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REVIEW ARTICLE

Femtosecond laser-assisted cataract surgery: an incision efficacy review

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ABSTRACT

Purpose: This study reviewed the scientific literature on corneal incisions in femtosecond laser-assisted cataract surgeries compared to keratome incisions in conventional phacoemulsification.

Conclusion: There are differences in the results of the studies. Automated incisions are more advantageous in the structure of the cut (reproducible tunnel architecture) and healing time of incisions (epithelial and endothelial gap, endothelial misalignment, Descemet membrane detachment and corneal thickening) compared to manual incisions, in addition to astigmatism correction <1.0 diopter with arcuate incisions. The induction of astigmatism and corneal aberrations is similar between the techniques. Incisions with an angle of entry of 110° in the cornea, triplanar shape, and width of <2.65 mm with the femtosecond laser platforms have presented the best results.

Introduction

The gold standard and highly cost effective technique for cataract removal is phacoemulsification[1], which was developed in 1967 by Charles Kelman[2] and performed on approximately 17.7 million people annually[3].

In 2008, femtosecond laser technology was used for the first time in cataract surgery[4]. Ultrashort pulses of light, in femtoseconds (10^{-15} s), generate a photodisruption of the tissue and enable the creation of corneal incisions and capsulotomy and fragmentation of the lens nucleus[5].

The learning curve of femtosecond laser facectomy is approximately 100 cases[6], and the additional cost of its use would be approximately $220 per eye[7].

There is evidence that femtolaser-assisted cataract surgery presents advantages over the conventional technique, such as reduction in the use of ultrasonic energy[8,9,10], reduction in endothelial damage[8,9,11], decreased incidence of corneal edema in the postoperative period[8], and more precise capsulotomy[12].

However, the femtolaser has some disadvantages in relation to the conventional technique, including increased prostaglandin concentration in the anterior chamber[8]; cost-effectiveness[13]; and positioning of the incisions farther from the limbus, toward the clear cornea, which may increase the risk of astigmatism[14].

Meta-analyses showed that the clinical results of visual acuity with and without correction and incidence of complications were similar between femtosecond laser-assisted cataract surgery (FLACS) and conventional phacoemulsification[8,11].

Femtosecond laser platforms allow for various incision configurations. Still, there are surgeons who perform keratome incisions, even in FLACS[15].

A literature review that compares the results of automated and manual incisions, with different equipment, and cutting methods, can support the choice of the technique used and elucidate the best path for future research. The present study aimed to evaluate the literature in relation to the quality and efficacy of corneal incisions with FLACS and conventional phacoemulsification, with different equipment.

Incision morphology

The incision morphology (architecture, length, epithelial and endothelial gap, endothelial misalignment, Descemet membrane detachment (DMD), and corneal thickening) and the risk of astigmatism and corneal aberration are considered indicators of sealing quality and surgical incision healing[16-23].

Endothelial gap is the apposition of the incisional edges of the posterior cornea[17] and indicates incomplete sealing of the incision. It is related to increased risk of astigmatism[16] and corneal thickness[13] and may delay visual rehabilitation.

Endothelial misalignment is the misalignment of the edges in the posterior cornea and caused by retraction of the limbar margin or thickening of the incision roof after hydration, indicating incomplete healing[19]. Its clinical effect is unknown, but it is supposed to induce changes in the anterior and posterior curvatures of the cornea and, consequently, alter corneal power, and astigmatism[19].

The main risk factors for localized DMD are advanced age, preexisting endothelial diseases, prolonged surgical time, hard cataracts, irregular corneal incisions, and inadvertent incisional trauma with blunt instruments or phacoemulsification probe[22]. DMD impedes the endothelial pump mechanism, which hinders the complete sealing of the incisional wound and consequently increases endothelial gap and corneal thickening at the incision site, leading to slower visual recovery[22,23].

Optical coherence tomography can be used to assess corneal features and guide treatment decisions[24] and was used in the following studies to investigate the morphological results of automated and manual incisions.

A prospective, nonrandomized case series study analyzed triplanar incisions, 2.5 mm wide and 1.8 mm tunnel length, in FLACS (LenSx, Alcon Laboratories, Inc., Fort Worth, TX) and compared the incisional changes in two periods in the surgery. The first examination was performed after the laser application but before the phacoemulsification phase, while the second examination was performed immediately after completion of the facectomy. The mean corneal thickness at the incision site was significantly higher in the second examination than in the first. The incidence rates of endothelial gap were 18% in the first exam and 91% in the second exam, while the incidence rates of DMD were 0% and 45%, respectively ($P < 0.05$). The data revealed that the complications did not occur due to the application of femtosecond laser but due to the surgical steps that followed it. Postoperatively, the prevalence rates of endothelial gap were 82%, at day 1 and 55% after 1 month. The prevalence rates of DMD were 36%, at day 1 and 0% after 1 month[25].

Rodrigues et al. (2019) in a nonrandomized prospective cohort analyzed 2.75-mm incisions of the surgical groups with the Victus femtolaser (Technolas/Bausch & Lomb, Munich, Germany) and keratome and found the following results: prevalence rates of endothelial gap of 77.8% vs 100% ($P = 0.47$) at day 1 and 22% vs 75.6% ($P = 0.33$) after 30 days; DMD of 33.3% vs 66.7% ($P = 0.35$) after day 1 and 0.0% vs. 11.1% ($P = 0.99$) after 30 days; and corneal edema of 88.9% vs. 77.8% ($P = 0.99$) at day 1 and in no eye after 30 days. The femtolaser was used to perform triplanar cutting in all cases, while the manually constructed architecture varied between uniplanar (22.2%), biplanar (44.4%), and triplanar (33.3%) incisions, with a significant difference ($P = 0.009$). The incidence rate of <50% loss of total sealing was significantly higher with automated incisions (100% vs 44%, $P = 0.03$) on the first postoperative day, with no difference after 30 days (22.2 % vs. 22.2%, $P = 0.99$)[26].

A prospective nonrandomized study by Titiyal et al. (2018) identified that, on the first postoperative day, DMD was statistically more frequent in the conventional phacoemulsification group (49.35%), with a keratome incision of 2.2 mm in diameter, than in the FLACS group (9.61%), with the LenSx platform (Alcon Laboratories, Inc., Fort Worth, TX) ($P < 0.001$). This alteration occurred more frequently after the stromal hydration step (83.7%), and in all cases, it was resolved within 1 month after surgery[27].

In a randomized study, incisions made by femtolaser showed less altered morphology (percentage of epithelial and endothelial gap and endothelial misalignment) than manual incisions. The increase in corneal thickness at the incision site was greater in the manual group than in the femto group, which was measured 30 and 180 days after surgery ($P < 0.05$)[28].

A series of cases compared incisions with femtolaser (Catalys, Johnson & Johnson, Santa Ana, CA) and 2.65-mm blade at 1 month after surgery. Triplanar incisions with a keratome were achieved in only 19% of cases. There was no difference in tunnel length (femto, 1.99 ± 0.07 mm, vs keratome, 2.04 ± 0.23 mm, P = 0.39). Some level of endothelial gap was found in all incisions; the gap ranged from 0.05 to 0.21 mm in the femto group and from 0.10 to 0.42 in the keratome group (P = 0.03). The femto group had a significantly lower prevalence of endothelial misalignment (P = 0.022) and DMD (0.0% vs 18.75%, P = 0.04)[29].

In 2018, a prospective review by Wang et al. evaluated the morphology of corneal incisions. Compared to the control group (steel blades), the femtolaser group (LenSx Alcon Laboratories, Inc., Fort Worth, TX) had a significantly lower incidence of endothelial gap at day 1 (P = 0.12) and lower incidence of DMD after 1 week (P=0.03), 1 month (0.048), and 3 months (0.048). Corneal thickening at the incision site decreased over time in both groups[29].

Another prospective case series compared incisions with femtolaser (Catalys, Johnson & Johnson, Santa Ana, CA) and manual, 2.65 mm, without stromal hydration, at the end of surgery. He separated the eyes into three groups: group A with femtolaser and 110° entry angle, creating a greater valvular effect in the incision; group B with femtolaser and 70° angle; group C with manual incisions. The intraocular pressure (IOP) that would cause the incision to leak were tested at 1 day, 2 weeks, and 1 month; the mean IOP that caused fluid to leak through the incision was as follows: group A, 28.20 mm Hg ± 11.69; group B, 15.07 ± 10.64 mm Hg (P = 0.005), and group C, 9.93 ± 9.90 mm Hg ($P < 0.001$). On the first postoperative day, the Seidel test was positive in 0% of the cases in group A, 53% in group B, and 87% in group C. Therefore, the femtolaser created incisions with better integrity, especially when performed with a cutoff angle of entry into the larger cornea[31].

Studies show significant differences in the morphology and healing time of incisions created by femtolaser and keratome blades. This difference in healing time can translate into greater speed of visual recovery.

Incisions with an angle of entry of 110° in the cornea, triplanar shape, and width < 2.65 mm, with the platforms LenSx (Alcon Laboratories, Inc., Fort Worth, TX) and Catalys (Johnson & Johnson, Santa Ana, CA), seem to have presented the best results.

Risk of astigmatism and corneal aberrations

Fernandéz et al. (2018) concluded that temporal incisions, 2.5 mm wide and 1.5 mm long, with the femtolaser (Victus, Technolas/Bausch & Lomb, Munich), induced similar amount of astigmatism to those manual incisions with a 2.2-mm keratome. The mean surgically induced astigmatism (SIA) for right eyes was 0.14 D (manual) and 0.24 D (femto) ($P > 0.05$) and for left eyes 0.15 D (manual) and 0.19 D (femto) ($P > 0.05$)[32].

A prospective case series with FLACS (LenSx, Alcon Laboratories, Inc., Fort Worth, TX) found the following SIA results after 3 months of surgery: anterior cornea, 0.25 D ± 0.15 D ($P = 0.002$); posterior cornea, 0.16 ± 0.11 D ($P = 0.395$); and total cornea, 0.28 ± 0.17 D ($P = 0.013$)[33].

A study by Serrao et al. (2017) compared 2.75-mm triplanar incisions with a keratome and femtolaser (150 kHz Intralase iFS femtosecond laser). Both techniques induced minimal change in the amount of astigmatism of the anterior cornea ($P > 0.05$). However, the automated incisions induced less alteration in the direction of the astigmatism vector ($P < 0.05$) at 1 week and 1 month. Manual incisions significantly increased high-order aberrations (HOA) in 3.5-mm and 6.0-mm pupils, while automated incisions increased HOA only in 6.0-mm pupils. There was a significant difference between the techniques, in favor of femtolaser, in the induction of HOA in 3.5-mm pupils after 1, 3, and 6 months ($P < 0.02$), and 6.0-mm pupils after 3 and 6 months ($P < 0.05$)[34].

In a prospective case series with incisions 2.0 mm wide and 2.2 mm long, the SIA was statistically higher in the laser group (LenSx, Alcon Laboratories, Inc., Fort Worth, TX) than in the manual group at 1 day, 1 week, 1 month, and 3 months. There was a difference in mean corneal thickness at the incision site between the two groups at 1 day and 1 week ($P = 0.001$) but not after 1 month ($P = 0.311$) and 3 months ($P = 0.749$). The authors hypothesized that the inaccuracy of the incision positioning caused this result because the manual incisions were more peripheral than the automated ones ($P = 0.001$)[14].

Mastropasqua et al. (2014) did not find a difference in the induction of astigmatism and corneal aberrations between the two techniques. Keratometric astigmatism was significantly lower in the femtolaser incision group after 30 and 180 days ($P < 0.05$)[28].

A prospective randomized study compared 2.8-mm manual incisions and those with femtolaser (LenSx, Alcon Laboratories, Inc., Fort Worth, TX). The SIA was similar between the manual group (0.41 ± 0.14) and femto group (0.47 ± 0.13) ($P = 0.218$). The HOA significantly increased in both groups after cataract surgery (manual, 0.13 ± 0.05 to 0.15 ± 0.05, $P = 0.025$; femto, 0.13 ± 0.09 to 0.18 ± 0.12, $P = .002$) but with no statistical difference between the techniques. The values of low-order aberrations and total corneal aberration remained stable in both groups ($P > 0.05$)[36].

Triplanar incisions with femtolaser, 2.2 mm wide and 1.50 mm long, did not alter the HOA of the cornea at 1 month postoperatively. Additionally, the prevalence rate of endothelial gap was 0% at 1 day, and that of endothelial misalignment was 5%, at 1 month[36].

The data on risk of astigmatism and corneal aberrations allow us to conclude that, with the configurations of incisions and laser platforms, one technique had no advantage over the other. Smaller incisions seem to have induced less astigmatism. Updates that allow better identification of the corneal limb and tests with different patterns of incision architecture can optimize the results with femtolaser technology.

Arcuate incisions

Residual astigmatisms >0.75 D may reduce visual acuity and increase patient visual dissatisfaction[37,38].

The effects of astigmatism correction by corneal arcuate incisions increase according to length[40], depth, distance from the limbus, patient's age[39,40,41], and all predictors of SIA[42]. The correction stabilizes between 3 and 6 months after surgery[39,43].

Femtosecond laser platforms allow you to control the positioning, width, and depth of arcuate incisions. Penetrating and intrastromal cuts (do not open anteriorly) with femtolaser are effective in reducing the incidence of corneal astigmatism[44].

Corneal biomechanics and the astigmatism meridian are independent predictors of the effectiveness of intrastromal incisions[45]. Intrastromal arcuate keratotomy is more predictable[46] and potentially leads to a lower risk of complications, such as infection, tunnel gap, and epithelial ingrowth in the anterior chamber[39.47].

Penetrating and intrastromal cuts with femtolaser have been effective in correcting mild and moderate astigmatisms[46,48]. A literature review by Chang et al. (2018) with automated incisions in virgin eyes concluded that penetrating incisions reduced astigmatism between 26.8% and 58.62%, and intrastromal cuts reduced between 36.3% and 58%. In posttransplant eyes, the results ranged between 35.4% and 84.77% with penetrating incisions and between 23.53% and 89.42% with intraestromal incisions[47]. Femtolaser has been effective in correcting astigmatism in corneas after penetrating transplantation or deep anterior lamellar keratoplasty[49].

Visco et al. (2019) found that 85.2% of cases had corneal astigmatism >0.50 D preoperatively. After treatment with femtolaser arcuate keratotomy (LENSAR Laser System, LENSAR, Inc.), 95.8% of cases had astigmatism ≤0.50 D. The mean total change in corneal astigmatism was 0.72 ± 0.51. Compared to the preoperative corneal cylinder of 0.92 ± 0.34 D, postoperative refractive astigmatism significantly decreased to 0.14 ± 0.23 D ($P < 0.001$)[50].

In a case series published by Day and Stevens (2016), femtolaser-arcuate incisions (Catalys, Johnson & Johnson, Santa Ana, CA) corrected, on average, 0.71 ± 0.43 D of the intended astigmatism of 1.24 ± 0.44 D or 59% ± 31% of the total[45].

A retrospective study analyzed penetrating arcuate incisions with femtolaser (LenSx, Alcon Laboratories, Inc., Fort Worth, TX). The mean preoperative astigmatism was 1.36 ± 0.44 D, and the mean SIA was 0.82 ± 0.43 D (60% correction) postoperatively[42].

An interventional clinical study evaluated cases of corneal astigmatism >0.50 D treated with femtolaser-arcuate incisions (LenSx, Alcon Laboratories, Inc., Fort Worth, TX). The mean astigmatism significantly decreased from 1.65 ± 0.83 D to 0.59 ± 0.54 D ($P < 0.001$) after 3 months of surgery, resulting in an SIA of 1.05 ± 0.44 D (64% correction). No complications were reported, and the eyeglass independence rate was 82.3%[51].

In a randomized case-control study, with target astigmatism of 1.50 D in the group of limbar relaxing incisions and 1.38 D in the group of intrastromal arcuate incisions with the femtolaser (LenSx, Alcon Laboratories, Inc., Fort Worth, TX), the SIA was 1.02 D versus 1.23 D (P = 0.21), and the index correction was 0.48 versus 0.73 (P = 0.02). The percentage of cases that reached a postoperative cylinder <0.50 D was 20% and 44%, with the manual, and automated technique, respectively (P = 0.01)[52].

A prospective case series evaluated femtolaser treatment (LenSx, Alcon Laboratories, Inc., Fort Worth, TX) to correct astigmatisms between +0.75 and +2.50 D. The mean astigmatism decreased by 47%, from 1.31 ± 0.41 D, preoperatively, to 0.69 ± 0.34 D, after surgery ($P < 0.01$)[53].

Sanmillan et al. (2023) developed an algorithm that considered the corneal biomechanics to improve the predictability of arcuate incisions with the LDV Z8 femtolaser (Ziemer Instruments, Port, Switzerland) and managed to reduce preoperative refractive astigmatism by 38% (−1.39 ± 0.79 D–−0.86 ± 0.67 D, $P = 0.02$)[54].

Ahn et al. (2022) compared the conventional phacoemulsification group with the arcuate incision group (80% deep) with FLACS (LenSx, Alcon Laboratories, Inc., Fort Worth, TX) for treatment of corneal astigmatism up to 3.00 D. The mean preoperative astigmatism was 0.85 ± 0.58 D in both groups, while the SIA was significantly higher after femtolaser treatment (0.82 D) than with the limbar relaxing incisions (0.63 D) (P < 0.001). However, when treating astigmatism <0.75 D, there was hypercorrection in 58.9% of cases with femtolaser and 48.8% with manual incisions[55].

After arcuate incisions in cataract surgeries with astigmatisms <1.0 D, more eyes achieved a result of ≤0.5 D in the FLACS group (Catalys Precision Laser System, Johnson &Johnson & Johnson, Irvine, CA) (89%) than in the conventional surgery group (71%) (P = 0.001). The preoperative cylinder decreased from 0.61 ± 0.18 D in the FLACS group and 0.57 ± 0.20 D in the conventional group to 0.43 ± 0.4 D and 0.26 ± 0.28 D, respectively, with a significant difference between the groups (P < 0.001). The percentage of patients with uncorrected visual acuity of 20/20 was 62% and 48%, respectively (P = 0.025)[56].

A prospective study concluded that manual penetrating incisions and femtolaser incisions (LenSx, Alcon Laboratories, Inc., Fort Worth, TX) are efficient for correction of corneal astigmatism, between 0.50 D and 1.75 D, with no statistical difference between the techniques. Mean corneal astigmatism in the manual group decreased from 0.98 ± 0.39 D preoperatively to 0.70 ± 0.40 after 3 months and from 1.05 ± 0.33 D to 0.63 ± 0.34 D in the femto group. The residual cylinder significantly decreased in both groups, from 1-month postoperative exam to the 3-month postoperative exam. Moreover, 95% of the eyes in the femto group and 89% in the manual group achieved refractive astigmatism ≤0.50 D after 3 months. Uncorrected visual acuity was similar between the groups, at 1, and 3 months[57].

A literature review by Gonzáles-Cruces et al. (2022) evaluated manual arcuate incisions versus femtolaser incisions. The mean correction of astigmatism was similar between the groups (manual = 0.77 ± 0.18, femto = 0.79 ± 0.17). The mean uncorrected visual acuity was 0.19 ± 0.12 and 0.15 ± 0.05

logMAR, for manual incisions with keratome and arcuate with FLACS, respectively (P = 0.39). Refractive stability occurred at 3 month[43].

The accuracy of femtolaser to correct astigmatisms from 1.25 to 3.0 D is less than that of toric intraocular lenses. The mean astigmatism at 3-month postoperative period was −0.63 ± 0.55 D in the toric lens group and −0.90 ± 0.53 D in the femtolaser group (*P* = .037) against a preoperative total corneal astigmatism of 2.16 ± 0.39 and 1.96 ± 0.55, respectively. Residual cylinder of up to 1.00 D was achieved in 84% and 64% of cases, respectively. Therefore, toric intraocular lenses are the best option for correction of astigmatisms >1.0 D[58].

Manual and femtolaser arcuate keratotomies are safe and effective, but the latter is more accurate and predictable[43], as well as fast, adjustable, and safe to reduce mild and moderate corneal astigmatisms[39,53]. The development of new nomograms can further improve the results[39].

Conclusions

The femtosecond laser proved to be efficient in the construction of precise and safe corneal incisions, with faster healing than keratome incisions. However, the general data show that the techniques are similar in inducing astigmatism and corneal aberrations. Some studies have shown statistical relevance in favor of automated arcuate incisions in relation to manual ones for astigmatism correction. Toric intraocular lenses are still the best alternative for treating cylinders >0.75 D.

To determine the best incision configuration with the femtosecond laser, further studies will be able to test different cutting angles in the anterior and posterior regions of the cornea, depth of the lamellar cut, level of energy used, and spacing between the points and layers of laser application.

Studies of new technologies and techniques for facectomy should include, in the future, in addition to traditional data (incision, capsulotomy, ultrasound energy, visual acuity, and complications), secondary data related to health (physical and mental well-being), quality of life (independence of glasses), and visual function (dysphotopsies)[59].

Conflicts of Interest Statement:

The authors have no conflicts of interest to declare.

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