal astigmatism correction in cataract surgery through corneal relaxing incision, manually and femtosecond laser assisted.

Methods The study was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement recommendations. We used PubMed, Scopus, and Web of Science (WOS) as databases from January 2010 to March 30, 2021. Patients with keratoconus, corneal ectasia, and a previous history of eye surgery were excluded because our aim was to analyze only healthy eyes.

Results A total of 1025 eyes were evaluated from 946 patients (mean age was 68.90 ± 5.12) in manual incision group articles, while 1905 eyes of 1483 patients (mean age was 65.05 ± 4.57) were evaluated in femtosecond laser arcuate keratotomy (FLAK) articles. The mean uncorrected distance visual acuity (UDVA) was 0.19 ± 0.12 and 0.15 ± 0.05 logMAR for manual incision and FLAK articles, respectively ($p = 0.39$). The mean correction index (CI) was similar in both groups: 0.77 ± 0.18 in manual incision and 0.79 ± 0.17 in femtosecond laser assisted incision ($p = 0.70$). Refractive stability was found after 3 months and no serious complications were reported during the follow-up in any group.

Conclusion Both techniques are safe and moderately effective in corneal astigmatism correction in cataract surgery. FLAK represents a more precise and predictable approach. However, since visual and refractive outcomes appear to be similar in both cases, the cost-benefit analysis is controversial.

Keywords Opposite clear corneal incision · Limbal relaxing incision · Femtosecond laser arcuate keratotomy · Cataract surgery

Key messages

What is known

- Manual and femtosecond laser corneal relaxing incision are safe and effective in corneal astigmatism correction in cataract surgery

What this paper adds

- Femtosecond laser arcuate keratotomy represent a more precise and predictable approach
- Cost-benefit analysis is controversial since visual and refractive outcomes appear to be similar between manual and femtosecond techniques

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Introduction

The classic goal of cataract surgery is to achieve acceptable uncorrected distance visual acuity (UDVA) after intraocular lens (IOL) implantation. Mean corneal astigmatism in age-related cataract surgery is approximately 1 diopters (D) [1]. The management of astigmatism during cataract surgery is crucial to controlling refractive residual error and achieving greater spectacle independence. Some studies have suggested that residual error astigmatism is a main factor in blurred vision and dissatisfaction after multifocal and monofocal IOL implantation [2, 3]. Therefore, Schallhorn et al. [4] have suggested that corneal astigmatism > 0.50 D be considered in surgical planning. Astigmatism correction in these patients can be performed by toric IOL implantation, excimer laser corneal surgery, or steep axis corneal incisions.

In the mid-1980s, IOL implantation surgery started to be performed with corneal incisions to manage preexisting astigmatism [5]. This technique is now widely accepted for correcting corneal astigmatism up to 2 D [6] and can be performed manually or by femtosecond-laser assistance. There are three different manual incision techniques depending on the location. The limbal relaxing incision (LRI) and the opposite clear corneal incision (OCCI) are performed on the peripheral cornea, and the arcuate keratectomy (AK) is performed more centrally.

LRIs are non-penetrating incisions made at the corneal periphery for the treatment of corneal astigmatism. Most are placed 1 mm inside the limbus [7]. Several studies have suggested that the LRI is an effective and safe method to reduce corneal astigmatism during cataract surgery up to 3 D [8]. The OCCI, as described by Lever and Dahan [9], is a modification of the standard coaxial small incision cataract surgery with an additional, identical incision on the opposite side, on the steep corneal axis. Correction of corneal astigmatism induced by the paired OCCI is greater compared to single on-axis incisions [10]. The OCCI has some advantages over the LRI, namely it is easier to perform and peripheral pachymetry measurements are not necessary [11]. However, because they are penetrating incisions, they are associated with a greater theorical risk of endophthalmitis [12].

Within the relaxing corneal incision category, an arcuate keratotomy (AK) can also be performed. Since the AK is performed closer to the corneal center (within 7.0–9.0 mm of the optical zone) [13], it has a greater impact on the steeper meridian and induces more change in corneal astigmatism. Femtosecond laser assistance can be used for this procedure, since it can make accurate and precise incisions regardless of the surgeon's experience, a technique known as femtosecond laser arcuate keratotomy (FLAK). Using this technique, a non-penetrating intrastromal incision can be used, which reduces the risk of adverse effects. The main challenge in using FLAK for managing astigmatism is having a suitable nomogram to achieve a satisfactory success rate. In addition, although the safety and effectiveness of femtosecond laser-assisted cataract surgery (FLACS) has been confirmed, its cost-benefit analysis is controversial [14, 15]. The benefits of FLACS are as follows: femtosecond laser capsulotomy is much more accurate [15] and endothelial cell loss is lower than with conventional surgery, reducing the effective phacoemulsification time [16]; the size, alignment, and localization of the corneal incisions are more reproducible [17]; and a multiplanar incision can be performed to improve wound sealing. However, the main drawback is the cost. Additionally, several authors [15, 18] have not found significant statistical differences in visual outcomes between FLACS and conventional phacoemulsification. Kanclerz et al. [15] suggested that FLACS represents an advantage only to some patient groups, such as those with a low endothelial cell count and those undergoing multifocal IOL implantation. In a recent review, Day et al. [19] also concluded that FLACS was not cost-effective.

The purpose of this review was to determine the best approach to manage astigmatism during cataract surgery by comparing both the manual and femtosecond laser-assisted corneal incision methods.

Methods

This systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [20] statement recommendations. We used PubMed, Scopus, and Web of Science (WOS) as databases from January 2010 to March 30, 2021. Data search strategy with Boolean operators were: (LRI OR Limbal relaxing incisions OR astigmatic keratotomy OR arcuate keratotomy OR AK OR arcuate incision OR clear corneal incision OR paired opposite clear corneal incision OR OCCI OR on-axis incisions OR paired opposite incision OR femtosecond laser-assisted keratotomy OR femtosecond laser intrastromal astigmatic keratotomy OR Femtosecond Arcuate Keratotomy OR AK-FLACS OR femtosecond laser-assisted astigmatic keratotomy OR Femtosecond laser AK) AND cataract surgery NOT Radial keratotomy NOT RK NOT SMILE NOT small incision lenticule extraction NOT KC NOT Keratoconus NOT ectasia NOT keratoplasty NOT corneal transplantation. Patients with keratoconus, corneal ectasia, and a previous history of eye surgery were excluded because our aim was to analyze only healthy eyes, and, due to alterations in corneal biomechanics, different responses to incisions may occur with both corneal ectatic disorder and a history of previous eye surgeries. All 520 articles retrieved were assessed by one author who selected them according to the inclusion and exclusion criteria. Data collection was performed by two unbiased authors who then verified the duplicates. The included articles were separated into two groups: the manual incision group (group 1) and the femtosecond laser-assisted incision group (group 2). Human studies, full-length original articles, case series, and retrospective and prospective studies with any subjects, duration of follow-up, and outcomes measured were included. The exclusion criteria were non-English publications, those published in low impact journals, single case reports, biased articles, toric IOL implantations associated with astigmatic corneal incisions, and letters to the editor.

Data from each study are summarized in Tables 1 and 2 (Design and methods) and Tables 3 and 4 (Results). For Tables 1 and 2, the following information was retrieved from each article: (1) author and date of publication (year), (2) study design, (3) mean follow-up time of all patients (expressed in months), (4) number of patients, (5) number of eyes involved, (6) information about the sex of the patients (female/male), (7) mean age of the patients (years), (8) range of preoperative corneal astigmatism (in Ds), (9) femtosecond laser platform (for the FLAK cases), (10) incision depth, (11) incision type, (12) incision number, and (13) location of the phacoemulsification incision. For Tables 3 and 4, the following data were retrieved: (1) author and date of publication (year); (2) uncorrected distance visual acuity (UDVA) logarithm of the minimum angle of resolution (logMAR) and Snellen notation, pre-and post-surgery; (3) corrected distance visual acuity (CDVA) logMAR and Snellen notation, pre- and post-surgery; (4) mean keratometry astigmatism (in Ds) pre- and post-surgery; (5) mean refractive astigmatism (in Ds), pre- and post-surgery; (6) target induced astigmatism (TIA; in Ds); (7) surgically induced astigmatism (SIA; in Ds); (8) correction index (CI); and (9) index of success (IS). Both indices (CI and IS) represented the success of the treatment. CI is defined as the magnitude of SIA divided by the magnitude of the TIA. A $CI < 1.0$ indicates an undercorrection, a $CI > 1.0$ indicates overcorrection, and a $CI = 1.0$ is ideal. In contrast, to calculate the IS, the difference vector (DV) is divided by the TIA, and an IS of zero is ideal. When the TIA value was not explicitly reported in the studies, it was completed using the preoperative keratometry astigmatism. All means were expressed together with their dispersion values using the standard deviation, range, or interquartile range, as reported in the original articles.

Analyses were performed using SPSS Statistics Software (version 25, IBM Corp., Armonk, NY, USA). The condition of normality of the variables was evaluated using the Shapiro–Wilk test, applying a parametric test (Student's *t*-test and one-way ANOVA) or non-parametric test (Mann–Whitney *U*-test) to independent samples, according to the nature of the data.

To avoid the risk of bias, two reliable authors created a synopsis table (Tables 5 and 6) based on the Quality Assessment Tool for Case Series Studies from the National Heart, Lung, and Blood Institute [21]. When disagreements occurred among the two assessors, a third non-blinded assessor decided the matter. The questions included in this tool were as follows: (Q1) Is the study oriented to a clear question? (Q2) Were all the patients results taken into account?; (Q3) Was the follow-up complete?; (Q4) Were the same conditions used in surgical treatment?; (Q5) Was the intervention clearly described?; (Q6) Was the duration of follow-up adequate?; (Q7) Were the results described correctly? This assessment did not determine the exclusion of any study. Articles with a high-level risk of bias had a lower weight for data synthesis.

Results

A total of 40 articles published between 2010 and 2021 were included in this systematic review. Half (20) of the articles discussed manual corneal incisions, and the other half discussed femtosecond-assisted incisions. The selection process is presented in a flowchart diagram (Fig. 1).

Manual corneal relaxing incision

All included studies regarding manual corneal relaxing incisions were case reports. The mean follow-up, expressed in months, was 3.83 ± 2.12 (range 1–6 months). Only two articles had a long-term follow-up of 36 months [22, 23]. A total of 1025 eyes from 946 patients were evaluated. The mean age of the patients was 68.90 ± 5.12 years (range 58–79 years). The type of corneal incision used to correct the pre-existing corneal astigmatism were as follows: the LRI was used in 13 articles (65%), the OCCI was used in five (25%), and the AK was used in two (10%). All OCCIs were penetrating incisions, while the LRIs were non-penetrating, with an incision depth of 80–90% of the peripheral corneal pachymetry or up to 600 microns. In the AK group, penetrating incisions were made in one study [24] and non-penetrating incisions were performed, to a depth of 95% of the peripheral corneal thickness, in another study [25]. In the LRI group, the nomogram used to achieve the desired astigmatic effect was the modified Gills nomogram (three studies) [22, 26, 27], the Fukuyama nomogram (one study) [28], the Nichamin nomogram (three studies) [7, 29, 30], and the Donnenfeld nomogram (five studies) [23, 31–34]. In the AK group, one study [25] used the Lindstrom nomogram and another [24] performed a 30° arc incision systematically. For the studies using OCCIs, the incision length was between 2 and 3.5 mm based on the amount of corneal astigmatism.

Table 1 Manual relaxing incision design and method characteristics

Autor (date)	Design	Follow-up (month)	Patients	Eyes	Gender M/F	Mean age	Pre-operative astigmatism (D)	Incision Size (Arc length mm or Nomogram)	Incision depth (µm)	Incision type	Incision number	Phacoemulsification incision	Incision overlaps
Fouda et al. 2010 [26]	CS	6	15	20	6/9	68.10 ± 12 .0	≥1.25	Modified Gills	80%	LRI	2	Temporal	No
Ouchi et al. 2010 [28]	CS	6	77	96	32/45	70.8 ± 7.9	≥0.75	Fukuyama	80–90%	LRI	2	Temporal/ Superior and oblique	No
Ganekal et al. 2011 [7]	CS	6	200	200	115/85	58 ± 11.5	≥1.00	Nichamin	600	LRI	1–2	Temporal	NR
Miyata et al. 2011 [37]	CS	1	36	44	NR	76.5 ± 5.9	≥2.0	80°	550	LRI	2	NR	NR
Freitas et al. 2014 [31]	CS	6	16	32	8/8	71.75 ± 8.87	≥0.75 & ≤2.50	Donnenfeld	600	LRI	1–2	Temporal	NR
Lim et al. 2014 [22]	CS	36	20	20	8/12	79 (IQR 73. 83)	>1.2	Modified Gills	600	LRI	1–2	Temporal/On axis	NR
Maedel et al. 2014 [35]	CS	3	21	21	NR	70.1 ± 11.8	≥1.00 & ≤2.50	2.85 mm	Penetrating	OCCI	2	On axis	Yes
Nemeth et al. 2014 [36]	CS	2	81	81	NR	71.02 ± 13.26	≥ 1.00	3.00 mm	Penetrating	OCCI	2	On axis	Yes
Razmjoo et al. 2014 [10]	CS	3	50	50	23/27	65.9±10.17	>1.50	3.2 mm	Penetrating	CCI/OCCI	1–2	On axis	Yes
Roberts et al. 2014 [25]	CS	6	13	20	7/6	68.8 ± 13.4	≥1.75 & ≤5.25	Lindstrom	95%	AK	2	Temporal	No
Titiyal et al. 2014 [24]	CS	3	17	17	NR	62.23 ± 3.29	≥1.25 & ≤3.00	30°	100% TPP	AK	2	Temporal	No
Chiam 2015 [11]	CS	6	84	84	27/57	73.53 ± 9.4	≥1.50 & ≤2.50	3.2/ 3.5 mm	Penetrating	OCCI	2	On axis	Yes
Leon et al. 2015 [29]	CS	6	48	50	22/28	70.9 ± 7.3	>1.00 & 2.00	Nichamin	600 or 85%	LRI	2	On axis	No
Monaco et al. 2015 [23]	CS	36	48	64	21/27	70.6 ± 8.4	>0.50	Donnenfeld	600	LRI	1–2	Temporal	No
Eliwa et al. 2016 [32]	CS	1	17	23	8/9	61.07 ± 13.14	>1.00 & 3.00	Donnenfeld	600	LRI	1	On axis	No
Lam et al. 2016 [30]	CS	3	29	29	11/18	67.7 ± 6.9	≤ 3.00	Nichamin	600	LRI	Nomogram	Temporal	NR
Mohammad-Rabei et al. 2016 [27]	CS	6	17	17	9/5	63.1 ± 12.4	≥ 1.25	Modified Gills	600 or Penetrating	LRI	1–2	Temporal/ On axis	Both
Roberts et al. 2018 [33]	CS	1	51	51	22/29	72.5 ± 10.5	>0.90	Donnenfeld	600	LRI	2	On axis/Off axis	Both

Table 1 (continued)

Autor (date)	Design	Follow-up (month)	Patients	Eyes	Gender M/F	Mean age	Pre-operative astigmatism (D)	Incision Size (Arc length mm or Nomogram)	Incision depth (µm)	Incision type	Incision number	Phacoemulsification incision	Incision overlaps
Ren et al. 2019 [38]	CS	3	68	68	31/37	66.16 ± 11.87	≥ 0.75	2 / 3 mm	Penetrating	OCCI	2	On axis	Yes
Stanojcic et al. 2020 [34]	CS	1	38	38	17/21	70.3 ± 14.7	≥ 2.00	Donnenfeld	600	LRI	2	On axis	Yes

M, Male; *F*, Female; *D*, Diopter; *NR*, Not reported; *CS*, Case Series; *IQR*, Interquartile range; *TPP*, Thickness paracentral pachymetry; *AK*, Arcuate keratotomy; *LRI*, Limbal relaxing incision; *OCCI*, opposite clear corneal incision; *WTR*, With the rule; *ATR*, Against the rule

Of the phacoemulsification incisions, eight articles [10, 11, 29, 32–36] used axis incisions, seven used temporal incisions [7, 23–26, 30, 31], two used both temporal and axis incisions, [22, 27], one article [33] used an on- and off-axis incision and another [28] used superior, temporal, and oblique incisions depending on the orientation of the corneal astigmatism. Standard coaxial small incision cataract surgery (C-SICS) was performed in most cases. A bimanual microincision cataract surgery (B-MICS) was performed in only one study [28], for which a 1.6 mm clear corneal incision was applied.

Regarding the CI, all the studies evaluated in this section resulted in a CI ≤ 1.0 (undercorrection). The average CI value was 0.77 ± 0.18 (range 0.39–1.0), suggesting that the TIA was greater than the SIA in these studies. In terms of the different incision types, the CI was 0.82 ± 0.13 and 0.69 ± 0.22 for studies using the LRI and OCCI, respectively ($p = 0.17$). In the AK group, the SIA and TIA values were not reported. There was no statistically significant difference between the different nomograms used in the LRI studies ($p = 0.75$). The mean UDVA pre- and post-surgery was 0.70 ± 0.28 and 0.19 ± 0.12 logMAR ($p < 0.01$), and the mean CDVA was 0.33 ± 0.19 and 0.16 ± 0.07 logMAR ($p < 0.01$), respectively. The mean keratometric astigmatism was reduced from 1.86 ± 0.53 D to 1.04 ± 0.48 D post-surgery ($p < 0.01$), and the mean refractive astigmatism was reduced from 1.96 ± 0.62 D to 0.98 ± 0.36 D ($p < 0.01$).

Risk of bias assessment was classified into three evidence-level groups. In manual incision group studies with yeses from zero to three: Ouchi et al. [28], Maedel et al. [35], Lam et al. [30], and Mohammad-Rabei et al. [27]. Studies with yeses from four to five: Ganekal et al. [7], Miyata et al. [37], Lim et al. [22], Nemeth et al. [36], Razmjoo et al. [10], Roberts et al. [25], Titiyal et al. [24], Monaco et al. [23], Eliwa et al. [32], Roberts et al. [33], and Stanojcic et al. [34]. Finally studies with yeses from six to seven: Fouda et al. [26], Freitas et al. [31], Chiam [11], Leon et al. [29], and Ren et al. [38].

Femtosecond assisted corneal relaxing incision

All included studies regarding femtosecond-assisted corneal relaxing incisions were case reports. The mean follow-up, expressed in months, was 3.11 ± 1.90, (range 1–6 months). Only two articles [39, 40] had a follow-up time > 6 months (12 and 24 months). A total of 1905 eyes from 1483 patients were evaluated. The mean age of the patients was 65.05 ± 4.57 years (range 53.6–73 years). The type of incision used in almost all the studies was an AK paired opposite incision between 7.5 and 9 mm in diameter. An OCCI was performed in only one study [41]. An anterior penetrating incision was used for nine studies (45%), an intrastromal incision was used for seven (35%), both an anterior penetrating and intrastromal incision was performed

Table 2 Femtosecond laser-assisted arcuate keratotomy design and method characteristics

Author (date)	Design	Follow-up (months)	Patients	Eyes	Gender M/F	Mean age	Pre-operative corneal astigmatism (D)	Laser platform	Incision nomogram	Incision depth	Incision type	Incision number	Diameter	Phacoemulsification incision
Rückl et al. 2013 [51]	CS	6	16	16	8/8	65 ± 12	> 1.0 & <3.0	IntraLase iFS	90° arc length	IE	AK	2	7.5	NR
Yoo et al. 2015 [43]	CS	5	23	23	NR	53.6 ± 16.6	> 1.0 & <3.0	IntraLase iFS	30% Donnenfeld	85% PT	AK	2	9	On axis
Day et al. 2016 [53]	CS	1	133	196	NR	62.1 ± 9.0	> 0.70	Catalys Laser	Personalized	60% IE	AK	2	8	Temporal
Day and Stevens 2016a [44]	CS	1	213	319	NR	61.3 ± 10.1	> 0.75 & <2.50	Catalys Laser	Personalized	60% IE	AK	2	8	Temporal
Day and Stevens 2016b [52]	CS	6	NR	87	NR	60.4 ± 11.6	NR	Catalys Laser	Personalized	60% IE	AK	2	8	Temporal
Baharozian et al. 2017 [45]	CS	1–2	116	161	NR	67 ± 10	≥0.25 & ≤2.00	Catalys Laser	Donnenfeld	80% PT	AK	1 or 2	9	Temporal
Blehm and Potvin 2017 [46]	CS	2	18	28	6/12	68.8 ± 6.1	≥1.0 & <2.4	LenSx	Woodcock	90% PT	AK	2	8	NR
Löffler et al. 2017 [13]	CS	3	23	27	NR	65 ± 8	≥ 0.75	LenSx	Wang	80% PT	AK	1 or 2	9	NR
Byun et al. 2018 [47]	CS	6	89	89	17/72	63.8 ± 10.2	NR	Catalys Laser	Julian Stevens	60% IE	AK	2	8	NR
Roberts et al. 2018 [33]	CS	1	53	53	31/22	69.7 ± 12.0	>0.90	LenSx	Day	NR	AK	NR	NR	On axis
Lee et al. 2019 [42]	CS	1	NR	14	NR	NR	>0.75	Catalys Laser	Julian Stevens	NR	AK	NR	NR	NR
Visco et al. 2019 [48]	CS	3	143	189	56/87	68.3 ± 8.1	≥0.50 & ≤2.0	Lensar Laser	Nichamin-Woodcock	90% PT	AK	2	8.6	Temporal
Chen et al. 2020 [41]	CS	3	138	138	58/60	59.5 ± 13.3	≥0.75 & ≤2.50	LenSx	Personalized	100% PT	OCCI	1 or 2	NR	NR
Ganesh et al. 2020 [54]	CS	6	25	25	NR	64.5 ± 10.1	≥0.75 & ≤2.00	Catalys Laser	20% Donnenfeld	PT	AK	2	8	Temporal
			25	25	NR	62 ± 9.2			Intrastromal AK	60% IE	AK	2	8	Temporal
Lim et al. 2020 [55]	CS	3	125	154	61/93	71.4 ± 9.3	≥0.20	Catalys Laser	Single, non-paired LRIs	60% IE	AK	1	9	Temporal

Table 2 (continued)

Author (date)	Design	Follow-up (months)	Patients	Eyes	Gender M/F	Mean age	Pre-operative corneal astigmatism (D)	Laser platform	Incision nomogram	Incision depth	Incision type	Incision number	Diameter	Phacoemulsification incision
Rani et al. 2020 [49]	CS	3	70	80	42/28	63 ± 9.1	≥0.40 & ≤1.50	Catalys-I Precision	Donnenfeld	80% PT	AK	Nomogram	8	Temporal
Wortz et al. 2020 [50]	CS	1	124	124	53/71	66.8 ± 8.0	<1.0D	Catalys-I Precision	Wörtz-Gupta™	80% PT	AK	1 or 2	9	Temporal
Moon et al. 2021 [56]	CS	3	79	79	35/44	66.9 ± 10.7	>0.50 & ≤3.00	Catalys-I Precision	Julian Stevens	60% IE	AK	2	8	NR
Schwarzenbacher et al. 2021 [40]	CS	24	43	43	NR	73 ± 11	≥1.00 & ≤3.00	LDV Z8	Castrop Femto	80% PT	AK	2	8.5	Temporal
Wendelstein et al. 2021 [39]	CS	12	27	35	14/13	69	≥0.50 & ≤2.50	Technolas Victus	Castrop Femto	80% PT	AK	2	8.5	Temporal

M, Male; *F*, Female; *D*, Diopter *NR*, Not reported; *CS*, Case series; *IE*, Intraestromal; *PT*, Penetrating; *AK*, Arcuate keratotomy; *LRI*, Limbal relaxing incision; *WTR*, With the rule; *ATR*, Against the rule; *OBL*, Oblique

in one article (5%), a total penetrating incision was reported in another article (5%), and two articles (10%) did not report this information. When the incision type was anterior penetrating, the incision depth achieved was approximately 80–90% of the pachymetry. For most non-penetrating incisions, an intrastromal incision was made with a depth between 20% and 80% of the corneal pachymetry. The main platform femtosecond laser used was Catalys Laser System (Abbott Medical Optics, Inc.) 11 studies (55%), followed by LenSx® (Alcon, Fort Worth, Texas, USA) five studies (25%), IntraLase iFS (Abbott Medical Optics, Inc.) two studies (10%), TechnolasVictus SW 2.7 (Bausch & Lomb Inc, Dornach, Germany) one study (5%), and finally LDV Z8 (Ziemer Ophthalmic Systems, Port, Switzerland) one study (5%). A great variety of different nomograms were used: Donnenfeld LRI Nomogram modified, Day Nomogram, Woodcock nomogram, Wang's et al. Nomogram, Stevens's nomogram, Nichamin-Woodcock Nomogram modified, standardized Nomogram of single, non-paired LRIs and Wörtz-Gupta™ Formula, Dr. Julian Stevens Nomograms and Castrop femto AK Nomogram.

In terms of visual outcomes, an acceptable UDVA/CDVA was found at the end of the postoperative period. For all the studies reporting visual data, the mean UDVA post-operation was 0.15 ± 0.05 logMAR and the mean CDVA was 0.03 ± 0.05 logMAR. There was a reduction in corneal astigmatism from 1.16 ± 0.26 D to 0.64 ± 0.21 D ($p < 0.01$) after surgery. Furthermore, refractive astigmatism decreased from 1.41 ± 0.17 D to 0.57 ± 0.22 D ($p < 0.01$). The mean magnitude of the TIA was 1.16 ± 0.24 D, while the mean SIA was 0.94 ± 0.31 D. Most of the studies analyzed obtained an undercorrection result with a mean CI of 0.79 ± 0.17 (range 0.53–1.0). For the articles in which intrastromal incisions were made, the average CI was 0.72 ± 0.06, while it was 0.86 ± 0.06 for the articles in which penetrating incisions were made, with no significant differences between the groups ($p = 0.13$). The mean index of success reported was 0.60 ± 0.19 (range 0.20–0.93).

In FLAK incision group studies risk of bias assessment was classified into three evidence-level groups with yeses from zero to three: Lee et al [42]. Studies with yeses from four to five: Yoo et al. [43], Day et al. [44], Baharozian et al. [45], Blehm et al. [46], Löffler et al. [13], Byun et al. [47], Roberts et al. [33], Visco et al. [48], Chen et al. [41], Rani et al. [49], Wortz et al. [50], and Schwarzenbacher et al. [40]. Finally, studies with yeses from six to seven: Rückl et al.,[51], Day et al. [52], Day et al. [53], Ganesh et al. [54], and Lim et al. [55], Moon et al. [56], and Wendelstein et al. [39].

Discussion

Corneal relaxing incisions are one of the most widely used methods for astigmatism correction during cataract surgery. This method is intended to reduce corneal astigmatism

Table 3 Manual relaxing incision resume results

Author (date)	UDVA		CDVA		Mean keratometric astigmatism (D)		Mean refractive cylinder (D)		TIA	SIA
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative		
Fouda et al. 2010 [26]	1.06 ± 0.53	0.49	0.49 ± 0.47	0.07	2.03 ± 0.49	1.34 ± 0.60	–1.72 ± 0.95	–0.98 ± 0.58	2.03 ± 0.49	1.33 ± 0.75
Ouchi et al. 2010 [28]	0.46 ± 0.72	0.03 ± 0.47	0.29 ± 0.32	–0.05 ± 0.52	1.79 ± 1.01	NR	NR	0.56 ± 0.87	1.79 ± 1.01	1.44 ± 0.79
Ganekal et al. 2011 [7]	NR	≥ 6/9 (76.5 %)	NR	≥ 6/9 (99.5 %)	1.58 ± 0.55	0.45 ± 0.25	NR	NR	1.58 ± 0.55	NR
Miyata et al. 2011 [37]	0.31 ± 0.14	0.006 ± 0.14	–0.10 ± 0.07	–0.15 ± 0.05	2.03 ± 0.92	1.33 ± 0.69	–2.61 ± 0.78	–0.74 ± 0.60	2.03 ± 0.92	NR
	0.34 ± 0.14	0.05 ± 0.15	–0.10 ± 0.07	–0.12 ± 0.08	2.36 ± 0.77	0.93 ± 0.70	–2.67 ± 0.80	–0.76 ± 0.54	2.36 ± 0.77	NR
Freitas et al. 2014 [31]	NR	0.15	0.44	0.05	1.32 ± 0.47	NR	NR	–0.74 ± 0.26	1.58	1.08
Lim et al. 2014 [22]	NR	NR	NR	NR	2.2 (IQR 2.0 to 3.0)	1.0 (IQR. 0.8 to 1.3)	NR	NR	2.2 (IQR 2.0 to 3.0)	1.7 (IQR 1.1 to 2.1)
	NR	NR	NR	NR	1.9 (IQR 1.6 to 2.4)	1.0 (IQR 0.4 to 1.4)	NR	NR	1.9 (IQR 1.6 to 2.4)	1.9 (IQR 1.6 to 2.8)
Maedel et al. 2014 [35]	NR	0.29 ± 0.30	NR	0.08 ± 0.16	1.67 ± 0.30	0.96 ± 0.70	NR	1.02 ± 0.54	1.67 ± 0.30	NR
Nemeth et al. 2014 [36]	NR	NR	NR	NR	1.06 ± 0.34	0.86 ± 0.68	NR	NR	1.06 ± 0.34	0.99 ± 0.57
Razmjoo et al. 2014 [10]	NR	NR	NR	NR	2.58 ± 1.03	2.15 ± 0.82	NR	NR	2.58 ± 1.03	1.01 ± 1.02
	NR	NR	NR	NR	2.70 ± 0.94	1.63 ± 1.21	NR	NR	2.70 ± 0.94	1.59 ± 0.70
Roberts et al. 2014 [25]	NR	NR	NR	NR	NR	NR	–2.41 ± 0.76	–1.33 ± 0.76	NR	NR
Titiyal et al. 2014 [24]	1.15 ± 0.51	NR	0.23 ± 0.66	NR	2.18 ± 0.59	0.57 ± 0.41	1.95 ± 0.47	0.99 ± 0.54	2.18 ± 0.59	NR
Chiam 2015 [11]	NR	0.2 R (0.0 to 0.3)	0.3 R (0.2 to 0.5)	0.1 R (0.1 to 0.2)	1.9 R (1.6 to 2.3)	NR	NR	0.5 ± 0.5	1.9 R (1.6 to 2.3)	1.6 R (1.0 to 2.1)
	NR	0.3 R (0.1 to 0.5)	0.3 R (0.2 to 0.6)	0 R (0.1 to 0.2)	1.9 R (1.5 to 2.4)	NR	NR	1.3 ± 0.5	1.9 R (1.5 to 2.4)	0.8 R (0.6 to 1.2)
	NR	0.2 R (0.0 to 0.4)	0.4 R (0.2 to 0.5)	0 R (0.1 to 0.2)	1.9 R (1.5 to 2.4)	NR	NR	0.6 ± 0.6	1.9 R (1.5 to 2.4)	1.5 R (1.1–1.8)
Leon et al. 2015 [29]	0.79 ± 0.31	0.22 ± 0.12	0.39 ± 0.13	0.05 ± 0.04	2.16 ± 0.40	0.84 ± 0.46	1.91 ± 0.63	1.1 ± 0.38	2.16 ± 0.40	NR
Monaco et al. 2015 [23]	0.70 ± 0.19	0.12 ± 0.01	0.51 ± 0.24	0.02 ± 0.00	2.22 ± 2.61	1.33 ± 2.03	NR	NR	2.22 ± 2.61	NR
Eliwa et al. 2016 [32]	NR	NR	NR	NR	1.60 ± 0.50	0.87 ± 0.49	NR	NR	1.33 ± 0.20	1.29 ± 0.71
Lam et al. 2016 [30]	0.79 ± 0.26	0.336 ± 0.153	NR	NR	–1.19 ± 0.45	–0.81 ± 0.50	–1.58 ± 0.28	–1.00 ± 0.60	1.19 ± 0.45	NR

Table 3 (continued)

Author (date)	UDVA		CDVA		Mean keratometric astigmatism (D)		Mean refractive cylinder (D)		TIA	SIA
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative		
Mohammad-Rabei et al. 2016 [27]	0.71 ± 0.33	0.18 ± 0.15	0.49 ± 0.29	NR	1.89 ± 0.51	0.78 ± 0.63	−1.30 ± 1.25	NR	1.89 ± 0.51	1.78±0.65
	0.75 ± 0.42	0.12 ± 0.13	0.51 ± 0.38	NR	1.78 ± 0.51	0.52 ± 0.33	−1.06 ± 1.37	NR	1.78 ± 0.51	1.65 ±0.63
Roberts et al. 2018 [33]	NR	>20/25 (37%)	0.45 ± 0.38	>20/25 (61%)	1.50 ± 0.46	1.17 ± 0.69	1.42 ± 0.79	1.18 ± 0.90	1.50 ± 0.46	1.02 ± 0.41
Ren et al. 2019 [38]	0.42 ± 0.93	0.18 ± 0.20	NR	0.07 ± 0.08	1.09 ± 0.52	0.52 ± 0.48	NR	NR	1.09 ± 0.52	1.07 ± 0.51
	0.78 ± 0.71	0.11 ± 0.15	NR	0.04 ± 0.07	0.99 ± 0.30	0.69 ± 0.42	NR	NR	0.99 ± 0.30	0.61 ± 0.35
Stanojcic et al. 2020 [34]	0.82 ± 0.55	0.27 ± 0.15	0.41 ± 0.38	0.06 ± 0.12	2.87 ± 0.78	2.16 ± 0.98	2.96 ± 1.39	1.91 ± 1.07	2.87 ± 0.78	2.35 ± 1.79

NR, Not reported; *D*, Diopter; *IQR*, Interquartile Range; *R*, Range; *UDVA*, Uncorrected distance visual acuity; *CDVA*, Corrected distance visual acuity; *TIA*, Target induced astigmatism; *SIA*, Surgically induced astigmatism

through a flattening effect on the steep meridian and a steepening effect on the flat meridian. Currently, the correction of preexisting astigmatism through corneal incisions can be performed manually or by femtosecond laser assistance, though the benefits and drawbacks of each technique must be considered.

Visual and refractive outcomes

The goal of relaxing corneal incisions during cataract surgery is to achieve acceptable UDVA and spectacle independence. In the articles included in this review, similar visual outcomes were found for manual and femtosecond-assisted incisions. The mean UDVA at the end of the follow-up period was 0.19 ± 0.12 and 0.15 ± 0.05 logMAR for manual incisions and for those using FLAK, respectively ($p = 0.39$). All studies achieved a reduction in preexisting corneal astigmatism, although most were undercorrected, regardless of the incision type and nomogram used. A slight undercorrection is always more desirable than an overcorrection because a residual astigmatism on the same axis is better tolerated than that on the opposite axis [45]. Additionally, the mean CI was similar for both groups. In the manual incision group, the mean CI was 0.77 ± 0.18 while in the FLAK group, it was 0.79 ± 0.17 ($p = 0.70$). However, Roberts et al. [33], in a comparative study, found a greater CI in the femtosecond laser-assisted group 0.73 ± 0.49 compared to the manual incision group (0.48 ± 0.57). In addition, in this study, FLAK was much more accurate than manual incisions for target correction due to the use of a target correction of 70% of total preoperative corneal astigmatism (TIA). In the FLAK studies, although no statistically significant differences were found between penetrating incisions and intrastromal incisions, Ganesh et al. [54] reported worse results for the latter. In this study, a more significant undercorrection was reported at 6 months in the intrastromal incision group compared with the penetrating incision group with a CI of 0.55 and 0.95, respectively. Considering the type of preoperative astigmatism, however, Baharozian et al. [45] found a greater tendency toward overcorrection (CI = 1.01; 18.6% with 150% of intended correction) in the against-the-rule (ATR) preoperative corneal astigmatism group compared with a systematic undercorrection (CI = 0.53) in the with-the-rule (WTR) group using the modified FLAK Donnenfeld nomogram. Similarly, Lim et al. [55] found, in their multivariable analysis, an association between overcorrection and ATR astigmatism using an arcuate femtosecond single laser-assisted LRI. However, Day et al. [52] reported a greater SIA value (0.13 D) in WTR compared to ATR astigmatism using a personal intrastromal AK nomogram [53].

For the manual relaxing incision, Chiam et al. [11] reported a greater effect in WTR compared to ATR astigmatism when an OCCI of the same size was achieved. This

Table 4 Femtosecond laser-assisted arcuate keratotomy resume results

Author (date)	UDVA		CDVA		Mean keratometric astigmatism (D)		Mean Refractive Cylinder (D)		TIA	SIA	CI	IS
	Pre	Post	Pre	Post	Pre	Post	Pre	Post				
Rückl et al. 2013 [51]	0.45 ± 0.27	0.26 ± 0.33	0.09 ± 0.15	0.12 ± 0.18	1.50 ± 0.47	0.63 ± 0.34	1.41 ± 0.66	0.33 ± 0.42	1.50 ± 0.47	1.59 ± 0.70	1.00 ± 0.44	NR
Yoo et al. 2015 [43]	0.52 ± 0.06	0.17 ± 0.03	0.34 ± 0.06	0.05 ± 0.02	1.31 ± 0.13	0.874 ± 0.135	1.71 ± 0.15	0.78 ± 0.10	1.31 ± 0.13	NR	0.81 ± 0.33	NR
Day et al. 2016 [53]	NR	NR	NR	NR	NR	NR	1.21 ± 0.42	0.74 ± 0.38	1.21 ± 0.42	0.74 ± 0.40	0.63 ± 0.32	0.63 ± 0.30
Day and Stevens 2016a [44]	NR	NR	NR	NR	NR	NR	1.24 ± 0.44	0.79 ± 0.41	1.24 ± 0.44	0.71 ± 0.43	0.59 ± 0.31	0.65 ± 0.29
Day and Stevens 2016b [52]	NR	NR	NR	NR	1.23 ± 0.49	NR	NR	NR	1.23 ± 0.49	0.69 ± 0.50	NR	NR
Baharozian et al. 2017 [45]	NR	NR	NR	NR	0.86 ± 0.32	0.63 ± 0.42	NR	NR	0.86 ± 0.32	NR	0.53 WTR, 1.01 ATR, and 0.95 OBL	NR
Blehm et al. 2017 [46]	NR	79% ↑ > one line	NR	NR	1.42 ± 0,54	NR	1.35 ± 0.30	71% ≤ 0.50	1.42 ± 0.54	NR	NR	NR
Löffler et al. 2017 [13]	NR	NR	NR	NR	0.97 ± 0.30	0.63 ± 0.34	NR	NR	0.97 ± 0.30	0.71 ± 0.37	NR	NR
Byun et al. 2018 [47]	NR	NR	NR	NR	1.16 ± 0.46	0.63 ± 0.35	1.54 ± 1.05	0.43 ± 0.37	1.16 ± 0.46	0.91 ± 0.50	0.87 ± 0.50	0.57 ± 0.34
Roberts et al. 2018 [33]	NR	>20/25 (40%)	0.69 ± 0.52	>20/25 (67%)	1.38 ± 0.40	0.89 ± 0.54	–1.34 ± 0.99	0.90 ± 0.50	1.38 ± 0.40	1.25 ± 0.77	0.73 ± 0.49	0.65 ± 0.4
Lee et al. 2019 [42]	NR	0.10 ± 0.09	NR	NR	1.10 ± 0.54	0.59 ± 0.18	1.51 ± 0.97	0.63 ± 0.43	1.10 ± 0.54	NR	NR	NR
Visco et al. 2019 [48]	NR	0.09 ± 0.16	NR	0.02 ± 0.05	0.92 ± 0.34	0.14 ± 0.23	NR	NR	0.92 ± 0.34	0.88 ± 0.35	0.94	NR
Chen et al. 2020 [41]	NR	0.16 ± 0.13	0.62 ± 0.38	NR	1.31 ± 0.41	0.69 ± 0.34	NR	54% < 0.50	1.31 ± 0.41	1.02 ± 0.54	0.72 ± 0.36	0.48 ± 0.20
Ganesh et al. 2020 [54]	NR NR	0.12 ± 0.08 0.18 ± 0.09	NR NR	0.008 ± 0.05 0.02 ± 0.06	1.07 ± 0.39 1.23 ± 0.88	0.65 ± 0.28 0.90 ± 0.74	NR NR	0.29 ± 0.35 0.56 ± 0.19	1.16 ± 0.63 1.50 ± 0.93	1.23 ± 0.86 1.08 ± 0.85	0.95 0.55	0.71 0.59
Lim et al. 2020 [55]	NR	NR	NR	NR	0.87 ± 0.42	0.87 ± 0.51	NR	0.61 ± 0.46	0.87 ± 0.42	0.80 ± 0.52	0.79 ± 0.72	0.93 ± 0.65
Rani et al. 2020 [49]	NR	NR	NR	NR	0.85 ± 0.27	0.47 ± 0.27	NR	NR	0.85 ± 0.27	0.38 ± 0.32	NR	NR
Wortz et al. 2020 [50]	NR	20/25 86.3%	NR	NR	0.611 ± 0.187	–0.256 ± 0.284	NR	NR	0.61 ± 0.19	NR	NR	NR

Table 4 (continued)

Author (date)	UDVA		CDVA		Mean keratometric astigmatism (D)		Mean Refractive Cylinder (D)		TIA	SIA	CI	IS
	Pre	Post	Pre	Post	Pre	Post	Pre	Post				
Moon et al. 2021 [56]	NR	NR	NR	NR	1.23 ± 0.52	0.80 ± 0.45	NR	NR	1.21 ± 0.52	0.76 ± 0.53	0.62 ± 0.34	NR
Schwarzenbacher et al. 2021 [40]	NR	NR	0.26 ± 0.17	0.03 ± 0.12	1.62 ± 0.49	0.66 ± 0.38	NR	NR	1.24 ± 0.46	0.95 ± 0.48	NR	NR
Wendelstein et al. 2021 [39]	0.84 ± 0.50	0.13 ± 0.30	0.30 ± 0.14	−0.04 ± 0.10	1.43 ± 0.34	0.55 ± 0.35	NR	0.27 ± 0.23	1.43 ± 0.34	1.39 ± 0.42	0.98 ± 0.20	0.20 ± 0.18

NR, Not reported; *D*, Diopter; *UDVA*, Uncorrected distance visual acuity; *CDVA*, Corrected distance visual acuity; *TIA*, Target induced astigmatism; *SIA*, Surgically induced astigmatism; *CI*, Correction index; *IS*, Index of success; *WTR*, with the rule; *ATR*, Against the rule; *OBL*, Oblique

is an expected result because the vertical incisions are closer to the visual axis, suggesting a greater effect [57]. However, Nemeth et al. [36] found no significant change in SIA according to the location of the incision when the OCCI was used.

Regarding the LRI method, Lim et al. [22] found a slightly higher SIA for ATR compared to WTR astigmatism using the modified Gills nomogram [58]. However, the differences between the two groups were not assessed statistically.

Stability

A regression of the effect of the incisions over time as a result of the wound healing process is a well-known phenomenon [59]. However, it is believed that this regression occurs during the first three months and then remains stable over time [23, 58]. Lim et al. [22] found a statistically significant decrease in SIA from 2 to 10 weeks after the LRI, which remained stable over the three subsequent years. Chiam et al. [11] reported refractive stability six months after performing the OCCI and the SIA remained more stable in WTR compared to ATR astigmatism.

With regard to femtosecond AK, Byun et al. [47] found no difference in keratometric astigmatism between the 2-month follow-up and the final follow-up of 6 months. These results were similar to those reported by Chan et al. [60], who reported stability in keratometric astigmatism from the 2-month to the 2-year follow-up. This suggests that the results obtained at 2 months are a good indicator of long-term success and would be sufficient to justify a short follow-up period [46].

Complications

Manual relaxing incision

LRI is considered one of the safest surgical techniques available for the treatment of corneal astigmatism during cataract surgery, with low risks of intra and postoperative complications [61]. Cases of perforation, incision gaping, and glare [58] have been described, although the main complications associated with this type of technique are related to keratitis during wound healing, mild epitheliopathy, and dry eye [62]. In the case of the OCCI, there is a greater risk of serious complications, such as wound leak and endophthalmitis, since it involves two paired penetrating incisions [63]. AK is the type of manual incision most likely to lead to adverse visual effects because of its proximity to the visual axis. Other complications have been described, such as microbial keratitis, endophthalmitis, epithelial ingrowth, and corneal ectasia.

Table 5 Manual relaxing incision risk of bias

Author and date	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Fouda et al. 2010 [26]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ouchi et al. 2010 [28]	No	No	No	Yes	No	Yes	No
Ganekal et al. 2011 [7]	Yes	Yes	Yes	Yes	No	Yes	No
Miyata et al. 2011 [37]	Yes	Yes	Yes	Yes	No	No	No
Freitas et al. 2014 [31]	Yes	Yes	Yes	Yes	Yes	Yes	No
Lim et al. 2014 [22]	Yes	Yes	Yes	No	No	Yes	No
Maedel et al. 2014 [35]	Yes	Yes	No	No	No	No	No
Nemeth et al. 2014 [36]	Yes	Yes	Yes	No	Yes	No	No
Razmjoo et al. 2014 [10]	Yes	Yes	Yes	Yes	No	No	No
Roberts et al. 2014 [25]	Yes	Yes	Yes	No	Yes	Yes	No
Titiyal et al. 2014 [24]	Yes	Yes	Yes	Yes	No	No	No
Chiam 2015 [11]	Yes	Yes	Yes	Yes	Yes	Yes	No
Monaco and Scialdone 2015 [23]	Yes	Yes	Yes	Yes	No	Yes	No
Leon et al. 2015 [29]	Yes	Yes	Yes	Yes	Yes	Yes	No
Eliwa et al. 2016 [32]	Yes	Yes	Yes	Yes	Yes	No	No
Lam et al. 2016 [30]	Yes	Yes	Yes	No	No	No	No
Mohammad-Rabei et al. 2016 [27]	Yes	No	No	No	Yes	Yes	No
Roberts et al. 2018 [33]	Yes	Yes	No	Yes	No	No	Yes
Ren et al. 2019 [38]	Yes	Yes	Yes	Yes	No	Yes	Yes
Stanojcic et al. 2020 [34]	Yes	Yes	Yes	No	No	No	Yes

NA, Not applied; *Q*, Question; (*Q1*), Is the study oriented to a clear question?; (*Q2*), Were all the patients results taken into account?; (*Q3*), Was the follow-up complete?; (*Q4*), Were the same conditions used in surgical treatment?; (*Q5*), Was the intervention clearly described?; (*Q6*), Was the duration of follow-up adequate?; (*Q7*), Were the results described correctly?

Table 6 Femtosecond laser-assisted arcuate keratotomy risk of bias

Author and date	Q1	Q2	Q3	Q4	Q5	Q6	Q7
Rückl et al. 2013 [51]	Yes	No	Yes	Yes	Yes	Yes	Yes
Yoo et al. 2015 [43]	Yes	Yes	Yes	Yes	Yes	No	No
Day et al. 2016 [53]	Yes	Yes	Yes	Yes	Yes	No	Yes
Day and Stevens 2016a [44]	Yes	Yes	Yes	Yes	Yes	No	Yes
Day and Stevens 2016b [52]	Yes	Yes	Yes	Yes	No	Yes	No
Baharozian et al. 2017 [45]	Yes	Yes	No	Yes	Yes	No	No
Blehm et al. 2017 [46]	Yes	Yes	Yes	Yes	No	No	No
Löffler et al. 2017 [13]	Yes	Yes	Yes	Yes	Yes	No	No
Byun et al. 2018 [47]	Yes	Yes	Yes	Yes	No	Yes	No
Roberts et al. 2018 [25]	Yes	Yes	No	Yes	No	No	Yes
Lee et al. 2019 [42]	No	No	Yes	Yes	No	No	No
Visco et al. 2019 [48]	Yes	Yes	No	Yes	No	No	Yes
Chen et al. 2020 [41]	Yes	Yes	No	Yes	No	No	Yes
Ganesh et al. 2020 [54]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lim et al 2020 [55]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rani et al. 2020 [49]	Yes	Yes	Yes	Yes	Yes	No	No
Wortz et al. 2020 [50]	Yes	Yes	Yes	Yes	Yes	No	No
Moon et al. 2021 [56]	Yes	Yes	Yes	Yes	Yes	No	Yes
Schwarzenbacher et al. 2021 [40]	Yes	Yes	No	Yes	Yes	Yes	No
Wendelstein et al. 2021 [39]	Yes	Yes	No	Yes	Yes	Yes	Yes

NA, Not applied; *Q*, Question; (*Q1*), Is the study oriented to a clear question; (*Q2*), Were all the patients results taken into account; (*Q3*), Was the follow-up complete; (*Q4*), Were the same conditions used in surgical treatment; (*Q5*), Was the intervention clearly described; (*Q6*), Was the duration of follow-up adequate; (*Q7*), Were the results described correctly?

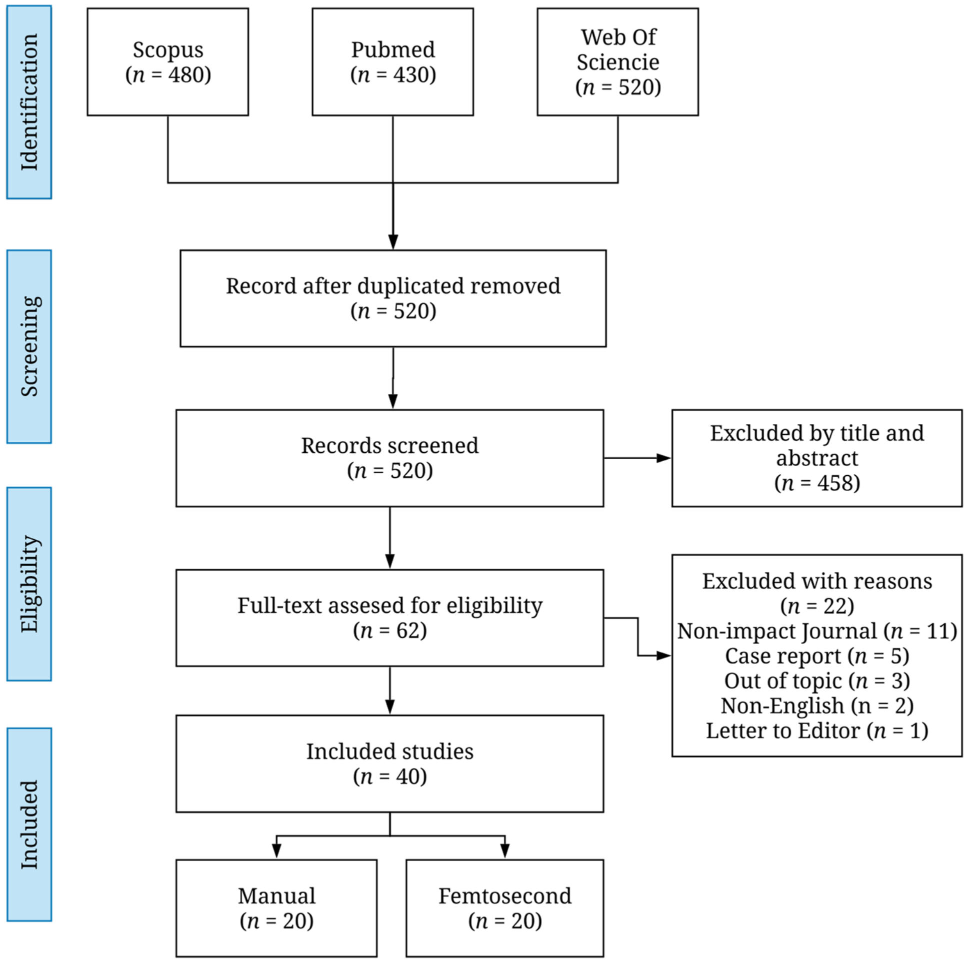

Fig. 1. Flowchart diagram

The studies included in this review did not describe any serious complications throughout the follow-up period. Eliwa et al. [32] reported foreign body sensations and tearing in 43.48% (10/23) of the patients treated with relaxing incisions. These symptoms were also found in the control cases, although to a lesser extent (22.73%; 5/22), and for a shorter time. Fouda et al. [26] had to suture one of the eyes (5%; 1/20) due to overcorrection, successfully reversing the result. In the report by Ouchi et al. [28], one patient experienced a rupture of the posterior capsule, which required the insertion of another IOL and wound suturing (0.5%; 1/192).

Only three studies [23, 26, 38] analyzed corneal aberration changes. Fouda et al. [26] indicated that LRI induces less high order aberration (HOA) spherical aberration accentuation three-months post-astigmatic keratectomy. Ren et al. [38] found that root mean square values of corneal trefoil, spherical aberration, and total high order aberration (HOA) slightly increase without statistically significant differences. Finally, Monaco & Scialdone [23] were in agreement with Ren et al. [38] results and propose LRI as a viable option when toric IOLs were contraindicated.

Femtosecond-assisted arcuate keratotomy

Laser-assisted femtosecond surgery has the advantage of eliminating complications related to inexperienced surgeons making manual incisions. However, other types of complications inherent in femtosecond laser surgery may include gas breakthroughs[64], inadvertent placement of the AK within the visual axis, a gape in the wound, or suction loss [51]. In addition, energy from the femtosecond laser can cause damage to endothelial cells [65]. Although some authors [51] have not reported loss of endothelial cells after AK with femtosecond laser assistance, Kankariya et al. [64] reported a case of anterior gas breakthrough that generated irregular astigmatism and an important overcorrection of corneal astigmatism. Despite this, previous reviews of FLAKs have shown a low rate of complications [66].

None of the studies included in this review reported serious complications associated with AK. However, mild adverse effects have been reported. Rani et al. [49] reported a corneal perforation in a patient during keratotomy without any serious consequences. Roberts et al. [33] had some adverse effects related to laser delivery, such as corneal abrasion in two cases (3.7%) and incomplete capsulotomy in three cases (5.6%). In addition, two patients had postoperative cystoid macular edema. Löffler et al. [13] found dry eye symptoms and foreign body sensations in a few patients in the early postoperative period. Rückl et al. [51] reported suction loss due to a patient's inadvertent movement, which caused a slight misalignment of the incision.

Intrastromal incisions in which the epithelium and endothelium are not damaged could be an advantage over penetrating incisions, where there is a greater risk of complications such as perforation, wound gape, and infection [51]. None of the articles included in the femtosecond group discuss aberrations. Therefore, comparison between both groups was not possible.

In short, although complications inherent to the use of the femtosecond laser technology exist, FLAKs provide greater precision and reproducibility in the depth, length, angulation, and centrality of the incision [67]. In addition, greater control over the shape of the incision could improve postoperative sealing of the wound [12]. The use of FLAK also reduces the risk of incision misalignment due to eye blockage during the incision [68].

Limitations and strengths

To the best of our knowledge, this is the first systematic review to compare the corneal incision techniques (manual and femtosecond laser-assisted) used for the management of astigmatism during cataract surgery. Recent articles published in high-impact journals have also been included. There was equal representation for each of the approaches (50%, manual incision; 50%, FLAK). However, some limitations should be considered. Only articles published in English were evaluated. There was also great variability between the studies in the outcomes reported and in the vector analysis of astigmatism. In some cases, follow-up was insufficient. In addition, many variables are involved in the correction of astigmatism through corneal incisions that cannot be compared in isolation. Standard Alpins method astigmatism vector analysis was absent. Therefore, we should improve our understanding of the factors involved in curvature changes after corneal incisions and thus develop more predictable nomograms. Further randomized clinical trials with a long follow-up period are necessary to determine which of these approaches is superior. As a future research line, we propose to compare this results with toric IOL.

Conclusion

The safety and moderate effectiveness of manual and femtosecond laser-assisted corneal incisions have been confirmed for astigmatism correction during cataract surgery. FLAKs represent greater precision and predictability in the performance of corneal incisions and allow for the standardization of nomograms. However, since visual and refractive outcomes appear to be similar in both cases, the cost-benefit analysis is controversial.

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Declarations

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest All authors declare that they have no conflict of interest.

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