Comparison of morphologic features of clear corneal incisions created with a femtosecond laser or a keratome

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PURPOSE: To compare the morphology of clear corneal incisions (CCIs) created with a femtosecond laser (Catalys) or a keratome (2.65 mm steel) during phacoemulsification using anterior segment optical coherence tomography (AS-OCT) and analyze the intended versus the achieved morphologic characteristics of femtosecond laser–generated CCIs.

SETTING: Northwestern University Feinberg School of Medicine, Chicago, Illinois, USA.

DESIGN: Comparative case series.

METHODS: Eyes with femtosecond CCIs and age-matched eyes with the keratome CCIs underwent AS-OCT of the incisions 1 month after phacoemulsification. ImageJ software was used to evaluate AS-OCT images for CCI length, endothelial gaping, endothelial misalignment, and Descemet membrane detachment.

RESULTS: In the femtosecond group (20 eyes) and keratome group (16 eyes), the mean values were CCI length, 1.99 mm $\pm$ 0.07 (SEM) versus 2.04 $\pm$ 0.23 mm (P = .39); endothelial gaping, 0.14 $\pm$ 0.03 mm versus 0.19 $\pm$ 0.09 mm (P = .03); endothelial misalignment, 0.04 $\pm$ 0.03 mm versus 0.08 $\pm$ 0.06 mm (P = .022). No eye in the femtosecond group and 3 eyes in the keratome group had a Descemet membrane detachment (P = .04). Six femtosecond eyes and 11 keratome eyes had posterior wound retraction (P = .02). The mean CCI length was 94.9% of the intended 2.1 mm, the posterior plane depth was 93.3% of the intended 70%, and the posterior side-cut angle was 91.7% of the intended 45 degrees.

CONCLUSION: Femtosecond laser–generated CCIs had significantly lower endothelial gaping, endothelial misalignment, Descemet membrane detachment, and posterior wound retraction than keratome-created CCIs and were within 10% of the intended length, depth, and angle measurements.

Financial Disclosure: Neither author has a financial or proprietary interest in any material or method mentioned.

J Cataract Refract Surg 2014; 40:521–530 © 2014 ASCRS and ESCRS

Cataract surgery is performed in more than 3 million people in the United States each year. The predominant surgical technique includes creating a clear corneal incision (CCI) using a metal keratome followed by phacoemulsification and intraocular lens (IOL) implantation. The recent introduction of femtosecond laser technology allows computer-guided construction of corneal wounds, the anterior capsulorhexis, lens fragmentation, and limbal relaxing incisions.[1] The pros and cons of the above-mentioned techniques of cataract surgery are a topic of interest at this time as surgeons evaluate which technique may benefit patients the most.

The importance of creating a strong and stable CCI for cataract surgery cannot be overstated. Most studies of the morphology and functional characteristics of CCIs report on CCIs created with a metal keratome. Results in previous studies suggest that there is a potential relationship between endophthalmitis after cataract surgery and CCIs.[2] Clear corneal incisions may allow entry of pathogens into the eye secondary to intraocular pressure (IOP) variations during the early postoperative period.[3,4] India-ink penetration studies found that corneal incisions are potentially physically unstable, allowing leakage from eye rubbing or forceful blinking early after surgery.[4] With

Published by Elsevier Inc.

0886-3350/$ - see front matter
http://dx.doi.org/10.1016/j.jcrs.2013.11.028

manual CCIs created with a keratome blade in a single pass, it is often difficult to precisely control the length and architecture of the incision. In contrast, with the femtosecond laser, the surgeon can fashion incisions that are more square and multiplanar.[5] Although in vivo studies of such incisions are awaited, in a pilot study using cadaver eyes, Masket et al.[6] found that corneal incisions created with a femtosecond laser were stable and that their creation was reproducible.

Anterior segment optical coherence tomography (AS-OCT) provides in vivo cross-sectional tomography, allowing visualization of CCIs and a means for qualitative and quantitative analysis. Using AS-OCT, several studies[7–18] have assessed the short-term (up to 1 month) architectural changes in CCIs created with a metal keratome. However, there are little data on the differences in CCI architecture between a femtosecond laser and the conventionally used metal keratome. There is also a lack of data comparing the intended (ie, machine programmed) versus achieved parameters as a measure of accuracy of the femtosecond laser in creating CCIs for cataract surgery. We sought to address these issues in our study by using AS-OCT to compare wound morphology in eyes in which CCIs were created with a standard metal keratome versus those in which a femtosecond laser was used.

PATIENTS AND METHODS

The study was approved by the Institutional Review Board, Northwestern University Feinberg School of Medicine, and adhered to the tenets set forth by the Declaration of Helsinki. A retrospective analysis was performed of the medical records of consecutive patients who had femtosecond laser–assisted cataract surgery (for CCIs, capsulorhexis, and lens fragmentation) at the Department of Ophthalmology, Northwestern Memorial Hospital, between November 2012 and March 2013. In addition, a group of age-matched patients undergoing conventional phacoemulsification during the same period were randomly selected for inclusion as controls.

The study was performed to test the null hypothesis that CCIs created using a femtosecond laser have reduced endothelial gaping and endothelial misalignment and that they result in a lower incidence of Descemet membrane detachment than those created using a steel keratome. The study analyzed the in vivo morphology of cataract surgery CCIs created using a femtosecond laser or a keratome. It also compared the achieved length (measured on AS-OCT images), posterior plane depth, and incision angle with the intended laser parameters (as programmed) for femtosecond CCIs.

All patients had AS-OCT imaging at the 1-month postoperative visit. ImageJ software (National Institutes of Health)[19] was used to compare the CCI morphology on the AS-OCT images. Patients who had a history of ocular disease other than cataract, previous intraocular surgery or laser treatment, or a history of ocular or medical conditions that could affect corneal wound healing and those concurrently using a topical or systemic medication that could impair wound healing were excluded. Also excluded were cases requiring enlargement of the corneal incision during the surgery, including for IOL insertion; those having intraoperative or postoperative complications that could potentially affect the cornea; those with significant postoperative corneal edema at the time of OCT; those requiring placement of a suture to close the CCI at the end of surgery; and those that had previous corneal surgery or preexisting scars affecting the area of wound creation. Surgery was performed by the same surgeon (S.B.) in both groups.

Surgical Technique

Femtosecond Laser Parameters The femtosecond laser treatment (Catalys Precision Laser System, Optimedica Corp.) was performed with the patient supine beneath the system. The 2-piece Liquid Optics interface was engaged to the patient's eye using suction. Thereafter, the system automatically measured the dimensions of the anterior chamber and the lens with in-built spectral-domain AS-OCT, identified the ocular surfaces, and created laser exclusion zones, which were verified by the surgeon.

To standardize wound creation, identical femtosecond laser parameters were used in all patients. These included a limbus offset of 0.3 mm, incision width of 2.6 mm, and incision length of 2.1 mm (Figure 1). Triplanar CCIs were created with the anterior plane depth (depth of the corneal incision plane at the anterior end) set at 30% and the posterior plane depth (depth of the corneal incision plane at the posterior end) at 70%. The anterior side-cut angle was 90 degrees, while the posterior side-cut angle (angle between the corneal incision and the posterior surface of the cornea at the incision exit) was 45 degrees. The anterior line density was 10 at a distance of 30% (150 μm), while the posterior line density was 4 at a distance of 30% (150 μm). These are the default settings for the corneal incisions programmed in the laser.[A] The line density influences the spacing between the cuts by the laser and can be adjusted individually for the anterior, central, and posterior regions of the incision. The horizontal spot spacing was 5 μm, and the vertical spot spacing was

Submitted: September 26, 2013.
Final revision submitted: November 12, 2013.
Accepted: November 13, 2013.

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Supported by a 2013 American Society of Cataract and Refractive Surgery Foundation research grant (Dr. Grewal) and in part by an unrestricted grant to the Department of Ophthalmology, Northwestern University Feinberg School of Medicine, Chicago, Illinois, from Research to Prevent Blindness, New York, New York, USA.

Presented at the annual meeting of the American Academy of Ophthalmology, New Orleans, Louisiana, USA, November 2013, and at the ASCRS Symposium on Cataract, IOL and Refractive Surgery, Boston, Massachusetts, USA, April 2014.

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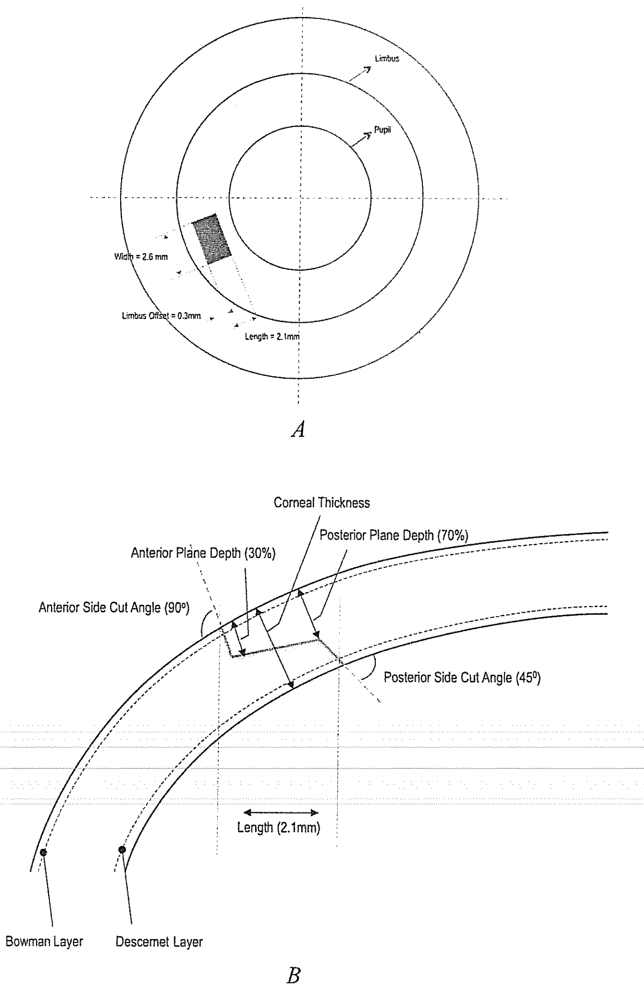

Figure 1. *A*: Femtosecond laser CCI parameters. *B*: Cross-sectional view of the main wound incision and the incision characteristics.

10 μm. The pulse energy was 5 μJ. The corneal thickness was measured at the projected intersection location of the incision with the anterior and posterior corneal surfaces and measured at 90 degrees to the anterior and posterior corneal surfaces. Incisions were created by the laser from the posterior to the anterior cornea.

The capsulotomy and lens fragmentation (sextant grid pattern) and softening parameters (350 μm grid size) were also standardized. The femtosecond laser incision was entered using a flat, tapered-tip spatula. Complete entry was possible without wound manipulation in all cases.

Conventional Phacoemulsification All patients had phacoemulsification using topical anesthesia. Initially, a side-port incision was created with a 15-degree blade (Beaver Optimum Knife, 15 degrees, Beaver-Visitec International). Sodium hyaluronate 1.0% (Healon) was then injected into the anterior chamber before the main incision was created. All main incisions were made in the temporal aspect of the cornea with a stainless steel blade (2.65 mm wide Xstar Safety Slit Knife, 45 degrees, Beaver-Visitec International). This blade has etchings on its anterior surface that the surgeon can use to determine the length of the corneal tunnel. Incisions were constructed to create a triplanar internal architecture. Initially, the blade was directed perpendicular to the corneal surface, buried partially in the stroma, and then advanced farther into the superficial stroma. It was subsequently brought parallel to the corneal surface and advanced to create a tunnel that was 2.0 mm long (estimated using the above-mentioned surface markings). Next, the anterior chamber was entered by redirecting the blade toward the center of the pupil. Standard phacoemulsification was then performed.

Both Groups

The wound width in the femtosecond group and the keratome group permitted easy entry of the IOL cartridge into the anterior chamber. The most common IOL was the Tecnis ZCB00 (Abbott Medical Laboratories, Inc.) implanted with the Unfolder Emerald One Series cartridge system (Abbott Medical Laboratories, Inc.). The other IOLs were the Acrysof IQ Restor multifocal IOL and Acrysof IQ toric IOL (both Alcon Laboratories, Inc.) injected with cartridge D of the Monarch III IOL delivery system (Alcon Laboratories, Inc.). In both groups, after the ophthalmic viscosurgical device was removed, stromal hydration of the main and side-port incisions was performed with a balanced salt solution. All incisions were confirmed to be watertight by drying with a Weck-Cel ophthalmic sponge (Beaver-Visitec International) and using counterpressure on the globe.

Image Acquisition

The Spectralis HRA+OCT anterior segment module (Heidelberg Engineering GmbH) was used to image the CCI at the 1-month postoperative visit. This instrument requires an additional lens adapter to the traditional posterior segment Spectralis OCT system to capture anterior segment images. The AS-OCT system has an acquisition speed of 40 000 A-scans per second and uses a scan beam 870 nm in wavelength with digital axial resolution of 3.9 μm and a transverse resolution of 10 μm for anterior segment imaging.[B] This enables the AS-OCT system to capture higher resolution images of the corneal incisions. Limitations of the AS-OCT system compared with time-domain OCT include a shallow scan depth (1.9 mm versus 6.0 mm) and its poor ability to penetrate tissues that produce high light scatter (eg, sclera, limbus). These limitations prevent the AS-OCT system from capturing a cross-section of the entire cornea in a single scan; thus, a scan localized to the CCI was used.

The raster scan option was used to image the temporal CCI at a working distance of approximately 12.0 mm. The AS-OCT images were captured using the 15-degree scan angle covering an area of 8.3 mm × 1.9 mm (768 pixels × 496 pixels). This scan pattern captures 41 B-scans. Active eye tracking was used, and images were averaged for noise reduction. The scanning beam was aimed perpendicular to the temporal corneal incision, which was achieved by asking the patient to look toward the other eye. This was done to avoid an "end-on" aberration effect in which the AS-OCT beam is reflected obliquely off the cornea if the patient is fixating straight ahead, which would cause the wound profile to appear artificially distorted.[8] Automated refraction correction was performed using the AS-OCT system's software. The AS-OCT scans free of motion artifact and the scan with the best image quality or the most obvious display of the incisions was selected for each patient.

Qualitative and Quantitative Assessment of Optical Coherence Tomography Images

The AS-OCT scans obtained were exported using the "export image" function in ImageJ software, which was used to perform the subsequent analysis.[19] The scale of the AS-OCT images was determined and used to calculate the dimensions of the CCI. The same investigator (D.S.G.), masked to the method of CCI creation, analyzed the AS-OCT images. Four architectural features were used to objectively describe the CCI as follows: gaping of the wound at the endothelial side, within-wound gape, misalignment of the roof and floor of the incision at the endothelial side (wound retraction), and localized Descemet membrane detachment.[8,10] Visualization of any of these architectural features in the AS-OCT scans of the incision was counted as "present."

The ImageJ "straight-line" tool was used to delineate the wound parameters. The "measure" function was used to calculate the distance in pixels, and this was converted into millimeters using the predetermined scale. These parameters were then compared between the 2 groups.

Also compared were the intended CCI measurements versus the achieved (actually measured) CCI measurements in the femtosecond group for the parameters of wound length, posterior plane depth, and posterior side-cut angle. Because of limitations of the AS-OCT images in defining the superficial edge of the CCI incision, the anterior plane depth and anterior side-cut angle were not analyzed. Intended parameters were obtained from the femtosecond laser system treatment report.

Statistical Analysis

Statistical analysis was performed using SPSS for Macintosh software (version 20.0, SPSS, Inc.). The unpaired *t* test was used to compare the parameters between the 2 groups (femtosecond and keratome). The CCI length, endothelial gape, and endothelial misalignments were calculated for the 2 groups using ImageJ software. The chi-square test was used to compare the incidence of Descemet membrane detachment, within-wound gape, and misalignment of the incision at the endothelial side between the 2 groups. Differences with a *P* value less than 0.05 were considered statistically significant. Demographic data are presented as mean ± standard deviation, while the CCI AS-OCT analysis is presented as the mean ± standard error of the mean.

RESULTS

The retrospective review identified 20 eyes of 17 patients who had femtosecond laser-assisted cataract surgery and who met the inclusion criteria. Also included were 16 age-matched eyes of 15 patients who had conventional phacoemulsification during the same time period. The mean age was 66.4 ± 8.5 years (range 42 to 77 years) in the femtosecond laser group and 63 ± 10 years (range 42 to 78 years) in the keratome group ($P = .4$) Wound leakage was not observed in any eye at the conclusion of surgery or postoperatively. All eyes were at physiologic IOP at the 1-month visit. Two patients (1 in each group) were excluded because of poor image quality.

Clear Corneal Incision Morphology: Femtosecond Laser Versus Keratome

Table 1 compares the CCI architecture between the 2 groups. The mean CCI length was similar in the 2 groups ($P = .39$). There was significantly lower endothelial gape in the femtosecond laser group than in the keratome group ($P = .03$). The amount of endothelial misalignment was also significantly lower in the femtosecond group ($P = .022$). Significantly more eyes in the keratome group than in the femtosecond group had a Descemet membrane detachment and visible posterior wound retraction ($P = .04$ and $P = .02$, respectively; 2-tailed χ^2 test). No eye in either group had a visible within-wound gape.

Figure 2 shows a representative AS-OCT image of endothelial gape in a femtosecond laser–generated CCI. Figure 3 shows endothelial misalignment in a femtosecond laser–generated CCI, and Figure 4 shows Descemet membrane detachment in a keratome-generated CCI. Figure 5 shows an example comparison of the CCI profile created with the femtosecond laser and that created with the metal keratome.

Table 1. Comparison of CCI architecture between groups.

CCI Parameter	Group: Femtosecond Laser (20 Eyes)	Group: Keratome (16 Eyes)	*P* Value
Mean length (mm) ± SEM	1.99 ± 0.07	2.04 ± 0.23	.39*
Endothelial gape (mm) ± SEM	0.14 ± 0.03	0.19 ± 0.09	.03*
Endothelial misalignment (mm) ± SEM	0.04 ± 0.03	0.08 ± 0.06	.022*
Descemet membrane detachment (n)	0	3	.04†
Visible posterior wound retraction (n)	6	11	.02†

CCI = clear corneal incision; n = eyes; SEM = standard error of the mean
*Unpaired *t* test
†Chi-square test

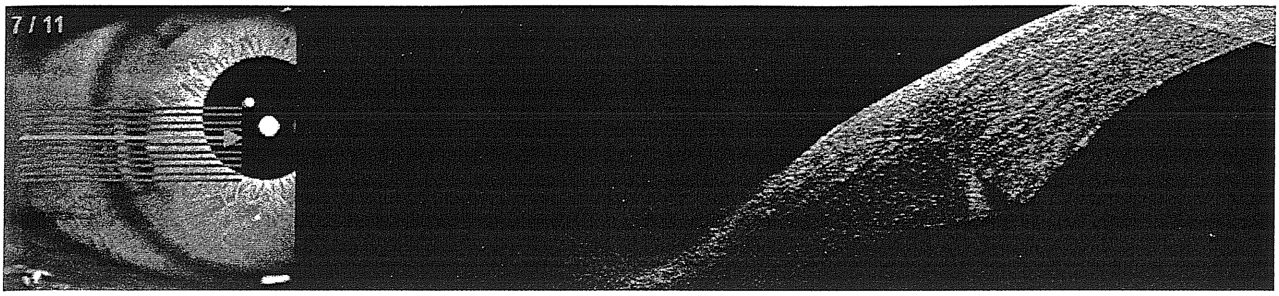

Figure 2. Representative AS-OCT image of a femtosecond laser CCI with endothelial gape measured at 0.122 mm. The lines represent the raster line pattern, and the arrow indicates the direction of scan using the AS-OCT, overlaid on the infrared image.

Comparison of Intended Versus Achieved Morphologic Characteristics Using Femtosecond Laser

The mean CCI length in the femtosecond group ranged from 1.86 to 2.13 mm and was 94.93% ± 3.27% (range 88.6% to 101.4%) of the intended 2.1 mm. The mean posterior plane depth was 65.31% ± 0.69% (range 58.9% to 69.63%), which was 93.3% ± 4.47% (range 84.14% to 99.47%) of the intended 70%. The mean posterior side-cut angle was 41.25 ± 0.95 degrees (range 36 to 49 degrees), which was 91.67% ± 2.1% (range 80.0% to 108.89%) of the intended 45 degrees. Figure 6 shows a frequency histogram of the measured percentage of the achieved versus target CCI measurements for incision length, posterior plane depth, and posterior side-cut angle. Figure 7 shows the Bland-Altman plots for CCI length, posterior plane depth, and posterior side-cut angle.

DISCUSSION

This study was designed to quantitatively assess the differences in morphology and architecture of CCIs created using a femtosecond laser versus a standard metal keratome. Imaging was performed with AS-OCT, whose utility in the examination of postoperative CCIs has been established.[9,20] Anterior segment OCT provides detailed visualization of subtle changes that may be difficult or impossible to appreciate at the slitlamp or with devices with less resolution and has been shown to give reproducible measurements.[21] In addition, being a noncontact method, it is preferred over contact imaging techniques such as ultrasound (US).

Using spectral-domain AS-OCT imaging and image-analysis software, we were able to determine the profile of the CCIs and quantify and compare different morphologic characteristics between the 2 groups 1 month after surgery. We found a significantly lower incidence of localized Descemet membrane detachment in the femtosecond laser group than in the keratome group. Previously, Xia et al.[22] reported that 82% of eyes had a localized Descemet membrane detachment in keratome-generated CCIs. In a study by Calladine and Tanner,[10] Descemet

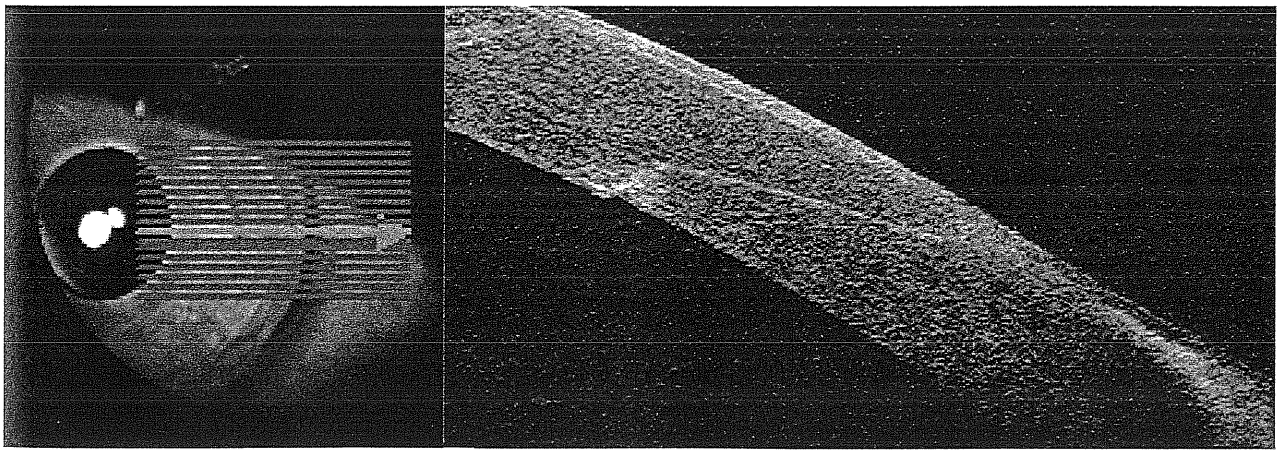

Figure 3. Representative AS-OCT image of femtosecond laser CCI endothelial misalignment or posterior wound retraction measured at 0.135 mm. The lines represent the raster line pattern, and the arrow indicates the direction of scan using the AS-OCT, overlaid on the infrared image.

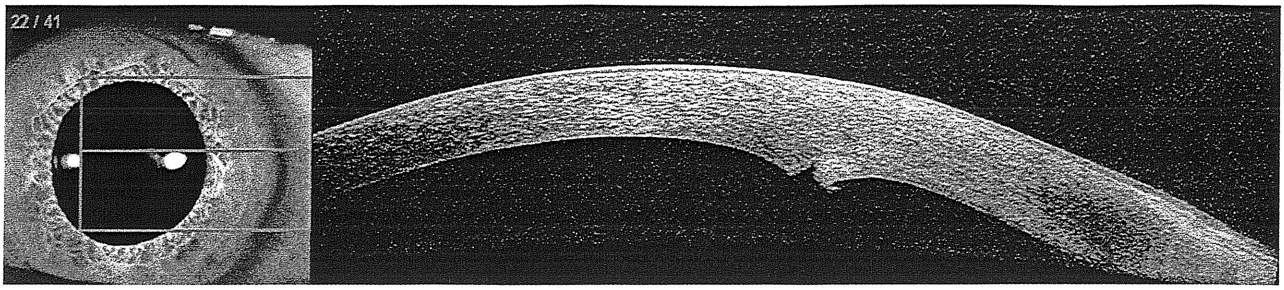

Figure 4. Representative AS-OCT image of a localized Descemet membrane detachment in a CCI created using a metal keratome The box represents the area of raster line scans and the arrow represents the direction of scan using the AS-OCT, overlaid on the infrared image.

membrane detachment was found in 63% of eyes with stromal hydration and 25% of eyes without stromal hydration. Local detachment of Descemet membrane is likely to impede the local endothelial pump mechanism, which could hinder wound sealing. Routine slitlamp microscopy often fails to show Descemet membrane detachments, especially in the early postoperative days because of corneal edema. Albeit rarely, small Descemet membrane detachments can progress to extensive detachments during intraoperative maneuvers as well as during wound hydration. Large Descemet membrane detachments can cause significant vision impairment and require additional procedures, including an anterior chamber sulfur hexafluoride gas injection or even endothelial keratoplasty.[23] A reduction in incision size has led to reduced recovery time after surgery and lower surgically induced astigmatism. In a recent histopathologic study, Vasavada et al.[24] found that incision as small 1.8 mm and 2.2 mm can cause Descemet membrane detachments at the point of internal entry. In contrast, using a 2.6 mm incision created with a femtosecond laser, we found no cases of Descemet detachment. This suggests a potential advantage of femtosecond lasers for corneal wound creation. However, a normal variation in stromal hydration can influence postoperative incision morphology and is a variable that is difficult to control. We aimed to minimize the impact of this variable by performing the imaging 1 month after surgery.

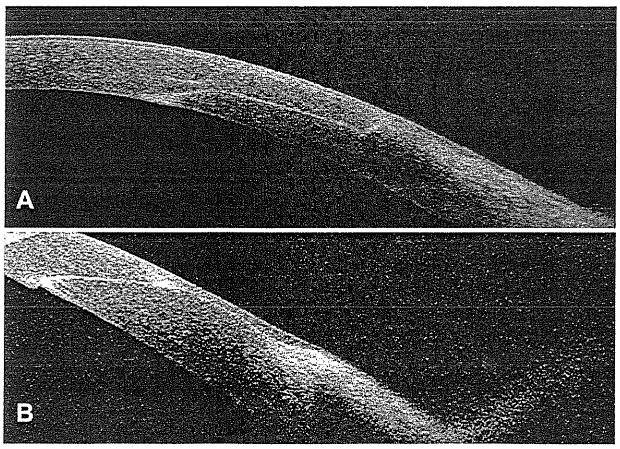

Figure 5. Comparison of incision profile of CCI created with the femtosecond laser (*A*) and the metal keratome (*B*).

Despite attempting to construct a 3-plane incision with the metal keratome, only 19% of eyes (3 of 16) had a 3-plane profile visible on AS-OCT. This was always the result of inadequate depth of the first stage of the incision because a partial-thickness groove was not created at the wound entrance, which often leads to a biplanar incision, and the blade was initially directed perpendicularly, buried partially in the stroma, and then angled to create the second plane.[25] In contrast, all eyes in the femtosecond group had a visible 3-plane profile. The architectural differences between the 2 groups support the hypothesis that corneal incisions for cataract surgery created by a femtosecond laser have a better morphology than keratome-created incisions.

It has been suggested that during the incision closure process, the epithelial side of the wound seals first.[26] As a result of the endothelial cell pump function, suction is generated within the wound, which opposes the wound margin.[11] Epithelial gape counteracts the suction and barrier mechanisms and creates a risk for endophthalmitis. No eye in our series had documented epithelial gaping based on slitlamp examinations in the postoperative period. There was a limitation of AS-OCT images in terms of viewing the epithelium and superficial stroma; therefore, we did not quantify gaping of the wound at the epithelial side. Some degree of gaping at the endothelial side was seen in all CCIs; it varied from 0.05 to 0.21 mm in the femtosecond laser group and from 0.10 to 0.42 mm in the metal keratome group. All CCIs were well apposed with adequate IOP. Endothelial gape has been shown to occur more with low or normal

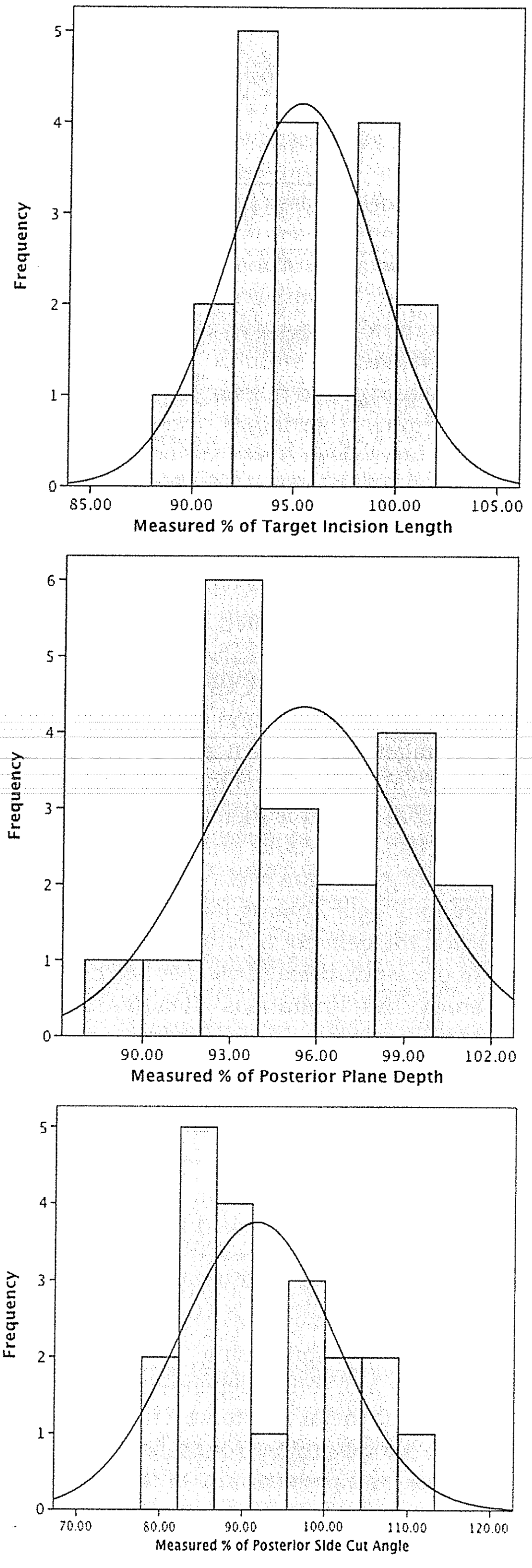

Figure 6. Frequency of measured percentage of the target CCI measurements for incision length, posterior plane depth, and posterior side-cut angle.

IOPs and is less common with high IOP. Shingleton et al.[27] found that wide variations in IOP are likely to occur in the postoperative period, with the IOP often dropping to less than 5 mm Hg. McDonnell et al.[14] found that with an IOP that low, gaping of the internal aspect of the incision could occur, a phenomenon also influenced by the incision angle.[17] Previous findings suggest that a steeper angle or higher IOP causes epithelial gaping, while a smaller angle or lower IOP causes endothelial gaping.[9] Although we did not include IOP in our analysis, the IOP at the 1-day and 1-month visits was within physiologic limits in all eyes in our study. It has been suggested that a longer CCI would be less affected by loss of coaptation because a lower proportion of the total length is misaligned.[9]

Nagy et al.[28] recently used AS-OCT to evaluate corneal incisions in 40 eyes after femtosecond laser–assisted cataract surgery (Lensx, Alcon Laboratories, Inc.). Using time-domain AS-OCT (Visante, Carl Zeiss Meditec AG), they found that the mean main corneal incision was 1.84 $\pm$ 0.12 mm against a programmed length of 1.80 mm while the mean width was 2.71 $\pm$ 0.11 mm against a programmed width of 2.80 mm. They performed AS-OCT imaging immediately after the procedure and did not compare the femtosecond incisions with keratome incisions. Masket et al.[6] studied the geometry of corneal tunnel incisions created with a 15 KHz femtosecond laser (Intralase model 1, Abbott Medical Optics, Inc.). They created single-plane angled CCIs that were 3.00 mm wide and with lengths ranging from 1.00 to 2.00 mm. They found that a 3.00 mm $\times$ 2.00 mm CCI was more stable than narrower incisions with less leakage at various levels of indentation pressure. Suboptimum construction of the cataract incision may result in leakage, hypotony, iris prolapse, or intraocular infection. Fluid may leak in and out of the eye through poorly constructed incisions with inadequate dimensions and orientation.[14,29] Although we did not assess wound strength in our study, our finding of a high intended-to-achieved ratio suggests that properly designed laser incisions can be expected to be created consistently. We believe such consistency is unlikely with the keratome, even in the hands of experienced surgeons.

Because there are varying degrees of corneal edema in the early postoperative period, making measurements inaccurate,[22,28] the AS-OCT images in our study were performed at a time (1 month postoperatively) when the cornea was compact, yielding high-quality images and reliable measurements. In this study, we did not assess the long-term changes in CCI architecture.

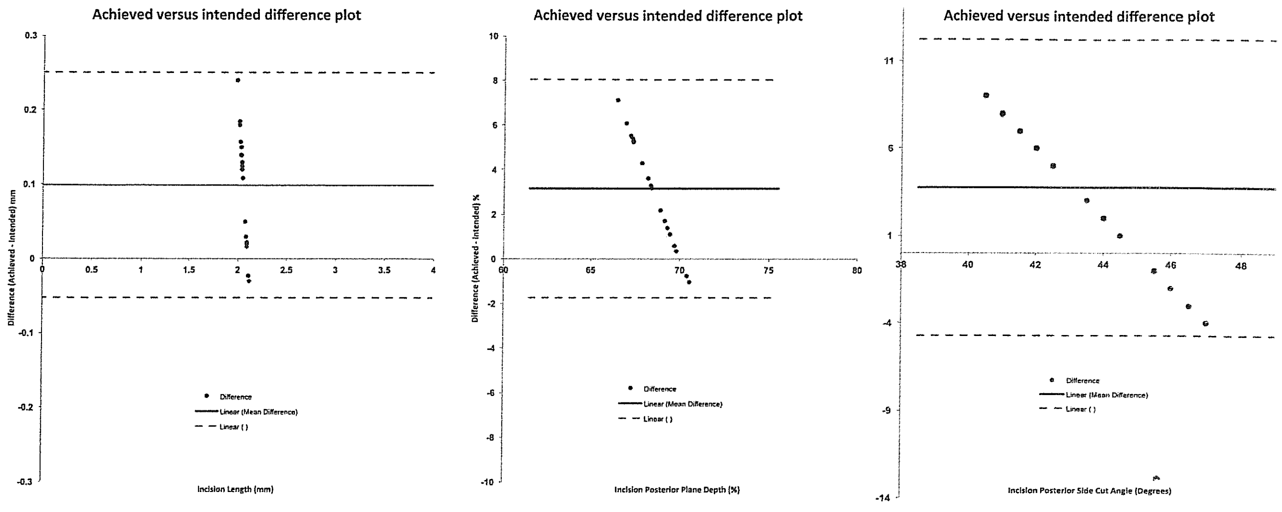

Figure 7. Plots of CCI length, posterior plane depth, and posterior side-cut angle (C) measurements with 95% limits of agreement.

The AS-OCT device used in our study captures 40 000 A-scans/sec, providing an axial resolution of 3.9 μm and a transverse resolution of 14.0 μm. The validity of the measurements can be influenced by the reproducibility. In addition, it remains to be ascertained whether a difference of a few microns in incision morphology translates into a clinically meaningful difference in wound healing and stability.

Alió et al.[30] recently found minimal changes in incision length and angle during the first postoperative month with the triplanar CCI. Torres et al.[18] found that CCI architectural features, including endothelial misalignment, improved over time, reducing from 45% at 1 day to 15% 1 month postoperatively. Similarly, they report an improvement in endothelial gaping postoperatively, from 25% at 1 day to 10% at 1 month. Using topical prednisolone acetate 1.0% as an agent for contrast enhancement at the wound interface, Gupta et al.[31] found internal wound gaping in 89% of eyes immediately after surgery; this decreased to 43% at 1 day. Using time-domain and spectral-domain OCT to evaluate CCIs, studies[9,18,32,33] found an incidence of posterior wound misalignment ranging between 15% and 35% 1 month after cataract surgery with incisions created using a keratome.

We evaluated the differences between the intended characteristics and the achieved characteristics of corneal incisions created with a femtosecond laser and found that the length, incision plane depth, and incision angle were within 10% of the intended laser parameters 1 month after cataract surgery. Using spectral-domain AS-OCT, Can et al.[11] found that the mean incision length was approximately 10% shorter than the intended length (1.75 mm) with a microcoaxial or a biaxial technique. We found approximately similar results using the femtosecond laser–created CCI, showing that a high level of accuracy is achieved by the AS-OCT-guided femtosecond laser CCI creation. The higher wavelength of the femtosecond laser is also thought to be an advantage because the near-infrared wavelength of the laser (1030 nm) is scattered much less than visible light (400 to 700 nm). It is therefore unlikely that mild corneal opacification would preclude the use of lasers in cataract surgery. However, significant scarring in the cornea may be a limiting factor in the imaging by AS-OCT and the delivery of laser energy. This was not a factor in our study because all eyes had clear corneas.

Our study has limitations. Relative to posterior segment OCT imaging, AS-OCT imaging and analysis are still in their infancy and features differ markedly between software versions and manufacturers. As a consequence, assumptions have to be made when using commercially available machines. Automatic image dewarping, in particular, can affect measurements, and patients were asked to look toward their opposite eye to allow perpendicular image acquisition, another variable that could affect image analysis. In addition, when imaging a corneal wound 1 month after incision creation using AS-OCT, the CCI morphology is not only dependent on the femtosecond laser– or metal keratome–created dimensions but also on changes in the wound based on the insertion technique and the anatomy of the inserter.

The retrospective nature and small sample are other limitations of this study. Stretching and tearing of the wound may happen when surgical instruments are introduced into the anterior chamber, especially when the incision tunnel is too tight, and could distort the incision architecture. There may also be direct damage to the wound by US power, which has been shown to be substantially lower in femtosecond laser-assisted cataract surgery.[34] We did not account for possible incision distortion attributed to the differences in phacoemulsification energy and surgical instruments, although we used only IOL injectors designed for 2.2 mm incisions to minimize wound stretch. Incision-site thickness is also affected by mechanical and thermal trauma during surgery as well as by the swelling caused by stromal hydration. Fine at al.[20] and Calladine and Tanner[10] suggest that stromal hydration results in a reduction in the incidence of endothelial gape. Routine stromal hydration was performed in all our cases in both groups. In addition, surgeon-dependent variables were minimized because all operations were performed by the same surgeon. Also, although there were morphologic differences between the 2 groups, we did not find clinical differences between the 2 methods. Whether the morphologic superiority of the femtosecond laser incisions translates into a clinically meaningful benefit for the patient has yet to be established.

In conclusion, we found a significant difference in the morphology of CCIs created with a femtosecond laser and those created with a metal keratome. In addition, the CCIs created using the femtosecond laser had a high degree of in vivo accuracy and were within 10% of the intended measurements. Further studies evaluating the long-term architectural changes in the clear corneal cataract incisions between the 2 groups are warranted, as is a study assessing the wound strength in femtosecond laser–generated corneal incisions.

WHAT WAS KNOWN

- Femtosecond lasers permit reproducible creation of square-shaped multiplanar CCIs in cataract surgery.

WHAT THIS PAPER ADDS

- Clear corneal incisions created using the femtosecond laser had significant morphologic differences compared with those created using a metal keratome. There were lower rates of endothelial gape, endothelial misalignment, and Descemet membrane detachment in the femtosecond laser group than in the keratome group.
- Clear corneal incisions created using the femtosecond laser were within 10% of the intended programmed measurements for incision length, depth, and angle.

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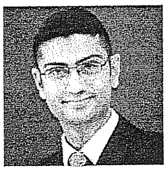

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