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ORIGINAL RESEARCH

Ultrasound-Energy Consumption During Phases of Phacoemulsification of Nuclear Cataracts Using Femtosecond Laser: A Comparative Study

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Purpose: To compare ultrasound (US) energy utilized in different phases of nuclear cataract removal in femtosecond laser–assisted cataract surgery (FLACS) with conventional phacoemulsification surgery (CPS) in relation to different nuclear densities.

Methods: A prospective nonrandomized comparative study was conducted at Ain Shams University and Al Watany Eye Hospital, Cairo, Egypt on 250 eyes with senile nuclear cataracts (NCs) of different nuclear densities (1–6). Eyes were divided into two groups — FLACS and CPS — and each group was subdivided according to cataract density into subgroups A (NC 1–2), B (NC 3–4) and C (NC 5–6). sextant-softened fragmentation patterns were assessed in the FLACS group and the quick-chop technique used in the CPS group. US energy required for nucleus cracking (EFX split) and for quadrant removal (EFX quadrant) was recorded.

Results: Total eyes included in the FLACS and CPS groups were 117 and 133, respectively. No significant differences between the groups for EFX quadrant and EFX split groups were observed (P=0.18 and P=0.49, respectively). For subgroup A, no significant difference was found between FLACS and CPS on EFX split (P=0.08) and EFX quadrant (P=0.49). For subgroup B, significantly lower values of EFX split (P=0.0001) and EFX quadrant (P<0.0001) were obtained with FLACS than CPS. For subgroup C, no significant difference was found for EFX split (P=0.86); however, EFX quadrant was significantly lower in the FLACS group (P=0.05).

Conclusion: FLACS lowers US energy utilized during quadrant removal at different nuclear densities, with highest significance in medium-density nuclear cataracts. Nucleus cracking by femtosecond laser is less effective in very hard cataracts. However, femtosecond-laser softening of hard nuclei is capable of of US-energy reduction during quadrant removal.

Keywords: phacoemulsification, femtosecond laser, FLACS, cataract surgery

Introduction

Conventional phacoemulsification surgery (CPS) is the standard procedure for cataract extraction nowadays with excellent outcomes.[1,2] However, femtosecond laser–assisted cataract surgery (FLACS) represents a potential paradigm shift in cataract surgery, yet with considerable controversy.[3] The femtosecond laser (FL) delivers ultrashort (10^{-15} seconds) pulses of energy at near-infrared wavelengths that can be precisely focused at various depths in the anterior segment of the eye.[4]

Owing to its photodisruptive effect and subsequent precise tissue cutting, the FL has been promoted to improve many of the critical steps of CPS.[5,6] These steps

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include astigmatic limbus-relaxing incisions, corneal wound construction, anterior capsulotomy/laser-incised capsulorhexis, and lens pretreatment using liquefaction or fragmentation patterns to segment the nucleus and soften harder cataracts.[7] It has been postulated that FL usage in these domains reduces the magnitude of ultrasound (US) energy delivery and reduces the potential of trauma to surrounding structures during lens extraction,[8,9] thus leading to faster and safer cataract surgery with better visual outcomes.[10]

Regarding cataract density, a number of large studies and meta-analyses have found comparable differences regarding the safety and efficacy of both FLACS and CPS when treating medium cataracts.[11] However, lens fragmentation using FL has an upper limit of capability in Lens Opacities Classification System grade 4 cataracts, and thus brunescent cataracts may require CPS or even extracapsular-cataract surgery.[12] This cataract type has been excluded from many of the published cohorts and deserves further investigation.[11,13] The aim of our study was to compare US-energy consumption between CPS and FLACS during both the nuclear splitting stage (EFX split) and quadrant-removal stage (EFX quadrant) at different nuclear densities.

Methods

This prospective nonrandomized comparative study was conducted at Ain Shams University Hospital and Al Watany Eye Hospital, Cairo, Egypt, between March 2018 and March 2019. Eyes with visually significant senile nuclear cataracts (NCs) in which corrected distance visual acuity was <0.5 (decimal) were included. All participants were adequately informed about the advantages, disadvantages, and cost of both FLACS and CPS by medical staff. Both procedures were presented as valid options to all patients, and the final decision was based on patient preference after signing a consent form.

Both CPS and FLACS groups were further subdivided into three subgroups according to nuclear density and color based on the Lens Opacities Classification System III. Also, nuclear grading was done using 3-D lens densitometry with Pentacam nucleus staging (Figure 1), included with Pentacam software (Oculus, Wetzlar, Germany). Nucleus staging results were a classification of each case as one of six stages (0–5). Additionally, a clear 3-D reconstruction of lenses with visible areas of opacification is offered.

In our study, NC density and color were determined on a scale of 1–6 for all eyes. Subgroup A included eyes with NC1–2, subgroup B; NC3-4, and subgroup C; NC5–6. Eyes with corneal opacities, zonular weakness, subluxated lenses, maximum pupillary dilation <5.5 mm, iris abnormalities, history of glaucoma/uveitis, intraoperative complications, or any other comorbidity that would have complicated cataract surgery were excluded. This study adhered to the tenets of the Declaration of Helsinki and was approved by the local ethics committee of Al Watany Eye Hospital, Cairo, Egypt.

Surgical Techniques

All surgeries in the FLACS and CPS groups were performed under topical anesthesia by the same experienced high-volume surgeon (AA).

FLACS Group

FL treatment was done using the Catalys precision system (Johnson & Johnson Vision) prior to US phacoemulsification and intraocular lens (IOL) implantation. Initially, the suction cone of the Liquid Optics Interface (was positioned on the limbus and the vacuum was activated. Once suction and ocular fixation had been confirmed, the suction cone was filled with balanced saline solution and then the eye was docked to the system. The dimensions of the anterior chamber and crystalline lens were then measured by 3-D spectral-domain optical coherence tomography, which is incorporated in the Catalys laser platform. Identified ocular structures in the anterior segment of the eye were overlaid by preprogrammed treatment zones and displayed to the surgeon for verification and/or redesigning the treatment plan. Finally, the selected treatment was initiated.

The FL was used for capsulotomy, lens fragmentation, and astigmatic keratotomies to address corneal astigmatism in some eyes. The FL made neither primary nor secondary corneal incisions. For lens prefragmentation, we used sextants with softening fragmentation function (Figure 2). Grid spacing was set at 350 μm, segmentation–softening spacing at 200 μm, and fragmentation diameter was set to the maximum. Segmentation repetition was set at 2–3 in soft nuclei of subgroup A, 3–4 in harder nuclei of subgroup B, and 5–6 in brunescent nuclei of subgroup C. Other laser settings were kept at default values: horizontal spot spacing 10 μm, vertical spot spacing 40 μm, anterior pulse energy 10 μJ, posterior pulse energy 40 μJ, anterior-capsule safety margin 500 μm, and posterior-capsule safety margin 500 μm.

Phacoemulsification for the FLACS and CPS Groups

The same phacoemulsification machine (Signature WhiteStar FX, Johnson & Johnson Vision) was used for all eyes.

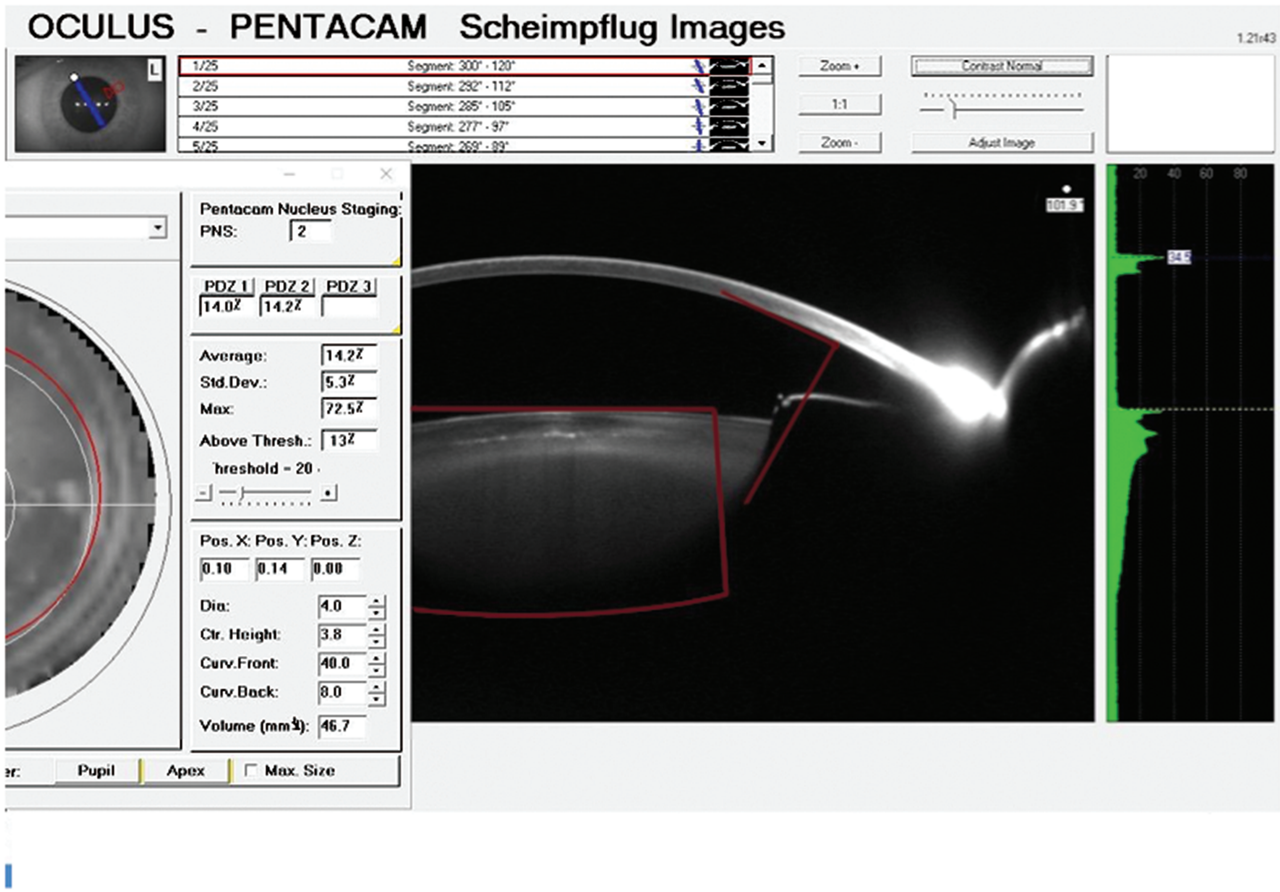

Figure 1 Pentacam nucleus staging (PNS).

Phacoemulsification settings used in both groups were US power 10%–40%, Ellips FX transverse US phacoemulsification handpiece, WhiteStar variable duty cycle 1, aspiration rate 28–32 cm^3/min, vacuum 350 mmHg max, CASE mode, and CASE vacuum 280 mmHg. Main incisions and secondary incisions were performed using 2.2 mm and 1.2 mm keratomes respectively. An ocular viscosurgical device (sodium hyaluronate 1.3% [Healon GV], Johnson & Johnson Vision) was injected into the anterior chamber. Manual capsulorhexis of 5–5.5 mm diameter was performed using capsulorhexis forceps in the CPS group. In the FLACS group, the capsulotomy button was removed using capsulorhexis forceps. Hydrodissection was performed in the usual way in both groups. However, it was gentle and with less fluid in the FLACS group to release trapped gases from underneath the nucleus into the anterior chamber. This was followed by the introduction of a 21 G laminar-flow phacoemulsification tip through the main incision. In both groups, minimal US energy coupled with high vacuum (350 mmHg) was used to impale the phacoemulsification tip within the central part of the nucleus for fixation. In the CPS group, a quick-chop technique was implemented on the nucleus using a Neuhann vertical chopper (Geuder). In the FLACS group, the same technique was used, and mechanical cracking of the nucleus into sextants was performed along preformed laser cuts.

After phacoemulsification, a foldable hydrophobic IOL was inserted into the capsular bag using the corresponding specific unfolder for each IOL. The same postoperative treatment was administered to all patients: prednisolone acetate 1% eyedrops (Pred Forte, Allergan) five times daily for 2 weeks, then gradual withdrawal over 2 weeks and topical moxifloxacin hydrochloride ophthalmic solution 0.5% (Vigamox, Alcon) five times daily for 10 days.

The EFX, which is a unitless value, denotes US% and US time utilized during phacoemulsification and corresponds roughly to the effective phacoemulsification time (EPT) with a specific coefficient for transverse movement expressed in seconds. EFX was the primary study parameter and recorded for all eyes at two phases: after nucleus disassembly (first phase, EFX split) and after the end of the surgery (second phase, EFX total). The US required for the quadrant-removal phase (EFX quadrant)

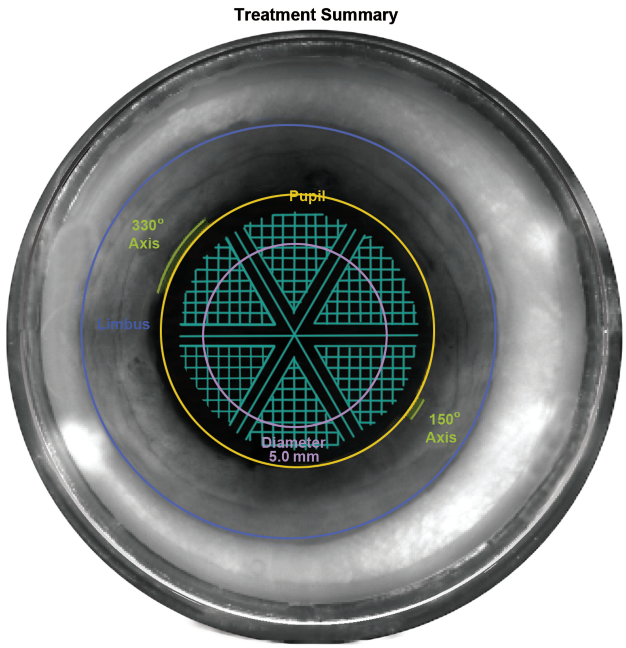

Figure 2 Lens fragmentation used in all cases in the FLACS group: sextants with lens softening, grid spacing 350 μm, seg-soft spacing 200 μm.

was calculated by subtraction of EFX split from EFX total. Average US% and US time in seconds were also documented and compared.

Statistical Analysis

Data analysis was performed using MedCalc version 18.9.1 (MedCalc Software, Ostend, Belgium). Normality of data samples was evaluated by means of the D'Agostino–Pearson test. The Mann–Whitney test, Kruskal–Wallis test, Conover post hoc test and Jonckheere–Terpestra trend test were applied to assess the significance of differences, as parametric analyses were not possible. For all statistical tests, $P<0.05$ was considered statistically significant.

Results

A total of 250 eyes of 145 patients (77 females and 68 males) were included in this study: 117 eyes in the FLACS group and 133 in the CPS group. Subgroup A comprised eyes with NC 1–2 (35 FLACS-operated eyes and 42 CPS-operated eyes), subgroup B eyes with NC 3–4 (40 FLACS-operated eyes and 47 CPS-operated eyes), and subgroup C eyes with NC 5–6 (42 FLACS-operated eyes and 44 CPS-operated eyes). The number of cases was unequal in the main groups, since we chose cases from our private practice and the cost limited patients' choice between the procedures. Regarding mean age, there was no statistically significant difference between the FLACS and CPS groups (62.5±8.1 and 62.4±8.4 years, respectively, *P*=0.96) or among the subgroups: subgroup A; 60.2±11.6 in FLACS and 60.4±10.7 years in CPS (*P*=0.99), subgroup B; 60.3 ±4.6 in FLACS and 64.6±6.6 years in CPS (*P*=0.54), and subgroup C; 62.8±6.8 in FLACS and 62.2±7.3 years in CPS (*P*=0.77; Table 1).

The intraoperative parameters recorded in the two groups — EFX and US measures — are shown in Table 2. Nonsignificant differences in EFX split, EFX quadrant, average US%, and total US time between the FLACS and CPS groups were found. EFX split was 9.96±8.8 in the FLACS group and 10.28±8.35 in the CPS group (*P*=0.49). EFX quadrant was 17.33±14.22 in the FLACS group and 19.96±15.1 in the CPS group (*P*=0.18). Average US was 5.9±3.3 seconds in the FLACS group and 5.8±3.4 in the CPS group (*P*=0.45). Total US time was 72±45.8 in the FLACS group and 66.5±45 seconds in the CPS group (*P*=0.44). As such, no statistically significant differences for these parameters were found (Table 2).

Table 1 Age differences among cases in FLACS and CPS groups and their subgroups

		n	Age (mean ± SD), years	*P*-value
FLACS		117	62.5±8.1	0.96
CPS		133	62.4±8.4	
Subgroup A	FLACS CPS	35 42	60.2±11.6 60.4±10.7	0.99
Subgroup B	FLACS CPS	40 47	60.3±4.6 64.4±6.6	0.54
Subgroup C	FLACS CPS	42 44	62.8±6.8 62.8±7.3	0.77

Abbreviations: FLACS, femtosecond laser–assisted cataract surgery; CPS, conventional phacoemulsification..

Table 2 Intraoperative parameters in FLACS and CPS groups

	FLACS (n=117)	CPS (n=133)	*P*-value
	Mean ± SD	Mean ± SD	
EFX split	9.96±8.8	10.28±8.35	0.49
EFX quadrant	17.33±14.22	19.96±15.1	0.18
Average US (%)	5.9±3.3	5.8±3.4	0.45
Total US time (seconds)	72.0±45.8	66.5±45.0	0.44

Abbreviations: FLACS, femtosecond laser–assisted cataract surgery; CPS, conventional phacoemulsification; US, ultrasound.

Table 3 Intraoperative parameters in FLACS and CPS subgroups

	Subgroup A (NC 1–2)			Subgroup B (NC 3–4)			Subgroup C (NC 5–6)		
	FLACS (n=35), mean ± SD	CPS (n=42), mean ± SD	P-value	FLACS (n=40), mean ± SD	CPS (n=47), mean ± SD	P-value	FLACS (n=42), mean ± SD	CPS (n=44), mean ± SD	P-value
EFX split	0.26±0.44	0.45±0.5	0.08	7.82±2.31	10.34 ±2.83	0.0001	20.07±4.93	19.59±4.7	0.86
EFX quadrant	2.11±1.64	2.29±1.04	0.49	14.3±5.92	20±4.65	<0.0001	32.9±0.45	36.8±8.98	0.05

Abbreviations: FLACS, femtosecond laser–assisted cataract surgery; CPS, conventional phacoemulsification; NC, nuclear cataract; US, ultrasound; EFX split, US energy required for nucleus splitting; EFX quadrant, US energy required for quadrant removal.

Intraoperative parameters recorded in the subgroups are shown in Table 3. In subgroup A, there were no significant differences between FLACS and CPS for EFX split or EFX quadrant (*P*=0.08 and *P*=0.49 respectively). In subgroup B, EFX split and EFX quadrant were significantly lower in the FLACS group than the CPS group (*P*=0.0001 and *P* <0.0001, respectively). Finally, for subgroup C, a tendency toward lower values of EFX split and EFX quadrant was observed in the FLACS group, but difference in EFX split compared to the CPS group did not reach statistical significance (*P*=0.86), while that for EFX quadrant was statistically significant (*P*=0.05, Table 3).

Discussion

Use of the FL has been expanding recently in cataract surgery, specifically in creating corneal incisions, performing capsulotomies, and producing nuclear fragmentation.[14,15] Many studies have reported the superiority of FLACS over CPS as regards US-energy consumption.[15–17] A study in 2013 with the VICTUS platform (Bausch + Lomb, NJ, USA) found a significantly lower EPT in its FLACS group (5.2±5.7 seconds) than its CPS group (7.7±6.0 seconds; *P*=0.025).[18] Similarly, Daya et al showed a significant reduction of 13.2% between their FLACS group (8.58±4.66 seconds) and CPS group (9.89±5.32 seconds; *P*=0.044).[17]

However, to our knowledge none of the available studies compared FLACS and CPS as regards US usage in the two specific phases of phacoemulsification surgery: nuclear splitting and quadrant removal. Therefore, in this study we compared the US-energy required for nucleus splitting (EFX split) and for quadrant removal (EFX quadrant) between FLACS and CPS in three subgroups with different nuclear densities.

We used lens-fragmentation patterns by FL, which has been demonstrated in previous studies as being the main factor contributing to the reduction in US energy in FLACS.[15,19] In addition, we used 350 μm grid softening, which has also been shown to lead to statistically significant lower EPT than other types of fragmentation grids.[20] Moreover, we divided segmentation patterns into sextants. Based on our experience, this pattern helps in dividing the nucleus into small segments with subsequent easier manipulation and emulsification and less required US-energy.

In subgroup A (soft cataracts, NC 1–2), differences between FLACS and CPS concerning both EFX split and EFX quadrant were not significant (*P*=0.08 and 0.49, respectively). This can be attributed to the already minimal or almost no US-energy required for both nuclear splitting and removal in CPS, owing to the fact that managing soft cataracts is more dependent on phacoemulsification fluidics than US-energy. This is most probably why FLACS was not superior to CPS in soft nuclear density.

As for subgroup B (medium density cataracts, NC 3–4), there was significantly lower US energy required in both splitting (EFX split) and quadrant (EFX quadrant) removal phases in favor of FLACS (*P*=0.0001 and *P*<0.0001, respectively). This was due to the efficiency of the FL in achieving complete division of the nucleus and effective softening of the nuclear quadrants, resulting in very minimal or no need for further US-energy for removal of nuclear parts.

Strikingly, in subgroup C(hard cataracts, NC 5-6), the difference in EFX split between FLACS and CPS was not significant (*P*=0.86). This was probably due to the incomplete nucleus splitting we faced in FLACS-operated eyes. Although we increased the segmentation-repetition rate up to sixfold in this subgroup with the aim of increasing the frequency of FL pulses, we achieved neither complete segmentation nor nucleus splitting in any of those eyes. The FL did not affect the

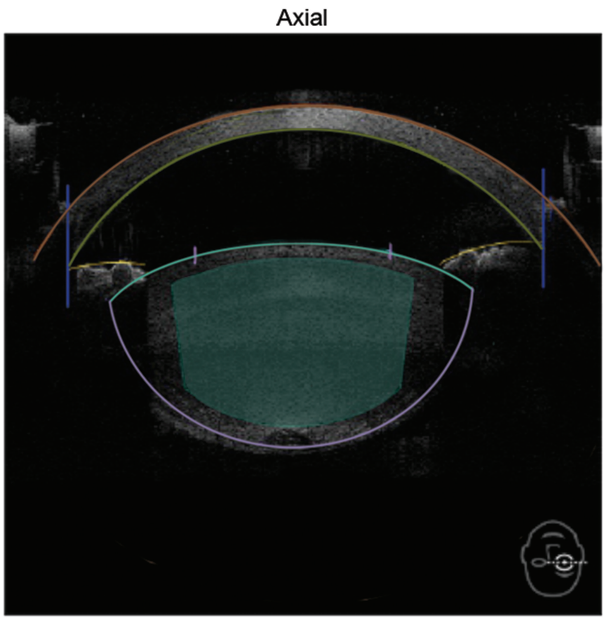

Figure 3 Anterior-segment axial scan by spectral-domain OCT of Catalys precision-laser system. Dense cataracts were noticed to extend posteriorly beyond the minimum laser-fragmentation offset of 500 µm from the posterior capsule.

posterior parts of such thick and dense nuclei, as the Catalys laser-precision system does not allow extending of the laser beyond 500 µm off the identified posterior capsule (Figure 3). This resulted in the need for subsequent US power to complete the step of nucleus cracking mechanically, with almost similar requirement of US energy as the CPS group (Figure 4).

It is important to say that we used 21 G laminar-flow phacoemulsification needles in this study, as in all our routine cataract surgeries. This needle has an inner diameter of 0.5 mm, and we assume that a 19 G phacoemulsification needle with a larger inner diameter (0.7 mm) would help to aspirate chunks of pre-fragmented nuclei by vacuum with less US energy. A wide phacoemulsification needle might add a further reduction in US energy. However, we do not have a clear conclusion yet, and this matter is currently under investigation.

Conclusion

FLACS was highly beneficial in medium-density NCs, as it significantly reduced US-energy during both nucleus cracking and removal. Regarding hard cataracts, FLACS was only capable of reducing US energy during the quadrant-removal phase, in contrast to nucleus cracking, in which were inable to induce significant effects. As for soft cataracts, FLACS may be considered for benefits other than reduction in US energy.

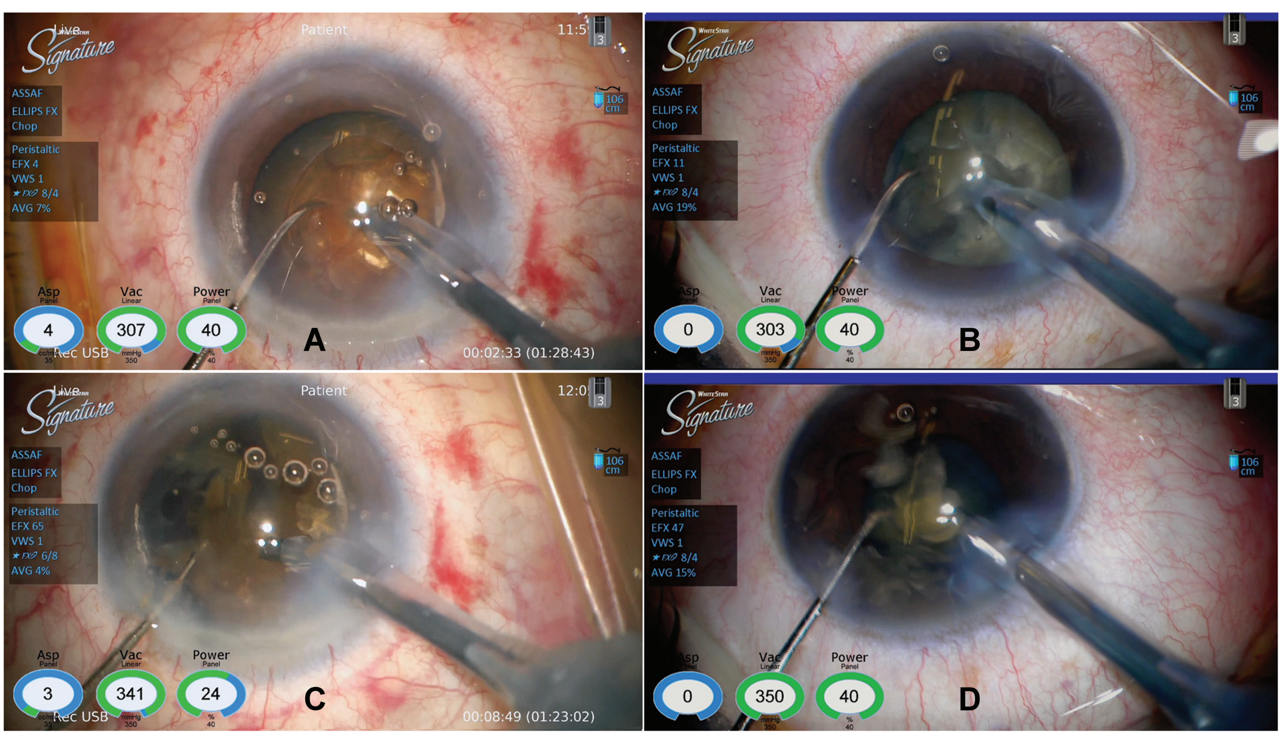

Figure 4 Dense (brunescent) cataract subgroup C. Nucleus-cracking phase. Similar US-energy levels were utilized in FLACS (**A**) and CPS (**B**). During quadrant removal, less US energy was utilized in the FLACS (**C**) than the CPS (**D**) subgroups.

Abbreviations

CPS, conventional phacoemulsification surgery; EPT, effective phacoemulsification time; FL, femtosecond laser; FLACS, FLemtosecond-assisted cataract surgery; G, gauge; IOL, intraocular lens;; NC, nuclear cataract; PNS, Pentacam nucleus staging; US, ultrasound; EFX split, US energy required for nucleus cracking; EFX quadrant, US energy required for quadrant removal.

Disclosure

The authors report no conflicts of interest in this work.

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