Int Ophthalmol
DOI 10.1007/s10792-016-0283-7

ORIGINAL PAPER

# All laser cataract surgery compared to femtosecond laser phacoemulsification surgery: corneal trauma

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Received: 13 May 2016 / Accepted: 21 June 2016
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**Abstract** The aim of this study was to evaluate corneal tissue trauma after femtosecond laser-assisted cataract surgery (FLACS) and phacoemulsification (femtophaco surgery) compared to FLACS and nanolaser emulsification (all laser surgery). This is a prospective nonrandomized clinical study conducted at the Ophthalmology Clinic, University "G. d'Annunzio" of Chieti-Pescara, Italy, involving forty-two eyes of 42 patients candidates to cataract surgery. Patients were enrolled in two groups: femtophaco surgery (group 1 with 21 eyes) and all laser surgery (group 2 with 21 eyes). Main outcome measures included uncorrected visual acuity and distance corrected visual acuity, corneal endothelial cell count, and corneal thickness at the tunnel site and at the center of the cornea. Best correct visual acuity was not significantly different between the two groups. Postoperatively, a significant decrement of endothelial cell count at the center of the cornea was observed in group 1 compared with preoperative values at 90 days ($p < 0.001$) while t remained stable in group 2. The central corneal thickness showed a statistically significant increase for both groups that reached a maximum thickness at 7 days and then returned to presurgery levels after 90 days for group 1 and after 60 days for group 2. The tunnel corneal thickness showed a statistically significant increase for both groups that reached a maximum thickness at 7 days, which did not return to presurgery level for group 1 but did return to presurgery levels after 60 days for group 2. All laser surgery induced lower central endothelial cell loss and lower increase of corneal thickness compared to femtophaco surgery.

**Keywords** Cataract surgery · Femtosecond laser-assisted cataract surgery · Phacoemulsification · Nanosecond laser

## Introduction

Although cataract surgery widely diffused and safety increases with surgical expertise, it continues to present challenges and risks. Risk for potential complications are associated with the surgical technique, underlying ocular conditions and type of artificial crystalline lens. Postoperative corneal edema, flare in the anterior chamber, and iritis are linked to postoperative inflammation, particularly in patients with predisposing conditions involving a blood-aqueous barrier breakdown [1]. Corneal tissue trauma with corneal tunnel edema and endothelial cell loss were associated with the surgical technique and ultrasound use during phacoemulsification [2].

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Published online: 05 July 2016

Recently, the introduction of femtosecond in cataract surgery has improved outcome. To date, it has been used to produce four types of incisions: clear corneal incisions, arcuate keratotomy, capsulotomy, and nuclear lens fragmentation [3–5].

Femtosecond laser-assisted cataract surgery (FLACS) presents numerous advantages over conventional cataract surgery, including better capsulorrhexis features (circularity, centration), [6–8] more precise corneal incision architecture with reduced keratometric astigmatism [9] and reduction of ultrasound energy [10]. Previous studies comparing FLACS and manual standard technique with phacoemulsification showed lower phacoemulsification time and energy with an overall reduction of cumulative dissipated energy (CDE) [10–12]. It was reported that surgical trauma and particularly ultrasound energy were related to ocular inflammation and consequently to corneal tissue injury such as corneal edema and corneal endothelial cell loss [13–16]. More recently, a nanosecond YAG laser that replaces phacoemulsification for cataracts up to grade 3 was reported to reduce the overall energy required to remove cataracts [17].

The aim of our study was to evaluate corneal tissue trauma (central corneal thickness, corneal thickness at the tunnel site, and endothelial cells loss) after femtophaco surgery and all laser surgery.

## Materials and methods

Enrollment and all surgical procedures for this prospective study were performed at the Department of Ophthalmology of the Medical University of "G. d'Annunzio" Chieti-Pescara following approval by the Institutional Review Board of the Department of Medicine and Science of Aging, University "G. d'Annunzio" Chieti-Pescara, Italy. It adhered to the tenets of the Declaration of Helsinki and patients provided written informed consent prior to enrollment.

Forty-two eyes of 42 consecutive cataract patients, candidates to phacoemulsification and IOL implantation, were enrolled. The inclusion criteria were age between 65 and 75 years, nuclear cataract of grade 3 [nuclear opalescence (NO) 3] (Lens Opacities Classification System III), and corneal endothelial cell count greater than 1200/mm [2]. The exclusion criteria were pathological alterations of the anterior segment (such as corneal opacities, keratoconus, chronic uveitis, zonular dialysis, pseudoexfoliation syndrome, glaucoma, and diabetes), other ocular pathologies impairing visual function, previous anterior or posterior segment surgery, and intraoperative or postoperative complications.

The enrolled patients were assigned to one of the two groups based on a chronological criteria: the introduction of the all laser surgery procedure at the study site: Group 1 (all laser surgery group) included the 21 eyes prior to its introduction and Group 2 (femtophaco group) included the 21 patients prior.

Before cataract surgery, patients underwent a complete ophthalmologic examination including visual acuity evaluation, manifest refraction, slit lamp examination, applanation tonometry, cataract grade/type assessment, and ophthalmoscopy through dilated pupils. In addition, the central corneal endothelial cell count (ECC) (cells/$mm^2$) was measured by means of corneal confocal laser scanning microscope (LSM) (HRT II Rostock Cornea Module, diode-laser 670 nm, Heidelberg Engineering GmbH, Germany) as previously described [7]. Three images were selected by a masked examiner from sequential images from automatic scans and manually acquired frames based on image quality. Endothelial cell density was calculated by counting the number of cells within an area of interest of 250 × 250 $\mu m^2$. The mean of the three counts was used for statistical analysis. Cell densities are reported as number of cells per square millimeter (cell/$mm^2$).

Corneal thicknesses (CT) at the corneal center and at the incision site were measured with anterior segment optical coherence tomography (AS-OCT) (Model 1000, Carl Zeiss Meditec, Inc., Dublin, CA). Cross-sectional scans at the central cornea were obtained for each patient, and scans with the best quality, in terms of visibility of corneal structure, were chosen to measure corneal thickness. Corneal thickness was obtained using the caliper function for biometric measurements of the software incorporated in the instrument. Measurements at the incision site were the maximum length between the epithelium and endothelium on a line crossing the incision tangent to the corneal surface.

### Surgical procedure

A single-experienced surgeon (LM) performed all FEMTO-assisted procedures, which included corneal incisions, anterior capsulotomy, phacoemulsification, and IOL implantation. Eyes were dilated and topical

anesthesia was administered repeatedly before starting the procedure. All surgical procedures were performed using standard surgical equipment. The 21 patients of group 1 underwent surgery from June 8 to July 27, 2015 and the 21 patients of group 2 between July 29 and September 30, 2015.

### FEMTO procedure

A three-plane (1600-micron long and 2.3-mm wide) primary clear corneal incision, a secondary one-plane corneal incision, the capsulotomy, and lens fragmentation were made using LensAR platform (Winter Park, FL). The capsulotomy diameter was 4.8 mm with an edge height of 1 mm. Proprietary spot separation and layer separation were used. Rhexis was centered on the pupil center automatically by the software of the femtosecond laser system and confirmed by the surgeon.

Lens fragmentation was performed after capsulotomy with a cubic pattern: dice pattern with 500 μ spacing with medium power treatment of 7 μJ. Proprietary spot separation and a layer separation were used. The anterior and posterior offsets for lens fragmentation were 500 and 800 μm, respectively.

#### *Standard surgical procedures after FEMTO surgery*

Standard phacoemulsification with a 2.2 mm tip and sleeve was used to complete the surgery in group 1 with combined longitudinal/torsional ultrasound mode (longitudinal US linear power, 40 % limits; continuous torsional phacoemulsification with linear amplitude, 100 % limits; and vacuum limit fixed at 300 mm Hg) using the Alcon Constellation System (Alcon, Fort Worth, TX, USA).

#### *Nanolaser surgery procedure after FEMTO surgery*

Nanolaser emulsification with a 2.2 mm tip and sleeve was used to complete the surgery in group 2 using the nanosecond (Cetus Nano-Laser-System; A.R.C. Laser) lasers. The Cetus system is composed by a base that contains the laser (a 4- to 5-ns-pulsed 1064 nm wavelength YAG laser with a pulse frequency up to 10 Hz) and an optic fiber that transmits the laser impulse to the disposable mono-use coaxial hand piece. The base unit was connected to the same phaco aspiration/irrigation system and was controlled by the pedal of that system. The tip of the handle was fitted with the same 2.2 mm sleeve used for phacoemulsification. The individual pulse energy ranged from 30 to 50 % of maximum power and pulse frequency of 1–2 Hz.

### Intraocular lens implant

All patients received the same intraocular lenses (AcrySof SN60WF-Alcon Laboratories) that were implanted in the capsular bag with a Monarch® III injector and Monarch® D Cartridge. The incision did not require hydration or sutures. Postoperative therapy consisted of ofloxacin 0.3 % and dexamethasone 0.2 % eye drops four times daily for 3 weeks.

### Main outcome measures

The main outcome measures were uncorrected and distance corrected visual acuity (UDVA and CDVA, respectively), corneal endothelial cell count centrally, and corneal thickness at the center and at the incision site. The scheduled follow-ups of the main parameters evaluated in the study were set at baseline and at 7, 30, 60, and 90 days postoperatively.

### Statistical analysis

All statistical analyses were performed using SPSS 22 (IBM, Armonk, NY) and evaluated at an alpha level of 0.05. The Mann–Whitney *U* test was applied for a statistical comparison of the mean logMAR visual acuity between the two groups at each time point.

Differences in baseline parameters were evaluated with Fisher's Exact Test (qualitative parameters) and two-tailed independent sample *t* test with correction for results of Levene's Test for Equality of Variances (quantitative parameters). Within group, variations over time were evaluated using a one-way ANOVA test and post hoc differences were evaluated with Tukey HSD. Inter-group differences at each time point were evaluated using a two-tailed student *t* test.

## Results

### Demographics

The mean age was 69.2 ± 3.3 years (range 65–75 years) in group 1 and 69.3 ± 2.8 years (range

65–75 years) in the group 2. All surgical procedures were completed and were uneventful. No patient was excluded due to intraoperative or postoperative complications. None of the patients were lost to follow-up.

Intraoperative surgical parameters

None of the patients were excluded due to intraoperative complications. The difference in mean laser time between the two groups was not statistically significant (14.66 ± 7.85 in group 1 and 12.47 ± 1.67 in group 2; $p = 0.091$). The mean cumulative dissipated energy was 2.54 ± 1.47 in group 1, and the mean nanolaser energy was 315 ± 29 mJ in group 2.

Visual outcome

Postoperatively UDVA and CDVA increased significantly in both groups during the follow-up period ($p < 0.001$) but, with the exception of UDVA at 7 days, were not significantly different between the two groups at different time points (Table 1).

Endothelial cell count and corneal thickness

Preoperatively the two groups did not present statistically significant differences for corneal endothelial cell count and corneal thickness at the tunnel site and at the center of the cornea.

Postoperatively, there was a significant decrement of endothelial cell count at the center of the cornea in group 1 compared with preoperative values at 90 days ($p < 0.001$) and between 30 and 90 days ($p = 0.008$). The between-group difference was statistically significant at 90 days ($p < 0.001$) Fig. 1.

There was a significant effect of follow-up time on central corneal thickness over the five time points for both groups: [$F(4, 100) = 40.498$, $p < 0.001$] and [$F(4, 100) = 23.039$, $p < 0.001$], respectively (Fig. 2). The central corneal thickness showed a statistically significant increase for both groups that reached a maximum thickness at 7 days and then returned to presurgery levels after 90 days for group 1 and after 60 days for group 2 (Fig. 2; Table 2). Postprocedure between-group differences (thicker for group 1) were statistically significant at all time points.

There was a significant effect of follow-up time on tunnel corneal thickness over the five time points for both groups: [$F(4, 100) = 30.899$, $p < 0.001$] and [$F(4, 100) = 22.095$, $p < 0.001$], respectively (Fig. 3). The tunnel corneal thickness showed a statistically significant increase for both groups that reached a maximum thickness at 7 days that did not return to presurgery level for group 1 but did returned to presurgery levels after 60 days for group 2 (Fig. 3; Table 3). Postprocedure between-group differences (thicker for group 1) were statistically significant at all time points.

## Discussion

One of the most widely reported advantages of FLACS over standard phacoemulsification was the reduced use of ultrasound energy due to crystalline lens disassembly by means of femtosecond laser. Related lower ocular inflammation and lower tissue trauma in terms of aqueous flare, corneal swelling, and corneal endothelial cell loss were also reported in FLACS compared to conventional cataract surgery [6–10].

**Table 1** Mean ± standard deviation of uncorrected (UDVA) and distant corrected (CDVA) visual acuity for each group preoperatively and 7, 30, 60, and 90 days postoperatively, expressed as logMAR

| Time | UDVA, mean ± SD | | | CDVA, mean ± SD | | |
|---|---|---|---|---|---|---|
| | Group 1 | Group 2 | *p* value† | Group 1 | Group 2 | *p* value† |
| Presurgery | 0.60 ± 0.10 | 0.59 ± 0.09 | *NS* | 0.54 ± 0.23 | 0.49 ± 0.21 | *NS* |
| 7 days | 0.39 ± 0.17 | 0.51 ± 0.19 | .021 | 0.25 ± 0.16 | 0.29 ± 0.21 | *NS* |
| 30 days | 0.34 ± 0.14 | 0.36 ± 0.13 | *NS* | 0.21 ± 0.13 | 0.20 ± 0.16 | *NS* |
| 60 days | 0.12 ± 0.21 | 0.11 ± 0.19 | *NS* | 0.08 ± 0.15 | 0.07 ± 0.13 | *NS.* |
| 90 days | 0.10 ± 0.15 | 0.11 ± 0.12 | *NS* | −0.05 ± 0.05 | −0.05 ± 0.09 | *NS* |

† Mann–Whitney *U* test

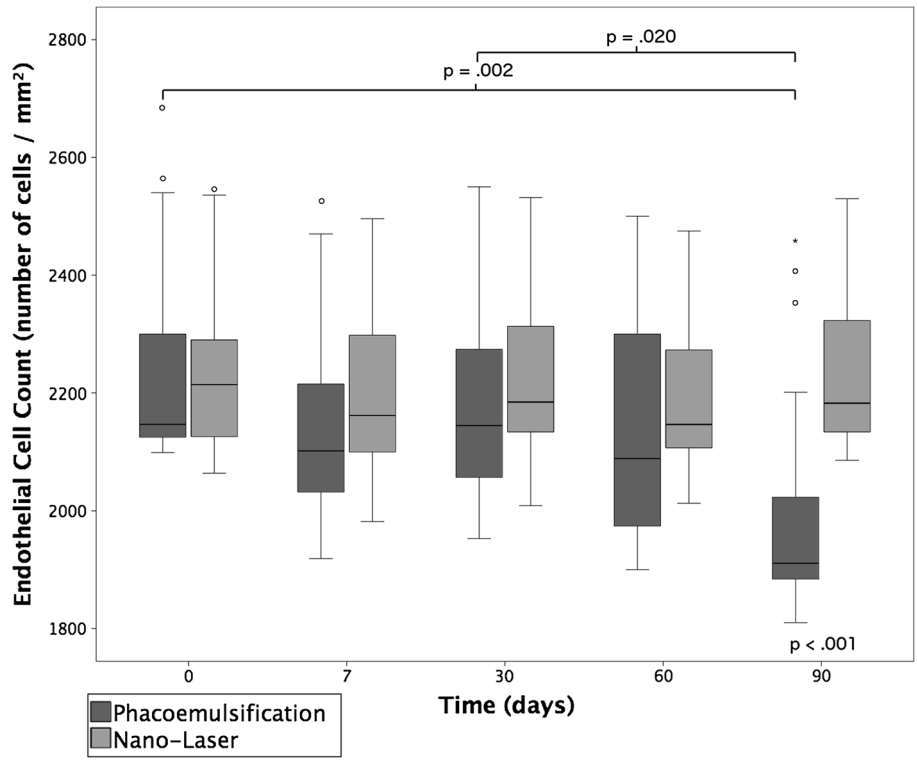



**Fig. 1** The cell count of the cornea (number of cells/mm$^2$) preoperatively and 7, 30, 60, and 90 days postoperatively for the two groups (Group 1 in *blue* and Group 2 in *red*)

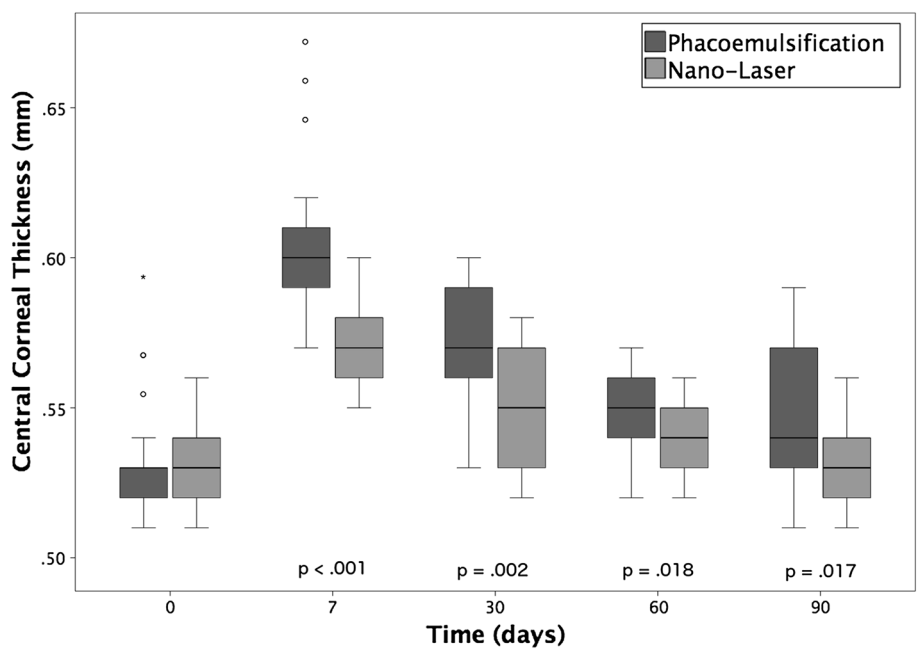



**Fig. 2** The thickness near the tunnel (mm) of the cornea preoperatively and 7, 30, 60, and 90 days postoperatively for the two groups (Group 1 in *blue* and Group 2 in *red*)

**Table 2** Central corneal thickness

| Phacoemulsification | | Time (days) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 7 | 30 | 60 | 90 |
| Time (days) | 0 | | <.001 | <.001 | .003 | .205 |
| | 7 | <.001 | | <.001 | <.001 | <.001 |
| | 30 | <.001 | <.001 | | .003 | .007 |
| | 60 | .003 | <.001 | .003 | | .999 |
| | 90 | .205 | <.001 | .007 | .999 | |

| Nano-Laser | | 0 | 7 | 30 | 60 | 90 |
|---|---|---|---|---|---|---|
| Time (days) | 0 | | <.001 | .009 | .258 | 1.000 |
| | 7 | <.001 | | <.001 | <.001 | <.001 |
| | 30 | .009 | <.001 | | .614 | .012 |
| | 60 | .258 | <.001 | .614 | | .323 |
| | 90 | 1.000 | <.001 | .012 | .323 | |

*Dark grey* indicates same group comparisons. *Light grey* indicates results that were not statistically significant

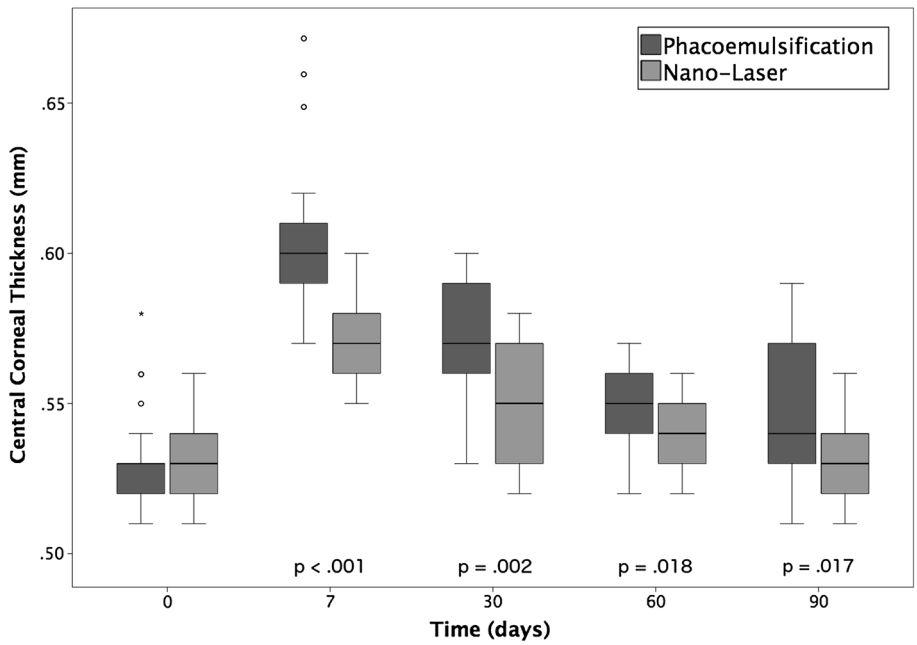



**Fig. 3** The thickness at the center of the cornea (mm) preoperatively and 30, 60, and 90 days postoperatively for the two groups (Group 1 in *blue* and Group 2 in *red*)

Abell et al. demonstrated that the effective phacoemulsification time (EPT) was reduced by 83.6 % in patients treated with FLACS when compared with controls ($p < 0.001$), with 30 % having 0 EPT ($p < 0.001$). The reduced EPT was related to lower postoperative aqueous flare at 1 day ($p = 0.089$) and at 4 weeks ($p = 0.0003$) in FLACS compared to manual and to a lower increase in outer retinal thickness measured with OCT ($p = 0.007$) [10].

Conrad–Hengerer et al. showed an endothelial cell loss of $7.9 \pm 7.8$ % 1 week postoperatively and $8.1 \pm 8.1$ % 3 months postoperatively in the FLACS group versus $12.1 \pm 7.3$ % and $13.7 \pm 8.4$ %, respectively, in the control group treated with standard phacoemulsification. This result was related to lower

**Table 3** Corneal thickness near the tunnel

| Phacoemulsification | | Time (days) | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 7 | 30 | 60 | 90 |
| Time (days) | 0 | | <.001 | <.001 | <.001 | .004 |
| | 7 | <.001 | | .436 | .002 | <.001 |
| | 30 | <.001 | .436 | | .217 | .001 |
| | 60 | <.001 | .002 | .217 | | .419 |
| | 90 | .004 | <.001 | .001 | .419 | |
| **Nano-Laser** | | **0** | **7** | **30** | **60** | **90** |
| Time (days) | 0 | | <.001 | <.001 | .077 | .998 |
| | 7 | <.001 | | .994 | .002 | <.001 |
| | 30 | <.001 | .994 | | .004 | <.001 |
| | 60 | .077 | .002 | .004 | | .413 |
| | 90 | .998 | <.001 | <.001 | .413 | |

*Dark grey* indicates same group comparisons. *Light grey* indicates results that were not statistically significant

corneal trauma and decreased postoperative corneal edema and endothelial cell loss [13].

Kacerovska et al. compared the endothelial cell loss after standard phacoemulsification and FLACS at 1, 7, and 30 days of follow-up. A statistically significant lower percentage of cell loss was noted in the FLACS group at all time points [14]. This result was in contrast with the one reported by Krarup et al. in a similar trial in which a significant difference in endothelial cell loss between FLACS and standard phacoemulsification was not demonstrated despite significantly lower mean phaco energy in FLACS compared to manual surgery [15].

More recently, nanolaser was used as a new laser source to fragment the crystalline lens [17]. The laser is a nanosecond-pulsed YAG laser suitable for fragmentation of moderate grade cataract. Lens fragmentation is performed via a process of photo fragmentation induced by the laser pulse striking a titanium plate located in the tip [17].

Kannellopoulos et al. reported that the nanolaser system was safe and effective for the removal of cataracts up to grade 3 with an average value of energy equal to 5.65 J per patient, which was lower than that required for phacoemulsification. The nanolaser procedures were also associated with a reduced rate of intraoperative complications [17].

In this study, we evaluated visual outcomes, endothelial cell count, and corneal thickness at the center and at the incision site after femtophaco cataract surgery and all laser cataract surgery. UDVA and CDVA increased significantly after surgery in both groups but were not significantly different between the two groups at different time points. Postoperatively, there was a significant decrement of endothelial cell count at the center of the cornea in group 1 compared with preoperative values at 90 days ($p < 0.001$) and between 30 and 90 days ($p = 0.008$). The between-group difference was statistically significant at 90 days ($p < 0.001$). The central corneal thickness showed a significant increase at 30 ($p = 0.018$) and 60 ($p = 0.009$) days postoperatively in group 1 and at 30 days postoperatively in group 2 ($p = 0.002$), and a significant decrease from 30 to 90 days postoperatively in group 2 ($p = 0.002$). Between-group differences showed a statistically significant decrease in group 2 at 60 ($p = 0.018$) and 90 days ($p = 0.017$). Both groups showed a peak of corneal thickness at tunnel site at 30 days. A statistically significant lower increase of corneal thickness was observed for group 2 at all three time points ($p < 0.001$). The difference in induced thickness increase could be explained by the greater amount of sustained turbulence and heat produced by phacoemulsification compared to nanolaser. This hypothesis is supported by the fact that the differences are greater at the tunnel site.

An important limit in this study is that the energy introduced into the eye with phacoemulsification and nanolaser was, at least at this time of the study, not directly comparable.

In conclusion, our results showed a significant lower corneal tissue trauma and lower endothelial cell lose in the all laser cataract surgery group compared to

the femtophaco group. In addition, we observed a reduced corneal edema at both the incision site and at the center of the cornea following surgery and a more rapid return to presurgery thickness in the all laser cataract surgery group compared to the femtophaco group.

**Acknowledgements** The authors do not have any proprietary interest in the material described in this manuscript, and financial support was not received in support of the study.

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