Comparison of Higher-Order Aberration Induction Between Manual Microkeratome and Femtosecond Laser Flap Creation

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ABSTRACT

PURPOSE: To compare the mean change in aberrations produced by a mechanical microkeratome and femtosecond laser.

METHODS: This was a retrospective study of 62 consecutive near emmetropic eyes that underwent LASIK and satisfied the following criteria: negligible laser ablation (for spherical equivalent of 0.00 to +0.50 diopters and maximum meridian of +0.50 diopters), and preoperative and at least 3 months postoperative Placido-based corneal aberrometry (ATLAS; Carl Zeiss Meditec, Jena, Germany). Eyes were divided into two groups according to the method used for flap creation: mechanical microkeratome (Hansatome zero-compression microkeratome; Bausch & Lomb, Rochester, NY [mechanical microkeratome group]) or femtosecond laser (VisuMax; Carl Zeiss Meditec, Jena, Germany [femtosecond laser group]). The root mean square total and individual higher-order aberrations were compared between the two groups.

RESULTS: Corneas with mechanical flaps, on average, possessed statistically significantly higher trefoil and horizontal coma ($P < .001$). There was no change in higher-order aberrations, except for spherical aberration in the femtosecond laser group. Average change in coma did not correlate with hinge position. Both groups showed statistically significant changes in spherical aberration ($P < .001$), although this was most likely due to the small hyperopic ablation performed.

CONCLUSIONS: There was greater induction of specific aberrations with the microkeratome than the femtosecond laser. Hinge position did not appear to influence the induction of coma directly, contrary to previously published reports. The difference in aberrations induction between the two groups might be due to the differences in flap thickness profiles.

PATIENTS AND METHODS

This retrospective study included consecutive patients who were medically suitable for LASIK, treated at the London Vision Clinic, London, United Kingdom, between December

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Submitted: September 15, 2014; Accepted: December 1, 2014

Dr. Reinstein is a consultant for Carl Zeiss Meditec (Jena, Germany) and has a proprietary interest in the Artemis technology (ArcScan, Inc., Morrison, CO) and is an author of patents related to VHF digital ultrasound administered by the Cornell Research Foundation, Ithaca, NY. The remaining authors have no financial or proprietary interest in the materials presented herein.

Prepared in part fulfillment of the requirements for the doctoral thesis of Dr. Reinstein for University of Cambridge.

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doi:10.3928/1081597X-20150122-09
2005 and April 2011. To isolate the optical effect produced by flap creation, the optical effect from ablation was minimized by restricting the inclusion to eyes for which the sphere treated was between 0.00 and +0.50 diopters and cylinder of -0.50 diopters or less. All patients included in the study were diagnosed as having emmetropia with presbyopia who had undergone Laser Blended Vision, in which one eye is corrected with an intended target of plano for distance vision and the other eye is corrected with an intended target of -1.50 diopters for near vision. Therefore, only the distance eyes were included in the current study, meaning only one eye was included per patient.

Our patient database was reviewed and all eyes that met the inclusion criteria were included and divided into two groups according to the method used for flap creation. The mechanical microkeratome group was treated with the Hansatome zero-compression microkeratome and included 24 eyes (24 patients) that underwent superior hinge flap creation. The femtosecond laser group was treated with the VisuMax femtosecond laser and included 39 eyes (39 patients) that underwent superior hinge flap creation. The ablation was performed using the MEL 80 excimer laser (Carl Zeiss Meditec). All flaps and ablations were centered on the coaxially sighted corneal light reflex.

The ATLAS 995 or 9000 Placido ring-based corneal topographer (Carl Zeiss Meditec) was used to obtain corneal front surface topography. The ATLAS 9000 review software was used to calculate the corneal front surface aberrations. Aberrations were described with Zernike coefficients up to the fourth-order using the Optical Society of America notation for a 6-mm analysis diameter. Previous studies on wavefront changes induced by flap creation have only employed whole-eye Hartman–Shack aberrometry. We considered corneal aberrations to be the more reliable method to study the change in aberrations because corneal aberrations are centered in the same place as the ablation and flap (the corneal vertex), whereas Hartman–Shack aberrations are centered on the entrance pupil center.

Data were analyzed comparing the preoperative and 3-month postoperative time periods. If the corneal topography was not available at 3 months, corneal topography from the 6- or 12-month time period was used instead.

### Statistical Analysis

To average the population data across right and left eyes, a correction factor of -1 was applied to Zernike coefficients that possessed odd symmetry in relation to the vertical axis. These include Z_{-2}, Z_{-1}, Z_{+3}, Z_{-4}, and Z_{-2}. For both the mechanical microkeratome and femtosecond laser groups, the change in aberrations was calculated individually for each of the third- and fourth-order Zernike coefficients. The root mean square value for total HOAs was calculated as the square root of the sum of the squares of the third- and fourth-order Zernike coefficients. The root mean square change was calculated as the difference between the average postoperative root mean square and the average preoperative root mean square. Two-tailed t tests were used to compare preoperative and postoperative data and P values less than .05 were considered statistically significant. Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA) was used for all statistical analyses.

### RESULTS

Table 1 shows the demographics for age, sphere, cylinder, and spherical equivalent treated for the eyes included in the study.

The mean change in corneal HOAs is plotted for each Zernike coefficient for the mechanical microkeratome group in Figure 1A and for the femtosecond laser group in Figure 1B. Table 2 shows the change in corneal aberrations after mechanical microkeratome and femtosecond laser flap creation, and the difference between the two groups. In the mechanical microkeratome group, corneal aberrations demonstrated a statistically significant change in horizontal coma Z_{+2}(P < .001) and trefoil Z_{+3}(P = .017), whereas these coefficients did not change in the femtosecond laser group. Both groups showed a statistically significant difference in spherical aberration Z_{-4}(P < .001), although this is for the most part attributed to the small hyperopic ablation. There were statistically significant

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mechanical Microkeratome</th>
<th>Femtosecond Laser</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of eyes</td>
<td>23</td>
<td>39</td>
<td>–</td>
</tr>
<tr>
<td>No. of patients</td>
<td>23</td>
<td>39</td>
<td>–</td>
</tr>
<tr>
<td>Age (y)</td>
<td>54.5 ± 5.8 (44.5 to 68.7)</td>
<td>53.3 ± 5.7 (44.2 to 65.1)</td>
<td>.368</td>
</tr>
<tr>
<td>Sphere (D)</td>
<td>+0.42 ± 0.12 (+0.25 to +0.50)</td>
<td>+0.41 ± 0.12 (+0.20 to +0.50)</td>
<td>.800</td>
</tr>
<tr>
<td>Cylinder (D)</td>
<td>-0.07 ± 0.14 (0.00 to -0.50)</td>
<td>-0.26 ± 0.20 (0.00 to -0.50)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>SE refraction (D)</td>
<td>+0.39 ± 0.12 (+0.13 to +0.50)</td>
<td>+0.28 ± 0.15 (0.00 to +0.50)</td>
<td>.007</td>
</tr>
</tbody>
</table>

SD = standard deviation; D = diopters; SE = spherical equivalent
differences between mechanical microkeratome and femtosecond laser flaps for induced coma \((P = .004)\) and induced trefoil \((P = .039)\) (Table 2).

**DISCUSSION**

The current study showed that front surface corneal HOAs increased more after flap creation with the mechanical microkeratome than with the femtosecond laser. In the mechanical microkeratome group, there were small but statistically significant changes in horizontal coma and trefoil \((P < .001)\) and spherical aberration \((P < .001)\). In the femtosecond laser group, there were no statistically significant changes in any Zernike term other than spherical aberration.

The main weakness of the current study is that small amounts of ablation were also performed, so it cannot be proven that changes in HOAs were solely due to flap creation. However, by limiting the sphere, cylinder, and spherical equivalent refraction treated to a maximum of +0.50 diopter, the induction of aberrations due
to stromal tissue removal was minimized. The small induction of negative spherical aberration observed was consistent with the small hyperopic ablation performed and was equivalent in both the mechanical microkeratome and femtosecond laser groups.

There are three previous studies that examined the change of aberrations induced solely by flap creation. These studies followed a two-step approach in which flap creation was performed in the initial procedure, followed a few months later by the excimer laser ablation. The first of these studies, by Pallikaris et al., reported a population of 15 myopic eyes in which a nasally hinged flap was created with a Flapmaker microkeratome (Refractive Technologies, Inc., Cleveland, OH). The study demonstrated an increase in horizontal coma 2 months after flap creation using the WASCA Hartman–Shack aberrometer (Carl Zeiss Meditec). It was suggested that the increase in horizontal coma was influenced by the nasal hinge position.

The two subsequent studies set out to investigate this hypothesis further. Tran et al. compared the aberrations secondary to the IntraLase femtosecond laser (IntraLase Corp., Irvine, CA) and Hansatome microkeratome flap creation in a contralateral eye study including 9 patients. In the Hansatome group, statistically significant increases in trefoil, quadrafoil, and total HOAs were found 10 weeks after flap creation using the COAS aberrometer (AMO Wavefront Sciences, Albuquerque, NM) (essentially the same technology as the WASCA). Specifically, they did not find coma aligned with the flap hinge and only found an increase in coma after excimer laser ablation in the Hansatome group. In the IntraLase group, no statistically significant changes in HOAs were found after flap creation.

Porter et al. examined a population of 17 myopic eyes in which a superior hinged flap was created with a Hansatome microkeratome. Data were collected at multiple time points, ranging from 20 minutes to 2 months after flap creation. The study found a statistically significant negative shift in trefoil $Z_4$ throughout the follow-up period using the Zywave aberrometer (Bausch & Lomb), which was thought to be secondary to the direction of the cut when the flap was made (temporal inferior to superior). The study recorded an acute increase in vertical coma 20 minutes after the flap creation; however, this aberration receded after 24 hours, meaning that there was no coma aligned with the flap hinge at the 2-month follow-up visit.

Therefore, only Pallikaris et al. found an increase in coma aligned with flap-hinge position. In the current study, we found horizontal coma in the opposite direction to the superior hinge in the mechanical microkeratome group, which contradicts the hypothesis that the hinge position induces coma. It is also worth noting that there was minimal or no coma induced with either the IntraLase or VisuMax femtosecond lasers. If induction of coma was secondary to the hinge, one would expect to find induced coma regardless of the method of flap creation.

Three of the four studies (ie, including the current study) included results for the Hansatome microkeratome, all of which found a statistically significant increase in trefoil. When analyzing the previously published topographic map of the Hansatome flap thickness profile, strong similarities with a trefoil pattern were noted (Figure 2). To demonstrate this similarity, we used the mean change for each Zernike term (Table 2) to generate a map of the mean change in aberrations (Figure 2). For microkeratome flaps, the flap thickness profile demonstrated an inferotemporal region where the flap was thinnest, approximately 133 µm. The flap was thickest peripherally, particularly in the inferonasal quadrant and superiorly. The average thickest area of the flap was 160 µm, located 3.1 mm nasally along the horizontal meridian. Direct
comparison to the mean change in HOA map demonstrated a similar pattern for the mean change in HOAs to the flap thickness profile. The large difference in flap thickness between the nasal and temporal cornea corresponds well to the induced horizontal coma seen on the mean change in HOA map. Similarly, the increased peripheral thickness inferonasally and supertemporally corresponds well to the induced trefoil seen on the mean change in the HOA map. This similarity suggests that the increase in trefoil and possibly coma when using the Hansatome might be due to the flap thickness profile and not related to the hinge position. Further study is required to test this hypothesis by comparing the flap thickness profile with the induced aberrations in the same eye.

It seems clear that different mechanical microkeratomes produce distinct flap thickness profiles, with another example being the flap thickness profile that we have previously published for the Moria LSK-One microkeratome (Moria, Antony, France), where the mean flap thickness profile was thinner centrally and thicker peripherally with a mean central flap thickness of 163.6 µm and standard deviation of 30.3 µm.18,19 Pallikaris et al.2 used the Flapmaker disposable microkeratome, which has a similarly high flap thickness standard deviation of 32 µm as reported in another study.20 Given the poor flap thickness reproducibility and irregular flap thickness profiles of other mechanical microkeratomes, it might be expected that the flap thickness profile of the Flapmaker was also irregular; based on this hypothesis, coma may be induced if the cut were relatively much deeper toward the nasal hinge. This may be a more likely explanation for the increased horizontal coma found by Pallikaris et al.2 rather than being induced by the hinge location.

The current study found a moderate increase in horizontal coma in the mechanical microkeratome group, which was not found in the previous two studies. However, the similarity between the induced aberrations and the flap thickness profile (Figure 2) suggests that the induction of horizontal coma observed was true and valid. It may be that the disagreement between studies regarding horizontal coma was due to the small sample size of the study by Tran et al.3 and the significantly lower resolution aberrometer used in the study by Porter et al.1

For femtosecond laser flaps, the flap thickness profile showed much higher uniformity compared to the microkeratome flaps, with only a small superior to inferior difference of less than 5 µm (Figure 2). Direct comparison to the map of mean change in HOAs demonstrated that this small asymmetry in flap thickness did not result in vertical coma induction, as shown by the mean change being in vertical coma of only -0.021 µm. The only aberration seen on the map of mean change in HOAs was a small change in spherical aberration secondary to the small hyperopic ablation. It is likely that the more regular flap thickness profile of the VisuMax femtosecond laser,21-22 similar to that previously reported for other femtosecond lasers,4,6,7,10,14,26,27 induces fewer biomechanical changes to the cornea than the more irregular flaps created by mechanical microkeratomes. This agrees with the results of Tran et al.,3 in which they found an increase in HOAs in the Hansatome group, but no statistically significant change in the IntraLase group. Numerous studies comparing the aberration changes induced by mechanical microkeratome versus femtosecond LASIK have demonstrated less induction of aberrations by femtosecond LASIK.3,13,14,28

The current study confirms that flaps created by femtosecond lasers induce fewer HOAs than mechanical microkeratomes, most likely secondary to their more regular flap thickness profile, and that the location of the hinge does not appear to influence aberrations. The more irregular flap thickness profile of the Hansatome zero-compression microkeratome was correlated to a similar and more irregular corresponding map of mean change in HOAs. The more regular flap thickness profile of the VisuMax femtosecond laser was accompanied by a more regular map of mean change in HOAs. Further study would be of interest to compare the flap thickness profile and localized change in HOAs within individual eyes to investigate this hypothesis.

AUTHOR CONTRIBUTIONS

Study concept and design (CY, TJA, MG, DZR); data collection (CY, TJA, MG, DZR); analysis and interpretation of data (CY, TJA, MG, DZR); drafting of the manuscript (CY, TJA, MG, DZR); critical revision of the manuscript (DZR); statistical expertise (TJA, DZR)

REFERENCES


