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ORIGINAL PAPER

Comparison of cumulative dispersed energy (CDE) in femtosecond laser-assisted cataract surgery (FLACS) and conventional phacoemulsification

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Abstract
Purpose To compare the amount of phacoemulsification ultrasound energy used between eyes undergoing femtosecond laser-assisted cataract surgery (FLACS) and conventional phacoemulsification.
Methods One eye of consecutive patients undergoing routine non-complicated phacoemulsification from January 2014 to December of 2015 was included in the analysis. FLACS was performed using the Alcon LenSx. Linear regression was used for analysis with type of surgery (FLACS versus conventional phacoemulsification) as the exposure and cumulative dispersed energy (CDE) as the outcome variable. Age, surgeon, eye side, and eye sequence (first versus second eye) were covariates.
Results A total of 1159 surgeries met inclusion criteria. The average age of the cohort was 70.6 (SD 8.6) years, 590 cases (51%) were performed by surgeon 1, and 582 cases (50%) were right eyes. Overall, FLACS resulted in significantly lower CDE as compared to conventional phacoemulsification ($\beta = 0.89$, 95% CI 0.83, 0.95). When stratified by eye side and surgeon, FLACS performed on left eyes operated on by surgeon 1 resulted in lower CDE as compared to conventional phacoemulsification ($\beta = 0.76$, 95% CI 0.66, 0.87), but not for right eyes operated on by surgeon 1 ($\beta = 0.92$, 95% CI 0.79, 1.07) or for eyes operated on by surgeons 2 or 3.
Conclusions The use of FLACS on the Alcon LenSx platform results in a small decrease in phacoemulsification energy as compared to conventional phacoemulsification in certain cases. Further study assessing optimal laser settings and surgical technique is necessary.

Keywords Femtosecond laser-assisted cataract surgery · Cumulative dispersed energy · Ultrasound energy · Alcon LenSx

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Introduction

Femtosecond laser-assisted cataract surgery (FLACS) is a relatively new innovation in which a femtosecond laser creates incisions, the anterior capsulotomy, and softens the lens in preparation for the aspiration and emulsification that follows. While the use of FLACS comes at substantial cost to the patient, proponents of its use tout its reproducibility, visual outcomes, and potentially lower requirement of ultrasound energy. Lower phacoemulsification ultrasound energy intraoperatively may reduce long-term ocular complications such as corneal endothelial cell loss [1] and cystoid macular edema [2].

The majority of studies comparing the ultrasound energy requirements between FLACS and conventional phacoemulsification are relatively small in size and report results from a single surgeon [3–9]. One of the few large prospective studies comparing FLACS and conventional phacoemulsification in multiple surgeons found a significant reduction in effective phacoemulsification time (EPT) with FLACS [10]. However, it should be noted that this study utilized the OptiMedica Catalys femtosecond laser platform (Sunnyvale, CA). Few studies [7–9, 11] utilized the Alcon LenSx femtosecond laser platform (Fort Worth, TX), which is more commonly used in the USA [12]. While both Mastropasqua et al. [8] and Hida et al. [9] studied the LenSx platform in a single surgeon, only Hida et al. demonstrated a significantly lower CDE with FLACS.

This study addresses the gaps in the literature by comparing ultrasound energy used in FLACS versus conventional phacoemulsification using a large sample of cataract surgeries conducted by three surgeons. Our study is one of the largest studies assessing the difference in ultrasound energy utilized between FLACS and conventional phacoemulsification, one of the few conducted in the USA, one of the few that compares multiple surgeons and includes hundreds of more patients than prior studies using the LenSx platform.

The aim of this study is to determine the difference in phacoemulsification ultrasound energy used in FLACS as compared to conventional phacoemulsification. We hypothesize that the use of FLACS results in a lower amount of ultrasound energy applied during cataract surgery as compared to conventional phacoemulsification.

Methods

We conducted a prospective cohort study of all individuals undergoing cataract surgery at an ambulatory surgery center affiliated with a private practice in Glen Burnie, Maryland, from January 2014 to December 2015. Data were collected prospectively for quality assurance purposes and then re-reviewed for the purposes of this study. The decision for FLACS versus conventional phacoemulsification occurred prior to the cataract surgery in which the amount of phacoemulsification ultrasound energy was then measured. This study adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the University of Maryland. Informed consent was obtained from all individual participants included in the study.

Patients were excluded for missing key information, specifically surgery type, surgery date, or phacoemulsification energy. Surgeries that were combined with other intraocular surgeries such as glaucoma or pterygium surgery were excluded. Surgeries in which a complication occurred were excluded; complications were noted prospectively at the time of surgery by nursing staff and records reviewed to confirm. We also excluded any case in which a three-piece lens was placed. In order to ensure one observation per patient, for patients undergoing surgery in both eyes during the study period, only one eye was included. A simple random sampling was used to randomly select either the first or second eye of all patients who underwent surgery in both eyes. Patients who only had one eye operated on during the study period had that one eye included in the analysis.

The exposure in this study was the type of cataract surgery, FLACS versus conventional phacoemulsification, and is dichotomous. The outcome variable was the amount of phacoemulsification ultrasound energy used intraoperatively, quantified by the cumulative dispersed energy (CDE). The pertinent covariates were patient age at the time of surgery, surgeon, eye side, and eye sequence (first versus second cataract extraction).

SAS software version 9.3 (Cary, NC) was used for statistical analysis. Univariate analysis was conducted to determine baseline patient characteristics. As CDE was right skewed, a log transformation was performed to spread the data more uniformly and allow for interpretation. This was then back-transformed after analysis for the sake of clarity. The crude association between the exposure (type of surgery) and the outcome (CDE) was calculated using a two-sample independent *t* test.

Bivariate analysis was conducted to determine the crude association between covariates and exposure as well as the crude association between covariates and the outcome. All variables were considered potential effect measure modifiers. Effect measure modification was determined using linear regression and determining the significance for the interaction terms between each variable and FLACS. For the assessment of effect measure modification, only age was dichotomized to less than 65 or age 65 and above. Assessment for confounding was conducted by determining the change in the β coefficient (a measure of the strength of effect) when adjusting for each covariate. Covariates that caused a 10% change or greater in the β coefficients for surgery type in this adjusted model were then added sequentially to the crude model. Results were then stratified by any effect measure modifiers (a distinct variable that may influence the association between independent and dependent variables). Another analysis stratifying by surgeon was conducted to better define the effect of surgeon on change in CDE due to FLACS. Linear regression was utilized in the final model.

Of 2002 eye surgeries performed during the study period, 32 were excluded because they were combined or were not phacoemulsification cases. Ninety-one cases were excluded due to complications noted at the time of surgery, and six were excluded due to the use of a three-piece lens. Sixty-four surgeries had either exposure or outcome data that were missing and were excluded. One patient had a CDE value of 613 s and another was noted to have an age of 854 years, both cases were excluded due to implausibility. Three patients were noted to have three cataract surgeries, so all nine surgeries associated with those three patients were excluded. Three patients were excluded due to missing medical record numbers. Finally, as stated above, we chose to analyze only one eye from each individual by including one eye taken from a simple random sample of first or second eyes for those patients that had two eyes operated on in the study period; 636 eyes were excluded in this manner. The final study sample included 1159 cataract surgeries from 1159 individuals.

Results

Table 1 describes the baseline demographics of the sample, showing a generally older patient population (mean age 70.6 years, SD = 8.6) with an approximately even distribution of right and left eyes as well as first and second eyes. Surgeon 1 operated on 590 eyes (51%). The distribution of the outcome variable, CDE, was noted to be right skewed and was subsequently log transformed for all subsequent analysis. Our crude, unadjusted analysis showed that while FLACS had lower CDE (mean = 13.8 s, SD = 9.7) as compared to conventional phacoemulsification (mean = 15.1 s, SD = 11.5), there was not a significant difference when comparing the log of CDE between the two methods ($P = 0.09$). The β coefficient in the crude analysis of the effect of FLACS on log CDE is $\beta = -0.074$ (CDE = 0.93), and this was not statistically significant ($P = 0.09$). We found eye side to be a significant effect measure modifier of the primary association (interaction term $P = 0.03$).

Age, surgeon, and eye sequence showed a significant association with both type of surgery and log CDE and resulted in a greater than 10% change in calculated β coefficient. When adding these variables sequentially to the crude model, surgeon and age resulted in a greater than 10% change in calculated β coefficient, but eye sequence did not. The final model (Table 2) included the exposure (type of surgery), surgeon, and age and shows that overall, the use of FLACS resulted in lower CDE as compared to conventional phacoemulsification. Table 3 shows the final model stratified by eye side, which we previously determined was an effect measure modifier. This notably shows a β coefficient of 0.92 (95% CI 0.84, 1.03) for the right eye and 0.85 (95% CI 0.76, 0.94) for the left eye. This indicates that the use of FLACS results in a statistically significant decrease in CDE in left eyes but not in right eyes.

To investigate the effect of both surgeon and eye side on the effect of FLACS on CDE, we created six strata to determine the β coefficient for each surgeon and eye side, while controlling for age (Table 4). While all the β coefficients were < 1, indicating that FLACS does cause a decrease in CDE as compared to conventional phacoemulsification, only the β coefficient for left eyes operated on by surgeon 1 was statistically significant.

Discussion

We found that, overall, the use of FLACS resulted in lower ultrasound energy used as compared to

Table 1 Sample characteristics, FLACS and CDE study, $N = 1159$

	Overall $N = 1159$	Conventional phaco ($n = 795$)	FLACS ($n = 364$)
Age (years), mean (SD)	70.6 (8.6)	71.0 (8.8)	69.7 (8.1)
Eye side *n* (%)			
Right	582 (50%)	388 (49%)	194 (53%)
Left	577 (50%)	407 (51%)	170 (47%)
Eye sequence *n* (%)			
First	574 (50%)	376 (47%)	198 (54%)
Second	584 (50%)	418 (53%)	166 (46%)
Surgeon *n* (%)			
1	590 (51%)	388 (48.8%)	202 (55.5%)
2	169 (15%)	101 (12.7%)	68 (18.7%)
3	400 (35%)	306 (38.5%)	94 (25.8%)

FLACS femtosecond laser-assisted cataract surgery, *CDE* cumulative dispersed energy

Table 2 Overall effect of FLACS on CDE accounting for age and surgeon

	β	95% CI
FLACS ($n = 364$)	0.89	(0.83, 0.95)
Surgeon		
1 ($n = 590$)	1.46	(1.36, 1.58)
2 ($n = 169$)	2.61	(2.36, 2.92)
3 ($n = 400$)	1	(REF)
Age (years)	1.03	(1.02, 1.03)

FLACS femtosecond laser-assisted cataract surgery, *CDE* cumulative dispersed energy, *CI* confidence interval

Table 3 Effect of FLACS on CDE accounting for age and surgeon stratified by eye side

	Right eye ($n = 582$)		Left eye ($n = 577$)	
	β	95% CI	β	95% CI
FLACS ($n = 364$)	0.92	(0.84, 1.03)	0.85	(0.76, 0.94)
Surgeon				
1 ($n = 590$)	1.46	(1.31, 1.63)	1.48	(1.32, 1.63)
2 ($n = 169$)	2.56	(2.16, 3.00)	2.64	(2.29, 3.03)
3 ($n = 400$)	1	(REF)	1	(REF)
Age (years)	0.03	(0.02, 0.03)	0.03	(0.02, 0.03)

FLACS femtosecond laser-assisted cataract surgery, *CDE* cumulative dispersed energy, *CI* confidence interval

conventional phacoemulsification. When stratified by both eye side and surgeon, and controlling for age, FLACS resulted in reduced CDE as compared to conventional phacoemulsification in left eyes operated on by surgeon 1. Increased age also resulted in greater CDE.

Multiple prior studies have assessed the role of FLACS in the reduction of phacoemulsification energy [3–11]. The largest study to our knowledge comparing ultrasound energy used in FLACS with conventional phacoemulsification was conducted by Abell et al. [10] in 2014. This prospective consecutive case series compared the results of five experienced surgeons with conventional phacoemulsification. This study included 1852 FLACS eyes and 2228 eyes that underwent conventional phacoemulsification and found EPT was significantly lower in eyes that underwent FLACS on bivariate analysis, but this did not adjust for age or account for patients who had surgery conducted in both eyes. Notably, this study used the Catalys FLACS platform, as opposed to the Alcon LenSx FLACS platform used in our study. There are data to suggest that use of the LenSx platform results in higher CDE as compared to the Catalys platform. In a prospective randomized control study conducted by Rivera et al. [13], 45 patients (90 eyes) underwent cataract surgery with the Catalys in one eye and the LenSx in the fellow eye. They found that the LenSx group showed significantly higher CDE and phacoemulsification power as compared to the Catalys group.

Only four previous studies [7–9, 11], to our knowledge, studied phacoemulsification ultrasound energy use in the Alcon LenSx platform, which is

Table 4 β Coefficient for FLACS stratified by surgeon and eye side

	Right eye (n = 582)		Left eye (n = 577)	
	β	95% CI	β	95% CI
Surgeon 1 (n = 590)	0.92	(0.79, 1.07)	0.76	(0.66, 0.87)
Surgeon 2 (n = 169)	0.92	(0.73, 1.19)	0.95	(0.77, 1.16)
Surgeon 3 (n = 400)	0.94	(0.78, 1.12)	0.98	(0.79, 1.21)

FLACS femtosecond laser-assisted cataract surgery, *CI* confidence interval

commonly used in the USA [12]. In a prospective RCT of 76 patients comparing LensX to conventional phacoemulsification, Takács et al. [7] found that LenSx use resulted in reduction of ultrasound energy but no significant difference in two other measures (phaco time or EPT). In a prospective randomized single-surgeon trial of 30 FLACS patients and 30 patients undergoing conventional phacoemulsification, Mastropasqua et al. [8] found a nonsignificant reduction in CDE in the LenSx group. Hida et al. [9] conducted a prospective randomized trial of 200 FLACS patients and 200 conventional surgery patients from a single experienced surgeon and found a significantly lower CDE with FLACS than with conventional surgery. Yesilirmak et al. [11] performed a prospective comparative nonrandomized clinical study of 145 FLACS patients and 425 conventional surgery patients from two experienced surgeons and found that CDE was significantly lower in the FLACS group than in the conventional surgery group. Our study is the largest series comparing CDE in FLACS patients using the LenSx platform versus conventional phacoemulsification. While we similarly found that FLACS lowers CDE overall, the large number of eyes and inclusion of different surgeons with different techniques allowed for further analyses by surgeon and by eye. Ultimately, our study showed that different surgical techniques may affect whether FLACS results in lower CDE or not.

The finding that use of the Alcon LenSx FLACS platform resulted in lower CDE for left eyes operated on by surgeon 1 may in part be because surgeon 1 is left-handed and operates superiorly, whereas surgeons 2 and 3 are right-handed and operate temporally. The difference in surgeon handedness and surgical approach may affect the placement of incisions, which may in turn result in a difference in the required ultrasound energy necessary in cataract surgery. Chen et al. [14] found significant differences in the average CDE among four experienced surgeons with different surgical techniques and phaco settings. Our finding that FLACS is most effective in some cases and not others would be consistent with some of the prior work [7, 8] that showed mixed results using the LenSx platform.

Ultimately, the potential reduction in phacoemulsification energy with FLACS is relatively small and may be of limited clinical significance. The reduction in CDE was 1–3 s depending on the surgeon and eye operated on. Doors et al. [15] found that a difference in CDE of 13 s in patients with Fuchs dystrophy was not a risk factor for corneal decompensation at 2 years of follow-up, indicating that the lower reduction of CDE due to FLACS is unlikely to cause complications in the general population that is at much lower risk for corneal decompensation than Fuchs' dystrophy patients. However, reduction of CDE may lead to a faster visual recovery in the short term.

Our study is one of the largest studies to assess the effect of FLACS on ultrasound energy and one of the only such studies that included results of multiple surgeons. Another strength was that the data were prospectively obtained. Limitations include that there could have been some unmeasured confounders of the data such as FLACS laser settings, surgeon approach, surgical technique, and lens density. Also, while the study assessed the phacoemulsification energy, it did not ultimately assess the potential long-term negative outcomes of high phacoemulsification energy, corneal endothelial cell count, and macular edema. Patients of surgeon 1 may have baseline differences (i.e., greater lens density) when compared to the patients of the other surgeons in the group, representing another potential confounder. Our study looked at all patients undergoing cataract surgery, some of whom had glaucoma or potentially other ocular pathology, although it is unlikely that in uncomplicated surgeries this would impact the effect of FLACS on CDE. Finally, there could have been errors in the transcription of data, although the effect of that would have been nondifferential.

Conclusions

The use of FLACS with the Alcon LenSx platform results in a modest reduction of phacoemulsification energy as compared to conventional phacoemulsification, most notably in specific surgical situations. While this modest reduction was statistically significant overall in our large series, it may not be clinically significant. Hence, further study accounting for surgical approach, surgical technique, lens density, and laser settings is required to better understand when FLACS may be most effective in lowering CDE.

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Compliance with ethical standards

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

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent We obtained a waiver of informed consent from the Institutional Review Board.

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