Comparison of changes in corneal endothelial cell density and central corneal thickness between conventional and femtosecond laser-assisted cataract surgery: a randomised, controlled clinical trial

Daliya Dzhaber, Osama Mustafa, Fares Alsaleh, Aleksandra Mihailovic, Yassine J Daoud

ABSTRACT

Background/Aim To identify changes in endothelial cell density (ECD) and central corneal thickness (CCT) in eyes undergoing femtosecond laser-assisted cataract surgery (FLACS) compared with conventional phacoemulsification surgery (CPS).

Methods This is an intraindividual randomised, controlled clinical trial. One eye was randomised to receive FLACS, while the contralateral eye of the same patient received CPS. The femtosecond laser pretreatment included creating main and side-port corneal incisions, capsulotomy and lens fragmentation. Non-contact endothelial cell microscopy and pachymetry were performed preoperatively and at postoperative day 1, week 1, month 1 and month 3.

Results A total of 134 paired eyes from 67 patients were included in the analysis. ECD was not significantly different between the two groups at either postoperative month 1 (2370±580 cells/mm² and 2467±564 cells/mm² in FLACS and CPS groups, respectively; p=0.18) or at postoperative month 3 (2374±527 cells/mm² and 2433±526 cells/mm² in FLACS and CPS groups, respectively; p=0.19). No significant difference was observed in the mean CCT values between the two groups over the follow-up period (p>0.05).

Conclusion Postoperative corneal ECD and CCT were comparable between FLACS and CPS during the 3 months' follow-up period.

INTRODUCTION

Cataract remains the leading cause of reversible blindness worldwide. Since cataract is largely age related, the demand on cataract surgery will likely continue to grow with the globally observed increase in life expectancy and population ageing. Advances in surgical equipment and techniques have made cataract surgery one of the safest in the clinical practice.1 Currently, phacoemulsification is the standard surgical technique used in the developed world.2 As the field continues to advance, newly standardized phacoemulsification surgery (CPS), 4–7 with several reports suggesting a reduction in effective phacoemulsification time (EPT) and cumulative dissipated energy (CDE).8–12 Higher EPT and CDE values are known to be associated with an increased risk of corneal endothelial cell injury intraoperatively and corneal oedema postoperatively.13–15 Thus, with the reduction of endothelial injury, it was postulated that the use of FL in cataract surgery may shorten the recovery period and improve visual outcomes.3

While theoretically conceivable, empirical evidence on the advantages of femtosecond laser-assisted cataract surgery (FLACS) over CPS has shown varying results. In a recent systematic review and meta-analysis, several postoperative outcomes were found to be comparable between FLACS and CPS.16 In addition, another systematic review found published clinical trials to be at an unclear or high risk of bias.17 With that in mind, we conducted this study to compare changes in postoperative endothelial cell density (ECD) and central corneal thickness (CCT) in paired eyes from the same subjects undergoing FLACS and CPS. The study also sought to explore correlations among preoperative and intraoperative parameters, such as EPT and CDE, in each of the treatment groups.

MATERIALS AND METHODS

This randomised, controlled clinical trial was conducted in accordance with Health Insurance Portability and Accountability Act regulations. The trial was registered at ClinicalTrials.gov (NCT02096627). Patients were enrolled from April 2015 to March 2018 and provided written informed consent to participate in the study. Patients were eligible for enrolment if they were ≥18 years old, had bilateral visually significant cataract and were eligible for enrolment if they were ≥18 years old, had bilateral visually significant cataract and were able to attend follow-up for at least 3 months postoperatively. Patients with Fuchs’ corneal endothelial dystrophy, other ocular pathology and/or previous/concurrent ocular surgery were excluded to prevent the inclusion of factors (eg, difficulty obtaining specular counts, endothelial decompensation propensity and longer postoperative oedema) that could confound the examined parameters.
placed on the eye and, then, the eye was covered with a patch.

The remaining steps were similar to those described in the FLACS group above.

Postoperatively, all patients received the same treatment regimen consisting of an antibiotic four times a day for 1 week. In addition, steroids and non-steroidal anti-inflammatory drops were administered four times a day during the first week, which were gradually tapered over the next 3 weeks.

A research assistant timed all intraoperative steps (operating room (OR) time). The starting point in the CPS group was the creation of the first corneal incision (paracentesis), whereas in the FLACS group, it was defined by the opening of the corneal incisions previously made by FL. Time measurement was stopped after hydration and closure of the incisions. Data on EPT, CDE and amount of balanced salt solution (BSS) use were obtained at the end of each case.

The primary outcomes of the study included changes in postoperative ECD and CCT. Secondary outcomes targeted intraoperative parameters and included EPT, CDE, amount of BSS use and OR time, as well as intraoperative complications. Postoperative outcomes were measured at 1 day (POD1), 1 week (POW1), 1 month (POM1) and 3 months (POM3) postoperatively. Nuclear sclerosis (NS) was graded during slit lamp examination in accordance with the Lens Opacities Classification System III (LOCs III).24 Central corneal endothelial cell counts and CCT were assessed using a non-contact specular microscope (CellChek, Konan Medical, Irvine, CA). Central corneal endothelial cell counts were either made automatically or manually by an experienced technician (depending on image clarity and the ability of the machine to recognise endothelial cells). Endothelial cell loss (ECL) was expressed as the percentage of preoperative to postoperative change in ECD over the preoperative ECD. ECD and ECL data from a POD1 and POW1 were not included in the statistical analysis due to a low number of eyes with reliable measurements.

Statistical analysis

All analyses were conducted using STATA V.14.0/IC (StataCorp, College Station, TX). The sample size was chosen to achieve a statistical power of 80% for the group comparison at a 5% significance level. Wilcoxon signed-rank test and paired t-test were used to compare the outcomes between the two techniques, as appropriate. Bivariate correlations were assessed using Spearman’s correlation coefficient (r), except for the correlation between CCT and BSS use in the FLACS group, which was assessed using Pearson’s correlation coefficient (r). A p value <0.05 was considered statistically significant.

RESULTS

A total of 154 eyes of 77 patients met our inclusion criteria, and thus were recruited into the study. However, 10 patients were later excluded. Of those, two patients had CPS in both eyes (inability to perform FLACS due to anatomical features) and another two had FLACS in both eyes (due to patient’s preference after having FLACS in the first eye). Six patients missed their 3 months’ follow-up visit. Therefore, 134 eyes of 67 patients were analysed in this study. The mean age of patients was 68.3±9.1 years (range 33–88 years). Over half (56.7%) of the study population were females.
Preoperatively, there was no statistically significant difference in NS grade between the two groups (p=0.7). Figure 1 shows the percentage of eyes with different types of NS according to the LOCS III grading system between the two groups.

Intraoperatively, BSS use, irrigation/aspiration time for cortex removal and OR time were significantly higher in the FLACS group (p<0.001) (Table 2). However, CDE and EPT were similar between the two groups. Of note, one case of intraoperative posterior capsular block syndrome (PCBS) was encountered in the FLACS group, necessitating anterior vitrectomy and sulcus IOL placement.

Preoperative and postoperative ECD values were not significantly different between FLACS and CPS groups (Table 3). Likewise, the difference in ECL was not statistically significant between the two groups at POM1 or at POM3.

Preoperative CCT was not significantly different between the FLACS and CPS groups at each follow-up point (Table 4). Also, no significant difference was observed in CCT between the two groups over the follow-up period. While the mean relative change in CCT was higher in the CPS group, the difference was not statistically significant at POM1 and POM3.

Table 5 shows correlations between postoperative outcomes and each of the preoperative and intraoperative parameters. In the FLACS group, each of NS grade, BSS use, CDE and EPT were negatively correlated with ECD at POM3. A positive, statistically significant correlation was noted between CCT and each of BSS use and EPT at POM3. In the CPS group, the ECD was negatively correlated with ECD at POM3. None of the other examined parameters were significantly correlated with ECD or CCT. CDE correlated with the NS grade in both FLACS and CPS groups (r=0.37 with p=0.007 and r=0.48 with p<0.001, respectively).

**DISCUSSION**

Endothelial cells play a pivotal role in the maintenance of corneal transparency. ECL can predispose to the development of corneal oedema, and thus the loss of corneal transparency. While endothelial attrition occurs naturally with time, insults to the corneal endothelium (eg, surgery) can accelerate this process. Several factors may make the endothelium susceptible to injury during surgery, such as patient age, cataract density and anterior chamber depth. Intraoperatively, irreversible injury may occur due to excessive manipulation, use of ultrasound (US) energy, ricocheting of nuclear fragments, fluid turbulence during irrigation/aspiration and IOL or surgical instrument contact with the cornea.

With the introduction of FL to cataract surgery, the debate about whether FLACS affects the rate of ECL differently from CPS has continued, with several limitations in the existing literature.

It was reported that reduction of US energy consumption could lead to a decrease in the postoperative corneal ECL. With CPS, the ECL rate has been reported to be around 4%–25%. However, it may be greater in eyes with hard nuclei, reaching as high as 25%–50%.

### Table 3: Mean ECD and ECL at each follow-up point

<table>
<thead>
<tr>
<th>Exam</th>
<th>FLACS group</th>
<th>CPS group</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECD (cells/mm²)</td>
<td>FLACS</td>
<td>CPS</td>
<td></td>
</tr>
<tr>
<td>Preoperative 2645±275</td>
<td>2644±309</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>POM1            2370±580</td>
<td>2467±564</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>POM3            2374±527</td>
<td>2433±526</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>*Wilcoxon signed-rank test.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: Central corneal thickness (µm) and mean relative change in central corneal thickness (%) between the FLACS and CPS groups at each follow-up point (mean±SD)

<table>
<thead>
<tr>
<th>Exam</th>
<th>FLACS group</th>
<th>CPS group</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCT (µm)</td>
<td>FLACS</td>
<td>CPS</td>
<td></td>
</tr>
<tr>
<td>Preoperative 581±45</td>
<td>579±49</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>POD1 607±59</td>
<td>574±45</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>POW1 595±53</td>
<td>604±57</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>POM1 593±50</td>
<td>590±57</td>
<td>0.27*</td>
<td></td>
</tr>
<tr>
<td>POM3 578±52</td>
<td>578±48</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>*Wilcoxon signed-rank test.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1** Percentage of eyes with different types of nuclear sclerosis according to the Lens Opacities Classification System III (LOCS III) grading system between the two groups. CPS, conventional phacoemulsification surgery; FLACS, femtosecond laser-assisted cataract surgery; NS, nuclear sclerosis.

**Table 2:** Means (±SDs) of intraoperative parameters in the FLACS and CPS groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FLACS group</th>
<th>CPS group</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDE</td>
<td>6.7±4.5</td>
<td>6.9±5.3</td>
<td>0.84</td>
</tr>
<tr>
<td>EPT (s)</td>
<td>0.6±0.3</td>
<td>0.6±0.3</td>
<td>0.70</td>
</tr>
<tr>
<td>BSS use (mL)</td>
<td>67.0±17.6</td>
<td>55.4±13.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Irrigation/aspiration time for cortex removal (s)</td>
<td>83.5±37.8</td>
<td>49.3±32.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>OR time (min)</td>
<td>8.0±2.8</td>
<td>6.6±1.9</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Bold values indicate significance. Means (±SDs) of intraoperative parameters in the FLACS and CPS groups.

*Wilcoxon signed-rank test.

BSS, balanced salt solution; CDE, cumulative dissipated energy; CPS, conventional phacoemulsification surgery; EPT, effective phacoemulsification time; FLACS, femtosecond laser-assisted cataract surgery; OR, operating room.
Clinical science

Table 5  Correlation coefficients (r) for intraoperative and postoperative outcomes

<table>
<thead>
<tr>
<th>FLACS group</th>
<th>P value</th>
<th>CPS group</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDE and NS</td>
<td>0.37</td>
<td>0.007</td>
<td>0.48</td>
</tr>
<tr>
<td>ECD (POM3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NS</td>
<td>−0.15</td>
<td>0.26</td>
<td>−0.11</td>
</tr>
<tr>
<td>BSS use</td>
<td>−0.33</td>
<td>0.02</td>
<td>−0.04</td>
</tr>
<tr>
<td>CDE</td>
<td>−0.26</td>
<td>0.07</td>
<td>−0.34</td>
</tr>
<tr>
<td>EPT</td>
<td>−0.28</td>
<td>0.06</td>
<td>−0.04</td>
</tr>
<tr>
<td>CCT (POM3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDE</td>
<td>0.41</td>
<td>0.03</td>
<td>0.1</td>
</tr>
<tr>
<td>BSS use*</td>
<td>0.49</td>
<td>0.007</td>
<td>0.06</td>
</tr>
<tr>
<td>EPT</td>
<td>0.38</td>
<td>0.04</td>
<td>−0.18</td>
</tr>
</tbody>
</table>

Bold values indicate significance.
*Pearson's correlation.

In our study, we found no statistically significant difference in ECL between the two groups. This is in contrast with the findings observed in another intraindividual randomised clinical trial, which showed a significantly lower ECL in the FLACS group compared with CPS group. Despite the matching study design, three observed differences should be noted between this study and the previously published one by Conrad-Hengerer et al. First, they observed a lower use of US energy in the FLACS study and the previously published one by Conrad-Hengerer et al. Second, the amount of irrigation fluid used in their study was higher than in our study (91±12 mL in FLACS and 89±10 mL in CPS group vs 67±17.6 mL and 55.4±13.6 mL in our study). Third, corneal incisions were made manually for the FLACS group in their study but using FL in this study. Although a combination of these factors may account for the differences in observed findings, we suspect that the creation of corneal incisions using FL could potentially be the most contributing factor.

Indeed, previous studies suggested that the addition of laser-automated corneal incisions to FLACS could lead to greater ECL postoperatively than with manually created incisions. In addition, several previous reports in which incisions were created using FL found no significant difference in endothelial cell counts between the two groups (similar to our study), while other studies with manual incisions found a significant difference in ECL, favouring FLACS over CPS.

Comparing the FLACS with CPS groups in our study, we did not observe a significant difference in postoperative CCT at any time point during the follow-up period. Since we observed no significant difference in ECD values between the two groups, it was expected that CCT would be similar between the two groups. It is interesting to note that even in studies that have reported reduced energy use in FLACS versus CPS, there was no difference in CCT at POM1.

Previous studies recommended the use of FLACS in high-risk cases such as guttae or Fuchs’ dystrophy because of the anticipated protection against postoperative ECL. However, our study findings do not support such a recommendation. While patients with Fuchs’ dystrophy may exhibit a postoperative response that is different from healthy eyes, emerging evidence suggests that CCT and corneal decompensation are similar between FLACS and CPS in eyes with compromised endothelial function (eg, Fuchs’ dystrophy).

Finally, the mean time for irrigation/aspiration of the cortical material was significantly higher in the FLACS group with an overall higher OR time (table 2). In a previous intraindividual study, significantly higher OR time was observed in the FLACS group in comparison with CPS. Such time difference was hypothesised to be due to learning curve. In our study, this was not the case. It is interesting to note that irrigation/aspiration step was, on average, 30 s longer in the FLACS group compared with the CPS group. We assume that the reason for this is more adherent cortical material in such eyes due to the thermal effect caused by the FL. In terms of intraoperative complications, we encountered one case of PCBS in the FLACS group. It should be noted that the final outcomes, in terms of ECD and pachymetry, were comparable to the outcomes observed in the rest of the study population.

While the rigour of this study’s design is duly acknowledged, there are a few limitations to be considered. According to the literature, endothelial cell recovery after cell damage may take up to 6 months. Therefore, further studies with longer follow-up will likely be needed to fully evaluate the effect of FL in the corneal ECD during cataract surgery. In addition, it is well known that specular microscope measures a small area of the cornea, which might not be truly representative of the total corneal endothelial cell population.

In conclusion, changes in ECD and CCT did not differ significantly between the FLACS and CPS groups over a 3-month follow-up period. We hypothesise that the creation of corneal incisions by the FL might be implicated in an additional injury to endothelial cells, resulting in an overall ECL rate that is similar to that in CPS. Further studies, designed specifically to investigate whether avoiding FL-assisted corneal incisions could provide extra endothelial cell protection, are strongly encouraged.

Contributors  Research design: YJD. Data acquisition and/or research execution: DD, FA. Data analysis and/or interpretation: DD, OM, AM, YJD. Manuscript preparation: DD, OM, AM, YJD. Manuscript revision: DD, OM, YJD.
Funding  Unrestricted research grants from the Michael O’Bannon Foundation and the Turner Family.
Competing interests  None declared.
Patient consent for publication  Not required.
Ethics approval  Institutional Review Board at the Johns Hopkins University.
Provenance and peer review  Not commissioned; externally peer reviewed.
Data sharing statement  Data are available upon request.
ORCID ID  Dzhaber D http://orcid.org/0000-0002-6468-884X

REFERENCES


