Review Article

Reviewing the visual benefits of femtosecond laser-assisted cataract surgery: Can we improve our outcomes?

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Femtosecond laser-assisted cataract surgery (FLACS) was introduced in 2009 and has increasingly been incorporated into surgical practice. The automation of three key aspects of cataract surgery was expected to deliver a significant improvement in both refractive and safety outcomes. The published literature has not yet shown consistent refractive improvement above conventional techniques. The purpose of this paper is to review current FLACS refractive outcomes and explore factors that may have contributed to the current findings and whether future improvements are possible.

Key words: Capsulotomy, femtosecond laser cataract surgery, incisions, refraction

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The introduction of novel technology to clinical or surgical practice is not a risk-free option, and the decision to incorporate any new development may be considered controversial, particularly if the current standard appears to provide consistently good outcomes. The desire to improve results means that ophthalmology, indeed all of medicine, is littered with examples of technology introduced before long-term data and established clinical trials.

The concept of femtosecond laser-assisted cataract surgery (FLACS) was introduced in 2009 with incorporation into routine surgical practice occurring in 2010.[1,2] The precision and reproducibility provided by the laser platform was expected to positively impact both the safety and accuracy of cataract surgery. Since the introduction of FLACS, over 300 articles have been published in the peer-reviewed literature; however, despite this apparent wealth of data the assertion that FLACS may provide a visual benefit over current standard manual phacoemulsification, for the most part, remains unfounded.[3] As Chang recently stated, this may suggest that "FLACS remains an impressive but expensive technology in search of a compelling indication."[4] This is an important consideration and is at the heart of the current conundrum of whether FLACS represents a valuable addition for both the patient and the practice. However is this where our emphasis should lie?

Randomized controlled trials (RCTs), remain the gold standard for evidence-based medicine.[5] Criticism of most FLACS meta-analyses remains the relative dearth of well-designed RCTs.[3,6,7] Given that two large-scale RCTs are currently underway, it may be reasonably expected that the evidence from these trials will provide confirmation as to the equivalence (or indeed superiority) of either manual or FLACS techniques.[8,9] On this basic level, these studies should allow surgeons to make a firm decision whether the FLACS procedure should be incorporated into current practice. However, the central tenet of our medical knowledge remains the understanding of the basic mechanisms of disease and treatment. Although we have markedly improved refractive and safety outcomes through recent time, our understanding of cataract surgical variables remains incomplete. If we view surgery from this perspective then perhaps we may be able to understand FLACS and its true potential role for the cataract procedure. This review will focus on the reported visual and refractive outcomes of FLACS, summarizing the main factors that contribute to poor or decreased visual outcomes and through discussion, explore how the introduction of FLACS may have contributed to our understanding of these concerns and how this may impact future results.

The Progression of Accuracy

From the first intraocular lens (IOL) implant in 1949, surgeons have retained an acute awareness of the impact of a refractive surprise. Although Ridley's initial surgery was declared a

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success, the patient was found to have a residual error in excess of 20D.[10] Among the errors contributing to this result was a significant difference, and therefore effect, of using a material with a higher index of refraction compared to the natural lens.[11] IOL designs and materials improved over time however as the focus of improvement remained on reducing intraoperative complications, our understanding and calculation of the essential refractive variables did not keep pace with surgical innovation. A prime example was surgeons' use of an IOL with a constant power which remained a feature of many practices well into the 1980s. Although a reasonable majority of patients may have achieved acceptable refractive results, Olsen showed that a fixed IOL may have resulted in a refractive surprise >5D in at least 5% of patients.[12] Results improved with the development of basic optical formulas, and the use of regression IOL calculation formulas served to further refine both systematic errors and biometric assumptions.[13] Limitations to achieving the optimal outcome on a consistent basis still persist. Preussner claimed individual prediction errors, typically 0.5–1.0 D, appeared to be unavoidable.[14] As recently as 2008, Norrby estimated that the lowest mean absolute error (MAE) achievable with then current formulae was between 0.36 and 0.40D.[15] This result implied that the maximum proportion of patient outcomes within ± 1D of the postoperative target refraction remained between 95% and 97%.[15] In practice, approaching this level appeared to be more difficult. Through the implementation of benchmark standards in the National Health Service, Gale *et al*. found that 79.7% of patients were able to achieve a final spherical equivalent within ± 1D of the intended target although this subsequently rose to 87.0% with the use of optimized A constants and partial coherence interferometry. Outcomes within ± 0.5D for the same study were between 48.9% and 60.2%.[16] A United Kingdom audit of 180,114 eyes undergoing cataract surgery between 2006 and 2010 found that for eyes without co-pathology, postoperative uncorrected visual acuity (UDVA) of 6/12 may be achieved in 80.9% of cases. Only 27.3% of eyes achieved UDVA of 6/6 or greater in the same study.[17] More recently, a significant database using a single formula optimized to the individual surgeon found that only 1% of surgeons attained an accuracy of 92% within ± 0.5D, with most surgeons clustered around 78% within this range.[18] Progress has clearly been made however further work is necessary.

Where is the Evidence of a Femtosecond Laser-assisted Cataract Surgery Visual Advantage?

Koch *et al*. recently identified a number of key variables that will improve the accuracy of postoperative refractive outcomes, including postoperative effective lens position (ELP), total corneal measurement, and availability of IOLs in smaller dioptric increments.[19] Most of these variables will be driven by improvement in external technology or formulae; however, surgical technique will continue to play a significant role. We will examine these in the context of current FLACS comparative literature.

Refractive parameters

Cataract surgery as a form of refractive surgery became possible with the introduction of small incision surgery and foldable lenses. Since that time, surgeons have attempted to refine the refractive outcomes to optimize visual acuity. The MAE provides the most valid indication of the difference between target and outcome.[20] The available comparative MAE outcomes between FLACS and conventional cohorts are listed in Table 1.

On review of the studies above, one can be certain only that by 2017, there is no dominant technique in terms of refractive accuracy. It is worth looking closer at these findings. Brunin *et al*. in a prospective matched cohort of residents undertaking FLACS and conventional surgeries show no difference between cohorts at 1 or 12 months postoperative.[21] Of interest, the FLACS results worsen postoperatively from 0.38 ± 0.24D to 0.49 ± 0.63D. Alternately, the conventional group improves outcomes from 0.41 ± 0.49D to 0.34 ± 0.26D at 12 months.

Table 1: Comparative values for mean absolute error in femtosecond laser-assisted cataract surgery literature

First author	Journal/year	FLACS MAE (*n*)	Conventional MAE (*n*)	Statistically significant	Methodology
Brunin	Graefes 2017	1M 0.38±0.24 D 12M 0.49±0.63 D (57)	1M 0.41±0.49 D 12M 0.34±0.26 D (67)	No	Prospective comparative
Manning	JCRS 2016	0.43±0.50 D (2814)	0.40±0.40 D (4987)	No	Prospective matched
Oakley	Clin Exp Ophthalmol 2016	0.65±0.49 D (323)	0.56±0.50 D (95)	No	Prospective comparative
Ewe	Ophthalmology 2016	0.41±0.37 D (988)	0.35±0.38 D (888)	Yes	Prospective comparative
Yu	Lasers Surg 2015	0.16±0.16 D (25)	0.74±0.65 D (29)	Yes	Prospective comparative
Chee	AJO 2015	0.30±0.25 D (794)	0.33±0.25 D (420)	No	Prospective cohort
Krarup	Acta Ophthalmol 2014	0.37±0.33 D (47)	0.41±0.42 D (47)	No	Prospective Intra-individual
Roberts	Clin Exp Ophthalmol 2013	0.29±0.25 D (113)	0.31±0.24 D (105)	No	Nonrandomised comparative
Abell	Ophthalmology 2013	−0.51±0.50 D (150)	−0.45±0.71 D (51)	No	Prospective comparative
Lawless	JRS 2013	0.26±0.25 D (61)	0.23±0.16 D (29)	No	Prospective cohort
Filkorn	JRS 2012	All 0.38±0.28 D <22 mm 0.43±0.41 D >26 mm 0.33±0.24 D	All 0.50±0.38 D <22 mm 0.63±0.48 D >26 mm 0.63±0.42 D	Yes	Prospective comparative
Mihaltz	JRS 2011	−0.6±1.50D sphere 1.30±1.01 cylinder (48)	−0.5±1.40D sphere 1.10±1.10 cylinder (51)	No	Nonrandomised comparative

FLACS: Femtosecond laser-assisted cataract surgery, MAE: Mean absolute error

Crucially 15/57 and 32/67 in the FLACS and conventional groups, respectively, did not attend follow-up or were removed from analysis for insufficient information. This was due to the practice's location and postsurgery referral methods; however, the results are impacted significantly as a result. Manning *et al*. provide the largest study to date in conjunction with the European Outcomes Registry project.[22] The authors found the conventional group were statistically, but not clinically significantly better than the matched FLACS cohort. The cohorts were matched preoperatively however due to the registry data collection follow-up visits were limited to 2 months, there was no independent validation of the results and no consideration to additional variables including capsulotomy centration. There were several significant differences in the groups; the FLACS group contained more postrefractive surgery and pseudoexfoliation eyes hence more difficult cases in terms of refractive accuracy.[23,24] Ewe *et al.* describe a statistically more accurate cohort of conventional surgery cases from two separate surgery centres.[25] Correspondingly, the authors found that the FLACS cohort had significantly better-corrected distance vision acuity (CDVA) postsurgery. Although the authors attempted to match the cohorts preoperatively there were differences, which may have accounted for both findings including a greater percentage of eyes with astigmatism requiring toric IOLs in the FLACS group and poorer preoperative corrected vision in the conventional cohort. The most significant difference in terms of MAE may be found in the article by Yu *et al*.[26] The FLACS MAE of 0.16 ± 0.16D represents the lowest published MAE for FLACS outcomes, which presents a possible insight to the outcomes achievable. The authors further report a significant increase in the absolute deviation between attempted and achieved capsulorhexis diameter which may suggest improved IOL stability as a differentiating factor between group outcomes. The outcomes are further enhanced by the long mean axial length in both groups and that >50% of eyes were classified as Grade III or IV cataracts. Unfortunately, the sample size of both groups remains too low to confirm these findings as a clinical benefit for FLACS. Of note, the best-CDVA postoperatively did not appear to reflect the refractive outcomes for the FLACS cohort (LogMar 0.12 ± 0.09 vs. 0.33 ± 0.56 for the conventional group). Earlier in 2013, Abell *et al*. in a paper that emphasized effective phacoemulsification time, indicated equivalent, if not slightly improved outcomes in a prospective matched cohort of conventional cases.[27] However, follow-up visits were at 3 weeks only and results were taken by autorefraction. Although refractive outcomes were not the emphasis of the paper, this highlights the need for consistent methodology. Filkorn *et al.* provide the only other paper with statistically significantly better outcomes for a matched FLACS cohort.[28] The authors used optimized A constants for all power IOL calculation formulas to provide an additional measure of equivalence. The difference was greater in eyes with both short (<22 mm) and long (>26 mm) axial length which the authors hypothesized may be related to the influence of IOL tilt, decentration and anteroposterior movement postsurgery. This reflected the groups earlier findings which detailed better shaped and centred capsulotomies leading to smaller variations in IOL position.[29,30] The study sample size is moderate and the number of eyes with extreme axial lengths is not known. Both Chee *et al*. and our own group found no difference in separate studies in terms of MAE however of interest, both studies reported a significant improvement in the percentage of patients that achieved uncorrected vision of 6/7.5 or better postoperatively.[31,32] In their discussion, Chee *et al*. suggested that such incremental benefits of enhanced visual outcomes may not be subjectively appreciated by the average patient. This is of course supposition; however, it highlights the potential need to improve or find more appropriate measurement outcomes.

The overall IOL prediction accuracy may be indicated by the percentage of patients that achieve spherical equivalent within 0.5D and 1D of the intended target. Few comparative papers exist in the FLACS literature. However, these are listed for review in Table 2. Findings are broadly similar to the MAE literature with most studies finding a marginal, but not statistically significant, improvement for either FLACS or conventional procedures.[22,27,33,34] Ewe *et al.* found that 82.6% of conventional patients were within 0.5D of the intended refractive outcome against only 72.2% in the FLACS cohort.[25] The findings mirrored a corresponding improvement in MAE. However, this may have been impacted by the greater percentage of astigmatism patients in the FLACS cohort. In an intraindividual randomized trial, Conrad-Hengerer *et al.* found contrary findings with a significant increase in the percentage of patients achieving outcomes within 0.5D of the refractive target.[35] The authors found that overall FLACS led to faster visual recovery and earlier stabilization of both the anterior chamber depth and patient refraction suggesting these results may reflect several factors including the influence of the capsulotomy. The intraindividual, randomized methodology of the trial provided the optimal comparative cohort; however, the sample size remained moderate and reflects the difficulty associated with carrying out such trials. There was no power calculation described by the authors, and they note that additional testing is required to provide further evidence of the surgical effect.

Meta-analyses may be expected to overcome the potential shortcomings of the study methodology and variable sample sizes. The results of recently published FLACS meta-analyses,

Table 2: Comparative values for refractive target±0.5D in femtosecond laser-assisted cataract surgery literature

First author	Journal/year	FLACS ±0.5D, *n* (%)	Conventional ±0.5D, *n* (%)	Statistically significant	Methodology
Manning	JCRS 2016	2814 (72)	4987 (74.3)	No	Prospective matched
Ewe	Ophthalmology 2016	988 (72.2)	888 (82.6)	Yes	Prospective comparative
Kanellopoulos	Eye Vis (Lond) 2016	67 (80.6)	66 (75.2)	No	Prospective comparative
Conrad-Hengerer	JCRS 2015	100 (92.0)	100 (71.0)	Yes	Randomised intra-individual cohort
Roberts	Clin Exp Ophthalmol 2013	113 (83.2)	105 (81.9)	No	Prospective comparative

FLACS: Femtosecond laser-assisted cataract surgery however, do not appear to add clarity to the existing comparative literature despite the availability of the same data to analysts [Table 3]. Ye *et al*. found a small but significant improvement in MAE in favour of FLACS patients.[36] There was no difference in uncorrected or corrected acuity. Day *et al*. arrived at similar conclusions to Ye *et al.* with a marginal but clinically insignificant advantage to FLACS in MAE and CDVA.[37] Due to concerns with the low certainty of the available evidence; however, only three studies were utilized in the refractive and visual comparisons. The authors proposed the introduction of standardized reporting of both complications and visual and refractive outcomes to facilitate future data synthesis. Popovic *et al*. included data from both RCTs and observational cohort studies to include 14,567 eyes for analysis. With this extended sample size, the authors did not find any significant differences across visual or refractive variables.[3] The authors highlight the potential inclusion of measures of visual quality such as contrast sensitivity and higher order aberrations to allow ophthalmologists to better understand the impact of surgery.

The role of capsulotomy as a potential refractive variable

A properly constructed capsulorhexis will provide the foundation for lens extraction and stable IOL fixation.[38] In 1999, Cekic and Batman demonstrated that a difference in capsulorhexis size subsequently resulted in a longer anterior chamber depth.[39] This was the first paper to suggest that postoperative anterior chamber depth and thereby refractive outcomes may be influenced by the creation of the capsulotomy. That FLACS was able to provide a consistently sized and circular capsulorhexis raised hopes of a clinical improvement. Tables 4 and 5 identify the comparative literature with respect to the available capsulotomy variables. The evidence clearly supports a FLACS-created capsulotomy as having a better shape and consistency of size compared to conventional procedures. The evidence that this leads to a clinical improvement in refractive parameters is less clear.

Yu *et al*. have described the most significant difference between FLACS and conventional refractive outcomes.[26] Not surprisingly the authors also note a significant difference between capsulotomy parameters for both groups. At 1 month, the difference from intended diameter was over 3 times larger in the conventional group. This was reduced to approximately twice the difference at 3 months. As the authors describe a more stable refraction over time in the FLACS group, it implies that the FLACS capsulotomy is an integral feature in the postoperative positioning of the IOL and thereby outcome. The mean axial length of 25.09 ± 2.85 and 26.94 ± 4.46 for FLACS and conventional groups, respectively, may have served to amplify the impact of possible IOL displacement. In their small randomized clinical trial, Toto *et al*. found that FLACS capsulotomies achieved a lower deviation from intended and better IOL centration.[40] This provided lower postoperative variability of the IOL position but crucially perhaps; this did not appear to impact the median absolute error, which although lower in the FLACS group, did not reach statistical difference. Panthier *et al*. describe FLACS capsulotomies as

Table 3: Recent meta-analysis of femtosecond laser-assisted cataract surgery literature (uncorrected distance visual acuity, corrected distance visual acuity, mean absolute error)

First author	Journal/year	Number of articles included (eyes)	UDVA	CDVA	MAE
Ye	J Ophthalmol 2017	10 RCT	WMD: −0.01 95% CI: −0.13-0.10 *P*=0.80	WMD: −0.03 95% CI: 0.07-0.00 *P*=0.09	WMD: −0.17 95% CI: −0.32-−0.02 *P*=0.02*
Popovic	Ophthalmology 2016	15 RCT, 22 observational cohort studies (14,567)	WMD: −0.02 95% CI: −0.04-0.01 *P*=0.19	WMD: −0.01 95% CI: −0.02-0.01 *P*=0.26	WMD: −0.02 95% CI: −0.07-0.04 *P*=0.57
Day	Cochrane Database 2016	16 RCT (*n*=1638 in total)	WMD: −0.06 95% CI: −0.26-0.14 *P*=NS	WMD: −0.03 95% CI: −0.05-−0.00 *P*<0.05*	WMD: −0.18 95% CI: −0.27-−0.09 *P*<0.05*

UDVA: Uncorrected distance visual acuity, CDVA: Corrected distance visual acuity, MAE: Mean absolute error, WMD: Weighted mean difference, CI: Confidence interval, RCT: Randomized controlled trial

Table 4: Comparative values for capsulotomy creation in femtosecond laser-assisted cataract surgery literature

First author	Journal/year	FLACS (*n*)	Conventional (*n*)	Statistically significant
Pajic	Sensors 2017	5.0±0.12 mm (68)	4.7±0.36 mm (62)	Yes
Titiyal	Clin Ophthalmol 2016	4.9±0.1 mm (40) Mean circularity index 0.996±0.003	5.3±0.4 mm (40) Mean circularity index 0.909±0.047	Yes
Yu	Lasers Surg Med 2015	Difference from intended diameter: 1M 192±212 µm 3M 256.6±181.9 µm	Difference from intended diameter: 1M 626.9±656.6 µm 3M 572.1±337.0 µm	Yes
Reddy	JCRS 2013	Relative diameter ration: 1.02±0.05 Circularity: 0.97±0.02 Decentration: 0.13±0.05	Relative diameter ration: 0.93±0.09 Circularity: 0.92±0.05 Decentration: 0.17±0.10	No Yes Yes
Friedman	JCRS 2011	Difference from intended: 29±26 µm	Difference from intended: 337±258 µm	Yes
Nagy	JRS 2009	5.02±0.04 mm	5.88±0.73 mm	Yes

FLACS: Femtosecond laser-assisted cataract surgery

Table 5: Literature comparisons for capsulotomy creation

First author	Journal/year	Finding (*n*)
Peng	Zhonghua Tan Ke Za Zhi 2017	Tilt and decentration significantly less in FLACS (*n*=100 FLACS, 50 conventional)
Mursch-Edlmayr	JCRS 2017	No difference in IOL centration (*n*=50)
Takagi	J Ophthalmol 2017	Capsule edge strength for CCC varied depending on size and irregularities (FLACS stable edge strength)
Panthier	JRS 2017	FLACS more precise and circular. FLACS modified less over time. No difference in refractive error or ACD (ELP) (*n*=33)
Zhang	Zhonghua Tan Ke Za Zhi 2016	FLACS capsulotomy significantly more precise and circular
Conrad-Hengerer	JCRS 2015	No change in mean SE at 1W and 1M
Toto	JRS 2015	Greater centration FLACS, less variation in size and less SE change over time (*n*=40)
Szigeti	JRS 2012	Less tilt in 5.5 mm versus 6.00 mm. No difference in VA or MRSE
Mihaltz	JRS 2011	Vertical tilt and coma significantly less (*n*=48 FLACS, 51 CCC)

FLACS: Femtosecond laser-assisted cataract surgery, IOL: Intraocular lens, CCC: Continuous curvilinear capsulorhexis, ELP: Effective lens position, ACD: Anterior chamber depth, SE: Standard error, VA: Visual acuity, MRSE: Manifest refraction spherical equivalent

Table 6: Literature findings for clear corneal incisions

First author	Journal/year	Finding (*n*)
Serrao	JCRS 2017	Mean K vale change postop: FLACS 0.16±0.14, conventional 0.34±0.16 (*n*=10) No difference corneal HOA at 3.5mm for FLACS, significant increase in HOA for conventional at both 3.5 mm and 6 mm
Day	JCRS 2016	Corneal biomechanical parameters and astigmatism meridian independent predictors of efficacy of AK
Diakonis	JCRS 2015	No difference in SIA between FLACS and conventional (*n*=36)
Chen	JCRS 2017	CDVA stable at 1M FLACS and 3M conventional (*n* = 47 FLACS, *n* = 48 Conventional group)
Nagy	JRS 2014	SIA 0.47±0.13 FLACS, 0.41±0.14 conventional (*n*=20, 20) Corneal HOA and LOA stable and no difference between groups
Mastropasqua	JRS 2014	No difference in SIA or corneal aberrations (*n*=30)
Serrao	Eur J Ophthalmol 2014	Difference in changes in corneal wave front due to CCI geometry

FLACS: Femtosecond laser-assisted cataract surgery, HOA: Higher order aberrations, LOA: Lower order aberrations, SIA: Surgically induced astigmatism, CCI: Clear corneal incision, CDVA: Corrected distance visual acuity, AK: Astigmatic keratotomy

more precise and with greater circularity.[41] The authors found that the FLACS cohort changed less over time, however, this did not appear to statistically impact the final refractive error nor anterior chamber depth. Mursch-Edlmayr *et al.* describe the only current study where there was no difference in IOL centration following either FLACS or conventional treatment.[42] The intraindividual comparison of fifty eyes was undertaken by several specialists who had minimum 1000 procedures experience with conventional surgery suggesting that even moderately experienced surgeons can replicate capsulotomies of consistent size and shape. The impact on refractive outcomes was not described. Taken together, this would suggest the impact of decentration, or in the case of FLACS, greater centration is minimal. The impact may be more subtle. Fujikado and Saika describe the increase in coma with decentration of aspheric IOLs suggesting an impact upon visual quality rather than refractive outcomes.[43] The effect can undoubtedly be clinically significant, as evidenced previously in two separate series where IOL decentration was the highest indication for IOL removal.[44,45] An additional consideration is the impact of pupil centre shift and misalignment between the visual and pupillary axis which has also been found to play a role in subjective symptoms.[46] The visual benefit of better centration remains unanswered by current comparative databases.

Mihaltz *et al.* previously described a significant difference in IOL tilt between FLACS and conventional cohorts.[47] Although there was no refractive difference, the authors note that coma was significantly less in the FLACS group again highlighting a potential contributing role for the capsulotomy in visual quality. The same group described less IOL tilt in capsulotomies that measured 5.5 mm compared to those 6.0 mm in diameter.[48] Similar to the earlier paper, this did not significantly impact refractive outcomes; however, it did suggest that perhaps an optimally sized capsulotomy may exist.[38]

Corneal incisions

Perhaps unsurprisingly given the previous reports, there does not appear to be a consistent change in astigmatism following FLACS or conventional procedures [Table 6].[49-51] In a small study, Serrao *et al.* describe a statistically significant difference in the change of mean keratometry in FLACS and conventionally created clear corneal incisions.[52] The study also found that FLACS incisions did not appear to influence the corneal higher order aberrations at a diameter of 3.5 mm but became significant at 6 mm. The comparative conventionally created incisions led to a significant increase at both 3.5 mm and 6 mm. These outcomes corresponded to their earlier report which suggested that the method of corneal incision creation significantly influenced changes in the anterior central topography postoperatively with greater steepening of the incision edges found through single-planed incisions created using disposable knives compared to the femtosecond laser created incisions.[53] The authors state that geometrical differences provide the basis for the difference.

One of the potential benefits of FLACS created incisions is the ability to place the incisions at any axis. Chu *et al*. recently found that corneal incisions at the 12 o'clock position eliminate more higher order aberrations.[54] This was confirmed in other studies and may be more important in multifocal or trifocal designs.[55]

As our understanding of factors such as corneal aberrations, posterior corneal astigmatism, and perhaps even consideration of the true effect of corneal incisions, improves, the relative outcomes of comparative studies may become more evident. Current literature, however, suggests some potential for FLACS incisions to positively impact refractive outcomes.

Corneal relaxing incisions

Approximately one-third of patients will have corneal astigmatism of 1D or greater.[56] If left untreated following cataract surgery, this is likely to have a significant impact on the patients' UDVA. Arcuate incisions, either at the time or following cataract surgery, have been used by surgeons for many years to reduce postoperative astigmatism with good, although still variable results.[57,58] Confirming that femtosecond laser-assisted incisions cannot be matched for precision, Mastropasqua *et al.* highlighted the potential for FLACS to improve on current manually completed arcuate incision outcomes.[49] There have been few studies however to confirm the potential improvements. Chan *et al*. showed a significant reduction in postoperative corneal astigmatism at both 2 months and 2 years in a sample of fifty eyes undergoing a single 450 μ deep, unopened incision created using the VICTUS Femtosecond Laser (Bausch and Lomb) in the opposite meridian to the main phacoemulsification incision.[59] The final mean cylinder remained at 0.74 ± 0.53D which suggests that a majority of patients, however, remained undercorrected. Not unsurprisingly perhaps, the authors found that all wavefront aberrations apart from spherical aberration increased significantly following incisions.

As Blehm and Potvin suggest, intraoperative incisions should also incorporate the effect of the surgical incision, lens centration and posterior corneal astigmatism among variables.[60] The authors suggest that completing the incisions once refraction has stabilized may provide more consistent refractive outcomes. In their small cohort ($n = 28$), the refractive cylinder was reduced by 1D at 2 months with 71% of eyes achieving a level 0.5D or better at this visit. The mean 10% undercorrection may be further decreased by additional nomogram improvements.[60] In an earlier study Yoo *et al*. also found a corresponding reduction in post-cataract patients undergoing arcuate incisions. The authors found no difference in the final refractive astigmatism compared to a corresponding cohort that underwent toric IOL implantation at the time of surgery.[61]

Further investigation is required, and the development of FLACS-specific arcuate incision relaxing incisions may increase the final accuracy. The ability to titrate the refractive effect postoperatively, by opening the incisions, remains a potential advantage for surgeons.

Are We at Our Limit of Femtosecond Laser-assisted Cataract Surgery' Refractive Capability?

The evidence presented so far suggests that, at best, FLACS procedures may offer small and relatively inconsistent refractive advantages over conventional phacoemulsification and clear corneal incisions. We have seen however that current study methodology within several of the comparative studies remains suboptimal. The question remains whether surgeons should currently take advantage of the potential benefits offered by the addition of the femtosecond laser during cataract surgery. Several authors have demanded greater consistency in study methodology. It is worthwhile looking at this in greater detail to determine if FLACS can possibly improve current IOL prediction and deliver better visual acuity and quality for patients.

The dominant error in IOL power calculations is the determination of the ELP.[15,62] ELP does not represent the postoperative position of the actual IOL, but rather the preoperative estimation that will provide the desired result; an important distinction. Each IOL prediction formula includes an algorithm to determine ELP which is based on a variety of preoperative measurements including, but not limited to; axial length, corneal power, anterior chamber depth, angle to angle (or white to white) measurements, lens thickness, age, and refraction.[63] The peer-reviewed literature suggests that each variable may contribute differently depending on the existing formula or lens choice. Srivannaboon *et al*. showed that the Holladay II formula performed equally well without the contribution of lens thickness.[64] Separately, lens thickness has been considered integral to calculations.[14,65] Alternately, Norrby *et al*. suggest that axial length and anterior chamber depth are the only significant predictors of the postoperative position of the anterior lens surface.[62] Understanding the contributions of each variable is key to improving physical models for pseudophakia and both accuracy and consistency of outcomes. Packer *et al*. believe this may reflect systematic methodological concerns.[38] The authors cite the influence of capsulorhexis on postoperative IOL tilt as an example. Previous findings in noncomparative studies suggest that the capsulorhexis size or shape has no impact on decentration or tilt.[66] This is in contrast to earlier findings within FLACS cohorts.[67] Packer *et al*. highlight that the respective variation between studies is between 2 and 4 times greater in the manual technique. This impacts results in two definitive ways; the first is that statistically it remains more difficult to show a significant difference in groups with higher internal variance and second, it is directly possible that by decreasing the variation within surgical parameters then surgeons may have a significantly greater opportunity to provide improvement as outcomes analysis refines future IOL calculation formulae.[38] In short, the consistency of the FLACS procedure may ultimately lead to more predictable models for IOL power calculation. This may be ultimately necessary before we see delineated changes in conventional and FLACS cohorts.

Allowing for a FLACS-derived improvement in IOL power calculations, if surgeons are then to improve outcomes further, IOL design and manufacture should similarly evolve. The current tolerances set by the International Organisation for Standardisation range from ± 0.3D for IOLs up to 15D through to ± 1D at 30D or above which remains unacceptably high.[68] Although most manufacturers claim to exceed these benchmarks, this level of reproducibility does not remove any theoretical benefit of decreasing IOL step size. If however this can be consistently replicated then reducing the step size of IOLs to 0.25D steps may present an opportunity to reduce the potential IOL error.

Our understanding of total ocular aberrations continues to increase. Previously, de Jong *et al*. suggested that postoperative aberrations may be adequately predicted from the preoperative corneal shape and biometric data.[69] Customising the selection of aspheric IOLs based on the patients preoperative total corneal aberrations represents an opportunity to provide quality of vision improvements for patients.[70] The consistency that FLACS appears to provide may allow surgeons to choose an appropriate lens with greater confidence. The incorporation of ocular wavefront data into current RCTs is vital to understand this potential benefit.

Conclusion

The current debate as to the real and perceived refractive benefits of femtosecond laser guided surgeries will not be resolved in the near future. This reflects a combination of methodological and systemic concerns with both existing literature and current power calculations. To obtain clarity, refining future clinical studies to reflect standardized reporting is essential. Furthermore, consideration of FLACS specific parameters to optimize current IOL power calculations may be necessary to provide greater consistency. FLACS remains an impressive technology. It is up to clinicians to provide a better platform to realise its true benefits.

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Conflicts of interest

There are no conflicts of interest.

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