Chapter 7
Correction of Corneal Astigmatism with Femtosecond Relaxing Incisions

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7.1 Background

The femtosecond laser is an ultrashort pulse laser (100 fs or 10^{-13} s) that operates in the infrared wavelength (~1045 nm). It causes photoionization of the tissue resulting in vaporization and the formation of cavitation bubbles. The bubbles consist of carbon dioxide and water which is dissipated in the tissue, forming a cleavage plane. Its precise and controllable properties allow for many ocular applications from the creation of corneal flap in laser-assisted in situ keratomileusis to the capsularhexis in cataract surgery.

The accuracy and reproducibility of the laser makes it an ideal tool to address the variability in performing astigmatic keratotomy. The femtosecond laser potentially offers no skip lesions, minimized risk of perforation, and increased precision through reproducible incision depth, length, angulation, and centration. This provides a safe and consistent means of performing astigmatic keratotomy.

Femtosecond astigmatic keratotomy (FSAK) can create three types of incisions. These include full thickness, intrastromal, and reverse full thickness (Fig. 7.1). Of these, full thickness is the only incision available using manual techniques. Stabilization has been shown to occur after a minimum of 3 months [1]. While the long-term stability and regression in manual techniques have been described, there are only short-term

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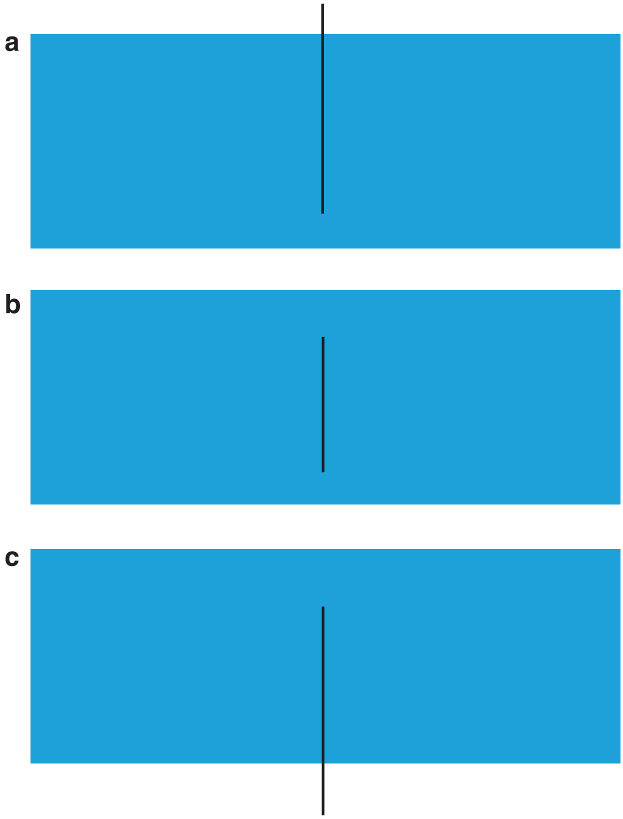

Fig. 7.1 The theoretically types of incision that can be made in femtosecond astigmatic keratotomy. (**a**) Full thickness, (**b**) Intrastromal, (**c**) Reverse full thickness

results for FSAK. The full-thickness incisions may have similar regression to manual techniques, but there is no published comparative data. In contrast, intrastromal FSAK has short-term data showing clinically insignificant regression over 6 months [2].

Intrastromal FSAK has the benefit of not disrupting the epithelium or Bowman's. This results in minimal wound healing and no fibroblast growth [3] that is associated with visual symptoms such as glare and halos. As the epithelium is not disturbed, these patients are comfortable and asymptomatic postoperatively. As the integrity of Bowman's is kept intact, the intrastromal FSAK has mostly been studied in minor or medium astigmatism—up to 3.5D. There is, however, one case report of it successfully treating a post-penetrating keratoplasty (PKP) patient with reduction in cylinder from 10.4D to 1.12D [4].

7.2 Surgical Planning

Preoperative evaluation of the patient should include a comprehensive exam and a combination of objective testing that may include keratometry, corneal topography, corneal tomography, pachymetry, and anterior segment optical coherence

Table 7.1 Arc length nomogram

	Cylinder axis	
Cylinder	@90	@180
0.50–0.75	35	45
0.75–1.00	40	50
1.00–1.25	45	55
1.25–1.50	50	60
1.50–1.75	55	–
1.75–2.00	60	–

tomography. Those patients with ectatic disorders or highly irregular astigmatism can be identified as they need to be approached with caution with FSAK [1].

There are numerous described nomograms that vary the treatment parameters (depth, arc length, optical zone diameter) based on the amount of astigmatism and patient age. Most of these are based on the nomograms available for manual AK that have been adjusted. One such modification is using 70% of the Donnenfeld nomogram. Our current nomogram consists of paired incisions, 85% depth, 80 μm below anterior surface, and 8.5 mm optical zone. The arc length depends on the axis and amount of astigmatism (Table 7.1). There is no augmentation performed, and if the patient needs more correction, then laser vision correction is offered.

There is only one study that has specifically developed a nomogram for FSAK after PKP and DALK [5]. The presence of peripheral blood vessels will interfere with the laser, so the location of the optical zone may need to be adjusted. The plasma shape of the laser and its extension beyond the set depth needs to be considered to avoid accidental perforation.

7.3 Surgical Technique

There are several commercially available femtosecond laser systems available that can perform astigmatic keratotomy. The settings will vary with each machine as per the manufactures guidelines.

To compensate for cyclotorsion, marking the limbus preoperatively at the slit lamp has been advocated. The patient is then prepped and anesthetized topically. In some devices, the axis is required to be marked and the pachymetry measured to be used to calculate the depth prior to engaging the suction ring. The more recent devices have built-in optical coherence tomography that allows for real-time measurement and simultaneous treatment. Once the suction ring is used to secure the eye, the applanation cone is applied and can be adjusted to ensure proper alignment. The inputted treatment parameters are then applied and the incisions created (Video 7.1). After creation, the applanation cone and suction ring are released. In full-thickness incisions, the incisions can be opened using a Sinskey hook. This can be done at the time of surgery or even delayed by several weeks.

7.4 Outcomes

Most of the early use of FSAK has been reported in patients following penetrating keratoplasty (PKP) [1, 6–13]. Its use in patients after cataract surgery [14, 15], after previous refractive surgery [16], after Descemet stripping automated endothelial keratoplasty [17, 18], and in those with naturally occurring high astigmatism [19] has also been reported. With the advent of femto-assisted cataract surgery, FSAK has been incorporated into treatment at the time of cataract surgery [2]. As shown in Table 7.2, there was a marked reduction in keratometric astigmatism following the treatment. This correction also resulted in improvement in the patients uncorrected visual acuity as well.

Comparing FSAK to manual astigmatic keratotomy, the results were similar; however, the manual technique had a tendency for greater axis misalignment or a shift in the astigmatism axis [6, 9]. In a randomized comparison between FSAK and manual AK, there was no significant difference in the worsening of high-order aberrations. The FSAK group had better uncorrected visual acuity and best correct visual acuity than manual AK [6].

7.5 Complications

Perforation is more likely to occur with manual AK with both comparative studies having perforations in manual AK and none in the FSAK [6, 9]. There is one report of a perforation after FSAK in a post-Descemet stripping automated endothelial keratoplasty patient, where it was recommended to not count the graft thickness into corneal thickness calculation [18].

Overcorrection is also more likely to occur in patients who have ectatic corneas [1]. In all studies published, excepted one case report [18], there was improvement in the patient's astigmatism.

The potential complications that can occur include transecting the corneal nerves and reducing corneal sensation, endothelial damage from the energy, incomplete cylinder creation, and no separation of the arc walls. Eye rotation or coronal movement at the time of laser can result in imprecise treatment. With the modification of the cornea, there exists the long-term risk of ectasia. This is likely lower with intrastromal FSAK, but there are no long-term studies to support this.

Conflict of Interests G. Belovay—none

B. Khan—Consultant with Alcon, AMO, Bausch & Lomb, Allergan and Zeiss

Table 7.2 Summary of all studies that have evaluated femtosecond astigmatic keratotomy

Author/year	Indication	Laser	Optical zone	Arc length	Depth	Eyes (n)	Mean keratometry (D) ± SD
Kiraly/2008 [10]	Post PKP	–	5.0–6.0 mm	–	75%/85%	10	7.70 ± 3.10 → 4.75 ± 2.86
Harissi-Dagher/2008 [8]	Post PKP	IntraLase FS[a]	6.0 mm 7.0 mm	60° 75°	400 μm	2	8.50 → 4.90 7.00 → 4.30
Kymionis/2009 [12]	Post PKP	IntraLase 30 kHz[a]	6.5 mm	60°	75%	1	4.40 → 0.67
Nubile/2009 [13]	Post PKP	Femtec[b]	1.0 mm smaller than graft	40–80°	90%	12	7.16 ± 3.07 → 2.33 ± 1.55
Buzzonetti/2009 [7]	Post PKP	IntraLase FS 60 kHz[a]	4.8–6.8 mm	70° 90° side-cut angle	80%	9	9.80 ± 1.90 → 5.20 ± 1.50
Kumar/2010 [1]	Post PKP	IntraLase FS 60 kHz[a]	0.5 mm small than graft	40–90°	90%	37	7.46 ± 2.70 → 4.77 ± 3.29
Bahar/2008 [6]	Post PKP	IntraLase[a]	0.5 mm	60–90°	90%	20	7.84 ± 2.35 → 3.58 ± 2.21
Hoffart/2009	Post PKP	Femtec FSL[b]	5.50–7.50	60–80°	75%	10	7.01 ± 3.02 → 3.97 ± 2.38
Levinger/2009 [17]	Post DSAEK	IntraLase FS[a]	8.0 mm	60°	90%	1	5.75 → 2.75 (Ref) K 4.66 → 0.81
Kook/2011 [11]	Post PKP	IntraLase FS 60 kHz[a]	6.0–7.2 mm	20–50° 90° side cut angle	90%	10	9.30 ± 4.10 → 6.50 ± 4.20
Yoo/2009 [18]	Post DSAEK	–	6.8 mm	80°	90%	1	6.11 → 12.75
Abbey/2009 [19]	Naturally occurring high astigmatism	IntraLase[a]	6.5 mm	80° 75° side-cut angle	400 μm	2	5.92 → 3.60 5.80 → 2.42

(continued)

Table 7.2 (continued)

Author/year	Indication	Laser	Optical zone	Arc length	Depth	Eyes (n)	Mean keratometry (D) ± SD
Ruckl/2013 [15]	Post CEIOL	IntraLase iFS 150 kHz[a]	7.5 mm	90° 30° side-cut angle	100 μm anterior to DM & 100 μm below surface of epithelium	16	1.41 ± 0.66 → 0.33 ± 0.42 (Ref) K: 1.50 ± 0.47 → 0.63 ± 0.34
Venter/2013 [16]	Previous refractive surgery	IntraLase iFS[a]	7.0 mm	40–60°	60 μm from surface to 80%	112	1.20 ± 0.47 → 0.55 ± 0.40 (Ref)
Viswanathan/2013 [4]	Post PKP	LenSx[c]	7.6/7.5	55–57°	60 μm from surface to 90%	2	OD:11.90 → 4.10 OS: 10.40 → 1.12
Nejima/2015 [14]	Post CEIOL	IntraLase iFS[a]	8.5 mm	80°	350 μm (≤3.5D) 375 μm (≥3.5D)	8	2.88 ± 0.64 to 0.91 ± 0.64 (Ref)
Day /2016 [2]	CEIOL	Optimedica catalys[a]	8 mm	30–90°	20–80% (60%)	87	1.23 ± 0.49 → 0.69 ± 0.50

PKP penetrating keratoplasty, *DSAEK* Descemet stripping automated endothelial keratoplasty, *CEIOL* cataract extraction and intraocular lens implant, *Ref* refraction

[a]Abbott Medical Optics, Inc., Abbott Park, IL

[b]Technolas Perfect Vision GmbH and Bausch & Lomb, Inc., Rochester, NY

[c]Alcon LenSx Inc., Aliso Viejo, CA

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