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Refractive surgery for myopia: review of options and the decision-making process

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Many options now exist for patients seeking surgical correction of myopia. The challenge lies in selecting the right procedure for the right patient. This article provides an overview of current refractive surgery options and discusses the clinical and imaging considerations in decision-making.

CURRENT REFRACTIVE SURGERY OPTIONS FOR MYOPIA

Of the currently used refractive procedures for myopia (**Figure 1**), *photorefractive keratectomy* (**PRK**) is the oldest. In PRK, the corneal epithelium is removed, and the excimer laser ablates the stroma starting at the Bowman's layer. *Laser in situ keratomileusis* (**LASIK**), popularized in the 1990s, has since replaced PRK as the gold standard for the correction of myopia. Comparative studies show no difference in outcomes between the two (**Table 1**), but LASIK is preferred due to minimal patient discomfort and faster visual recovery.[1-3] Without removing the epithelium, the surgeon creates and lifts an anterior corneal flap and applies the excimer laser directly to the stroma. Improvements to the technique now allow for highly predictable outcomes. These include the use of the femtosecond laser to fashion the flap, elliptical shapes to enhance flap fit, and iris registration to ensure centration. The advent of wavefront-optimized and customized (wavefront-guided and topography-guided) ablation profiles has increased tissue preservation and treatment accuracy.[4-6]

In *small incision lenticule extraction* (**SMILE**), a femtosecond laser sculpts a stromal convex lenticule corresponding to the myopic correction and a 2–4 mm incision through which the surgeon extracts the lenticule. SMILE has similar efficacy outcomes compared with femtosecond-LASIK.[7-10] It eliminates flap-creation issues but has its own potential complications, namely a higher risk of decentered ablation and incomplete lenticule extraction.[10] Purported advantages are increased biomechanical stability[11] and corneal nerve preservation;[12] however, a corresponding decrease in the incidence of postoperative dry eye[13] and keratectasia has not been replicated across clinical studies.[14,15] Furthermore, SMILE does not have customized profiles and has shown poorer and slower visual recovery compared to customized LASIK.[16-18] Combined with the less well-studied post-SMILE enhancement options,[19] these limitations have slowed its adoption in Canada.

Intrastromal corneal ring segments (**ICRS**) are indicated in low myopia and keratoconus. Inserted intrastromally at two-thirds of corneal depth, they add "tissue" to the midperiphery, with an arc-shortening and flattening effect on the central cornea.[20] Since "tissue" is added, biomechanical stability is enhanced. More flattening and myopia correction is obtained with proportionally thicker and smaller-diameter devices.[21] Intacs® (Addition Technology Inc.), is the only ICRS approved in Canada and can be obtained in thicknesses ranging from 0.21 to 0.45 mm.[22] Given the excellent results obtained with LASIK in low myopia, surgeons reserve ICRS for patients with keratoconus.

Current *phakic intraocular lenses* (**p-IOLs**) are designed for iris-fixation in the anterior chamber (Verisyse/Artisan, Ophtec B.V.) or for posterior chamber placement (Visian Implantable Collamer Lens, STAAR Surgical). The Visian requires a 3.2 mm corneal incision for intraocular insertion and has a central aperture to prevent pupillary block and avoid iridotomies. P-IOLs are contraindicated in shallow anterior chambers, narrow angles, and low corneal endothelial counts and have good efficacy, predictability, and safety.[23] Although results are less favourable in high myopia compared to lower refractive errors, p-IOLs provide better outcomes in these eyes than subtractive cornea-based procedures.[23]

Refractive lens exchange (**RLE**) is an off-label procedure involving the replacement of the clear crystalline lens with an IOL to correct spherical or astigmatic errors of all ranges. Although the approach is similar to cataract surgery, a discussion concerning simultaneous presbyopic correction and efforts to minimize intraoperative manipulation are of heightened importance in this purely refractive procedure. Of significance in this patient group, the risk of retinal detachment with current techniques is 0–4%–similar to the general myopic population,[24]–but is higher in younger patients, higher myopia/axial length, or lattice degeneration.[24,25]

CHOOSING THE BEST OPTION

In the absence of contraindications–such as pregnancy, monocular status, and risk factors for poor healing[26]–the main considerations in identifying good candidates for laser cornea-based surgery are corneal shape and thickness, manifest and target refraction, estimated residual stromal bed thickness (RSBT), age, lens, and accommodative status. The surgeon must distinguish good candidates from patients who (1) need a lens-based procedure for an optimal visual outcome, (2) are at risk of developing keratectasia postoperatively, or (3) have frank corneal ectasia preoperatively (**Figure 2**). Tissue removal during laser refractive surgery compromises biomechanical stability and, in a susceptible cornea, can trigger or exacerbate an ectatic process.

Good candidates for cornea-based surgery

Young patients with healthy corneas of normal shape and with an estimated RSBT >275-300 µm are ideal candidates for LASIK (**Figure 3**). PRK is a superior option when LASIK may be less safe from a biomechanical standpoint. This occurs in cases that combine a higher refractive error with a thin cornea, resulting in RSBT <275 µm with LASIK (**Figure 4**). Below this threshold, the risk of postoperative keratectasia is greater even in the absence of ectasia preoperatively. Without a flap, PRK allows for a thicker RSBT for the same corneal thickness and manifest refraction compared to LASIK.[27]

PRK is also a better choice in anterior corneal pathologies, such as anterior basement membrane dystrophy, anterior stromal dystrophies, or scars. Unaddressed, these pathologies may limit the visual outcome following LASIK and cause epithelial defects or incomplete interface cuts during flap creation.[27] PRK eliminates flap-related issues in these cases and may also offer therapeutic value. Anterior-segment optical coherence tomography is useful to assess the depth and extent of stromal scars or dystrophies (**Figure 5**), and the likelihood of interference with flap creation during LASIK or of successful removal with PRK.[27] Other cases in which PRK is preferred include (1) patients with occupational risk of traumatic flap dislocations, (2) irregular corneas following radial keratotomy or corneal grafts, and (3) corneas at risk of free cap or buttonhole during flap creation.[27]

SMILE has the same contraindications as LASIK.[28] In most cases, the choice between the two comes down to patient preference and surgeon experience. Since it involves no flap and less postoperative discomfort than PRK, SMILE may be prioritised in patients at risk of traumatic flap dislocation.[28] LASIK may be preferred over SMILE in cases with greater astigmatism, significant higher order aberrations or irregularities on topography, as iris registration and customized ablation may then be employed to enhance outcomes.[16-18,28]

Older patients with presbyopia or early lens changes

RLE may be best in older patients with presbyopia or early lens changes even in the absence of contraindications to cornea-based procedures. It has the advantage of permanence because it addresses the unstable variable–the lens–whereas cornea-based procedures offer only a temporary solution. Nonetheless, certain patients choose a cornea-based procedure with the understanding that a cataract surgery may be needed soon thereafter. Monovision can be employed to address the presbyopia in these patients if a cornea-based procedure is elected.

"Borderline" corneas at risk of postoperative keratectasia

Risk factors include younger age, high refractive errors, thinner pachymetry, low RSBT (<275 µm) even with PRK, family history of keratoconus, and personal history of eye rubbing.[29] The surgeon may attempt to decrease the risk with prophylactic corneal collagen crosslinking (**CXL**) during primary LASIK, PRK or SMILE – a combination called "Xtra". "Xtra" procedures promise to preserve corneal rigidity and decrease the likelihood of postoperative keratectasia and myopic regression.[30] More studies are needed to justify their routine use in high risk patients, however.[30] More frequently, these patients undergo a lens-based procedure to avoid weakening the cornea. While p-IOLs are preferred in younger patients, RLE is a better option for those >40 years old. The surgeon may also choose to observe the patient for progression of suspect characteristics before proceeding with surgery.

Patients with ectasia

Corneal topography, epithelial thickness mapping, and the Belin-Ambrosio Enhanced Ectasia Display (Pentacam, Oculus) are essential to reliably identify preoperative corneal ectasia. When facing suspicious topographical features (**Figure 6**), the first step is to rule out pseudo-keratoconus due to inadequate image acquisition, dry eye, anterior basement membrane dystrophy, corneal warpage, trauma, or scars.[31] Repeat topography, careful slit-lamp examination, and inspection of keratoscopy mires can help the process. Epithelial thickness mapping is especially useful (**Figure 7**). In cases of warpage, trauma, scars, and anterior basement membrane dystrophy, epithelial mapping reveals hyperplasia corresponding to affected areas. In true keratoconus, however, it displays epithelial thinning over the cone with surrounding thickening, even in early cases.[32] This is due to a compensatory remodelling of the epithelium to minimize changes to the anterior corneal curvature as the stroma gradually protrudes.[32]

With the advent of CXL, there is renewed interest in the role of cornea-based refractive procedures in the visual rehabilitation of patients with keratectasias. Procedures termed CXL-"Plus",[33] combining therapeutic CXL with phototherapeutic keratectomy (**PTK**), topography-guided-PRK, or ICRS, have emerged as promising approaches to reduce corneal irregularity, visual aberrations, and contact-lens intolerance in these patients.

Epithelial removal using transepithelial PTK to a 50 µm depth during CXL yields better visual outcomes in keratoconus than mechanical debridement.[34,35] This has been attributed to the excimer laser breaking through the epithelium to Bowman's layer in areas where the epithelium is thinnest.[34] The result is differential removal of 10 µm of Bowman's at the cone apex that improves anterior corneal regularity.[33] With CXL-topography-guided-PRK, the goal is to flatten the steepest (usually inferior) zone of the cornea using myopic ablation and to steepen the flattest (superior) zone with hyperopic ablation.[36] This "evens out" the surface. Although results with CXL-topography-guided-PRK are encouraging, there is controversy surrounding its benefit over CXL alone with respect to, predictability, timing, use of mitomycin C, and long-term safety.[33,37] ICRS have been used for a long time in keratoconus to displace the cone towards the center of the cornea and flatten it. The optimal timing and protocol of ICRS implantation as an adjunct to CXL is still debated. Simultaneous ICRS and CXL seem to provide the greatest benefit.[33]

In deciding among the CXL-“Plus” procedures, the degree of astigmatism and visual acuity are important considerations.[38] PTK-CXL can be considered in mild astigmatism where superficial ablation is judged to be sufficient to regularize the anterior cornea. A recent study suggested CXL-ICRS was more effective at reducing astigmatism and improving vision than CXL-topography-guided-PRK and recommended that it be used in eyes with significant astigmatism and poorer corrected vision.[38] For CXL-topography-guided-PRK, the best candidates are considered to be patients with preserved corrected vision and <10D difference in curvature across the cornea, i.e. between the steepest and flattest areas (**Figure 8**).[36,38]

CONCLUSION

Various options are now available to surgically correct myopia, even for corneas traditionally considered ineligible for cornea-based refractive interventions. Although longer-term studies are needed, “Xtra” and CXL-“Plus” procedures have shown promise for the visual rehabilitation of at-risk and ectatic corneas, respectively. Innovations in diagnostic imaging, such as epithelial thickness mapping, are a valuable addition in guiding the choice of the best surgical approach.

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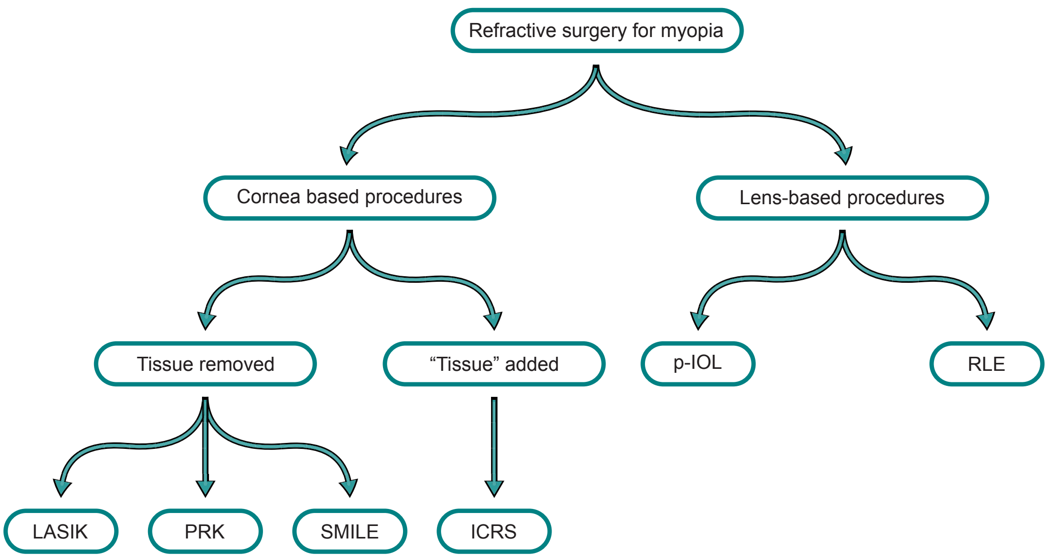

Figure 1: *Classification of refractive surgery options for myopia. LASIK, laser in situ keratomileusis; PRK, photorefractive keratectomy; SMILE, small incision lenticule extraction; ICRS, intracorneal ring segments; p-IOL, phakic intraocular lens; RLE, refractive lens exchange.*

Procedure	Sphere range	Cylinder range	Efficacy (UCVA)	Predictability (achieved vs. target SE)
LASIK	≤-10.00D	≤4.00D	84-94% ≥20/20[4-6]	76-95% ≤0.50D[4-6]
PRK	≤-10.00D	≤4.00D	82-94% ≥20/20[39, 40]	83-98% ≤0.50D[39, 40]
SMILE	≤-10.00D	≤3.00D	50-96% ≥20/20[7-10]	80-100% ≤0.50D[7-10]
ICRS (Intacs®)	≤-3.00D	-	69% ≥20/20, 96% ≥20/40[41]	69% ≤0.5D[41]
P-IOL	≤-20.00D	≤6.00D		
Artisan/Verisyse®			31% ≥20/20; 84% ≥20/40[42]	76.7 ≤0.5D[42]
Visian ICL®			≤-7D: 72.4% ≥20/20; 98.3% ≥20/40[43]	84.7 ≤0.5D[43]
			-7D to -10D: 62.7% ≥20/20; 92.8% ≥20/40[43]	71% ≤0.5D[43]
			>-10D to -20D: 37.5% ≥20/20; 93.8% ≥20/40[43]	56.9% ≤0.5D[43]
RLE	All ranges	≤3.00D	71.4-83.7% with vision better than pre-operatively[25]	70.8-86.5% ≤1.0D[25]

Table 1: *Summary of sphere and cylinder correction range, efficacy, and predictability of refractive surgery options for myopia.*

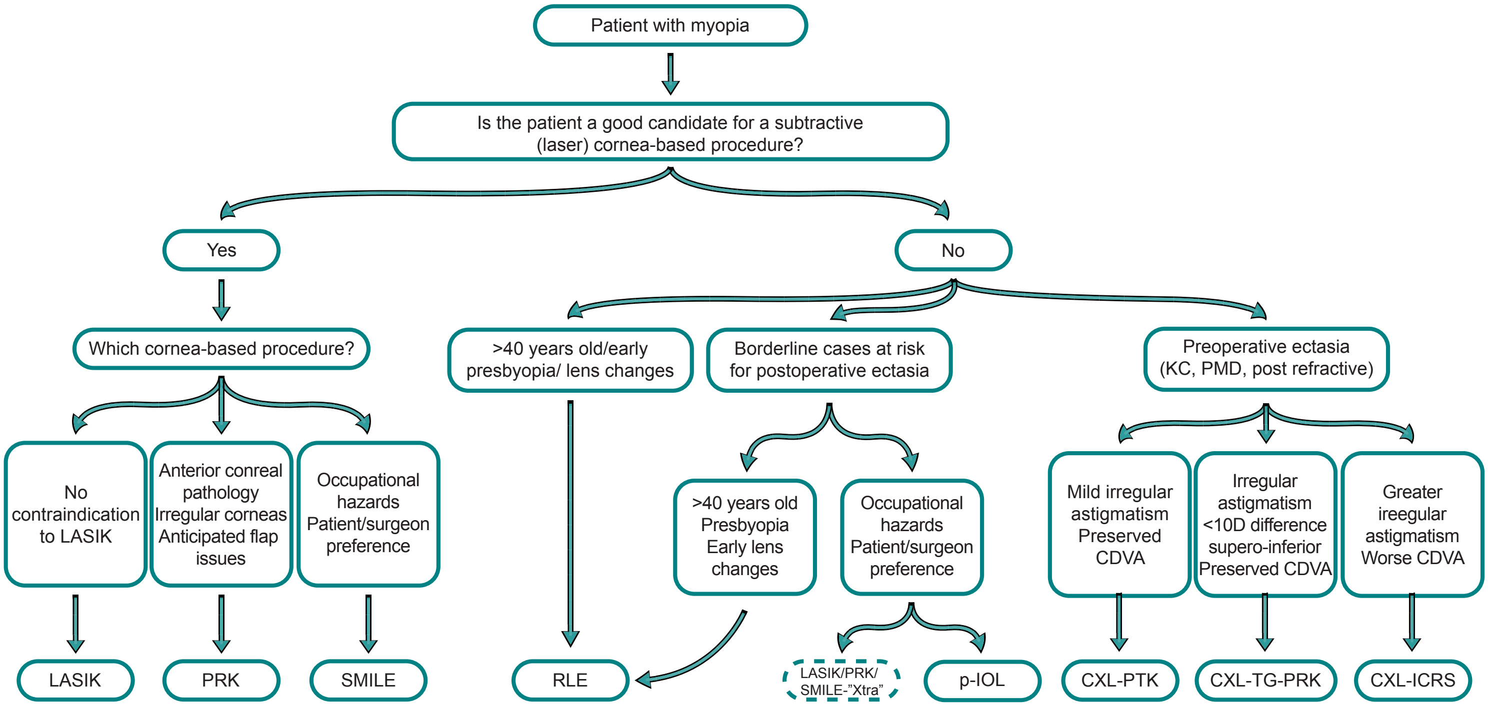

Figure 2: *Simplified diagram of the decision-making process in the refractive correction of myopia. KC, keratoconus; PMD, pellucid marginal degeneration; CDVA, corrected distance visual acuity; LASIK, laser in situ keratomileusis; PRK, photorefractive keratectomy; SMILE, small incision lenticule extraction; RLE, refractive lens exchange; p-IOL, phakic intraocular lens; CXL, corneal collagen crosslinking; PTK, phototherapeutic keratectomy; TG, topography-guided; ICRS, intracorneal ring segments.*

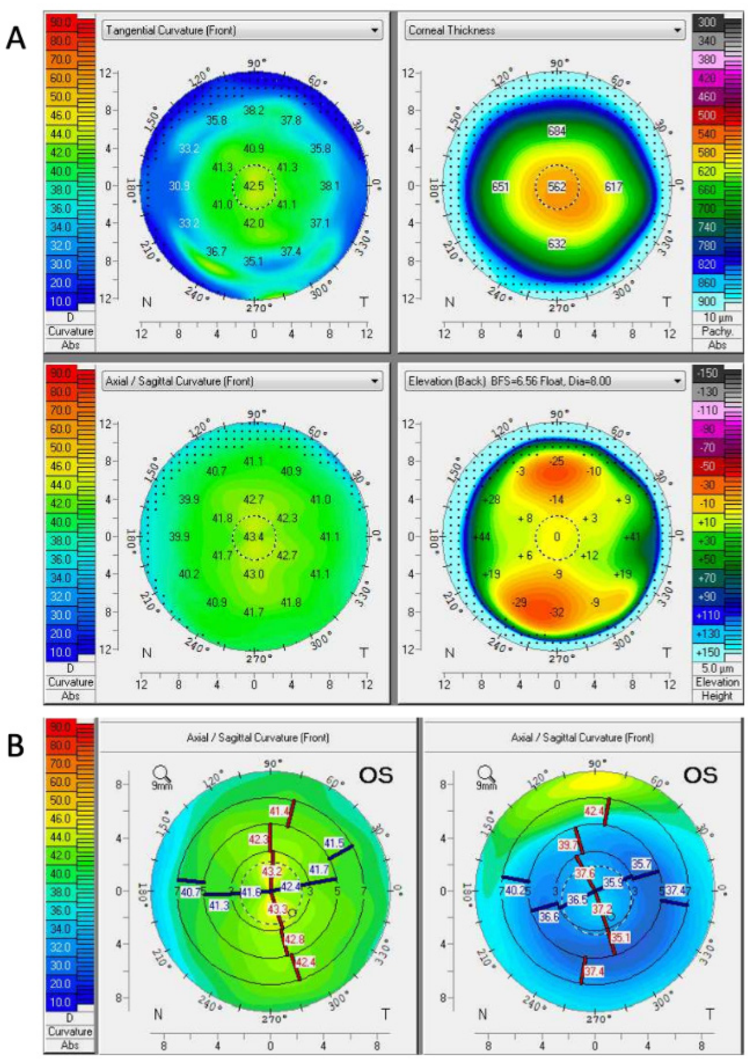

Figure 3: *(A) Four-map composite Pentacam image of the normal left cornea of a 24-year-old male with a manifest refraction of -5.75 +0.50 x 95. The Pentacam shows normal corneal thickness and no signs of corneal ectasia on the anterior curvature and posterior elevation maps. With an estimated residual stromal bed of 322 μm and no other contraindications, this patient was a good candidate for LASIK. (B) Preoperative (left) and postoperative (right) curvature maps show central anterior surface flattening following myopic LASIK.*

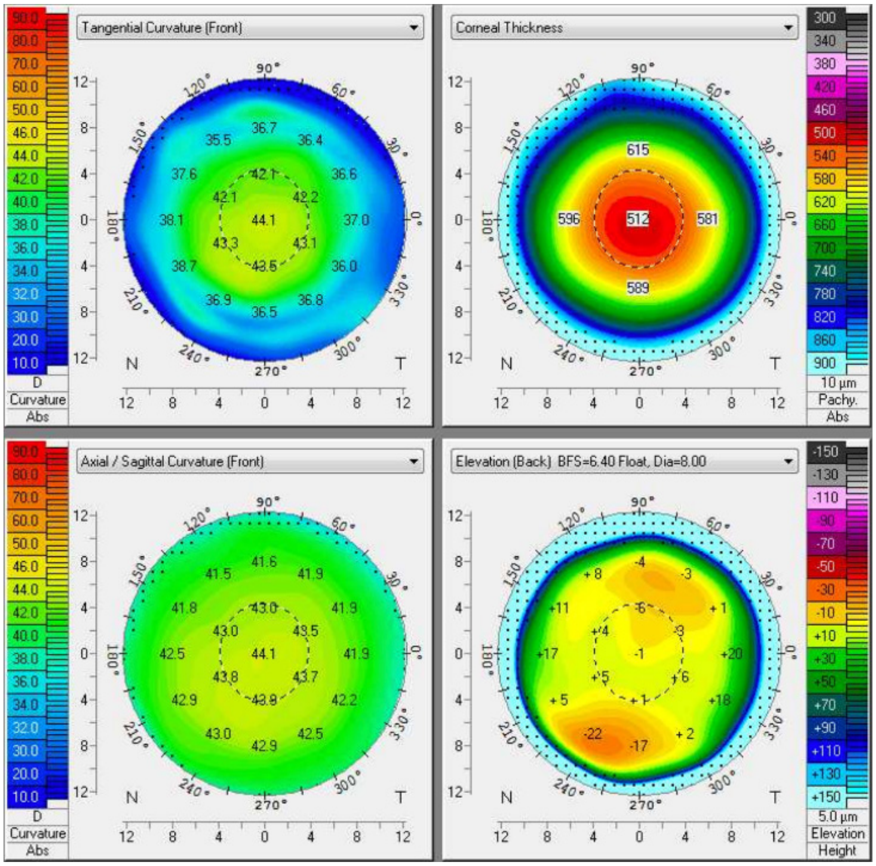

Figure 4: Four-map composite Pentacam image of the left cornea of a 22-year-old female with a manifest refraction of -10.75 +1.00 x15. There are no signs of ectasia, but the cornea is on the thin side, with a central thickness of 512 µm. Given the high refractive error and the thin cornea, the estimated residual stromal bed for LASIK was below 250 µm. PRK allowed a RSBT of 313 µm and was a better option.

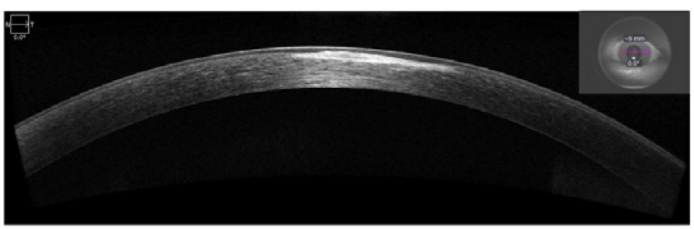

Figure 5: Anterior segment optical coherence tomography showing focal hyperreflectivity at the level of an anterior stromal scar secondary to a contact lens-related ulcer. Note the compensatory overlying epithelial hyperplasia. Considering its depth and location, this scar would interfere with LASIK flap creation. PRK was more suited in this case and allowed both to avoid flap-related issues and to fully remove the scar for a better visual outcome.

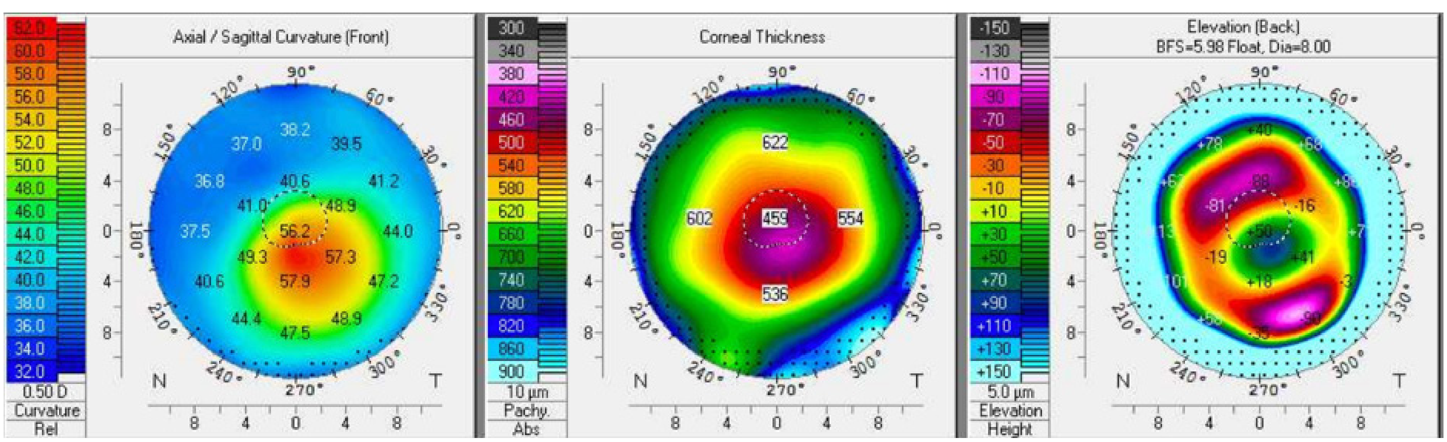

Figure 6: Three-map composite Pentacam image of a left keratoconic cornea. The curvature map (left) displays infero-temporal steepening up to 57.9D and superior flattening. Certain cases may display asymmetric astigmatism with skewing of radial axes and a "lobster-claw" pattern. The pachymetry map (middle) shows corneal thinning, with the thinnest point slightly eccentric and corresponding to the location of the maximum steepening. The posterior elevation map (right) demonstrates an eccentric island of protrusion of the posterior surface, coincident with the points of maximum steepening and thinning.

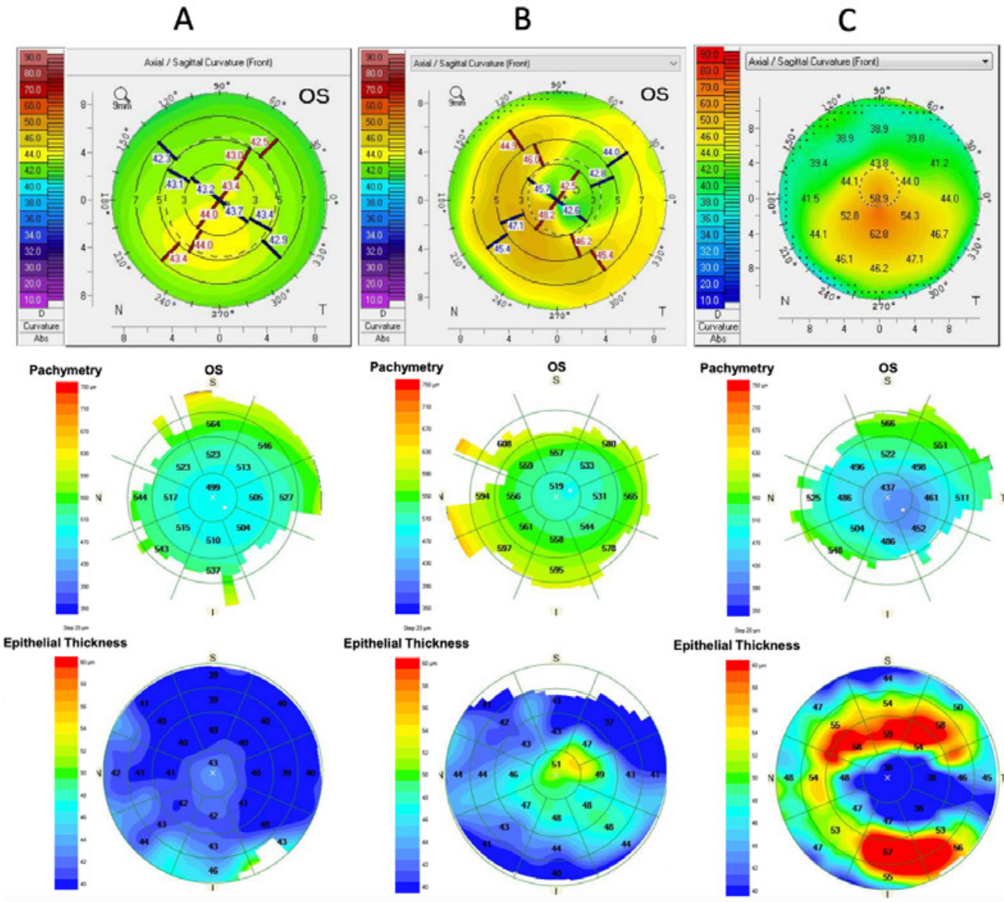

__Figure 7:__ Composite image of Pentacam sagittal curvature maps (top row) and anterior segment optical coherence tomography pachymetry (middle row) and epithelial thickness maps (bottom row). (A) The curvature map shows mild inferior steepening. The epithelial thickness map is normal, however, with 43 µm in the central cornea and +/- 2-3 µm in the corneal periphery, showing no thinning over the slightly steeper area. This is not an ectatic cornea. (B) The curvature map displays asymmetric astigmatism with supero-temporal flattening and adjacent infero-nasal steepening. The epithelial thickness map shows focal epithelial thickening reaching 55 µm that overlies the flattened area. This is the same patient as in Figure 3; the flattening and compensatory epithelial thickening overlie the anterior stromal scar. (C) The curvature map shows marked irregular astigmatism with inferior steepening up to 62.8D. The epithelial thickness map shows epithelial thinning to 32 µm over the protruded zone and thickening up to 66 µm surrounding the cone in a "doughnut-shaped pattern", consistent with keratoconus.

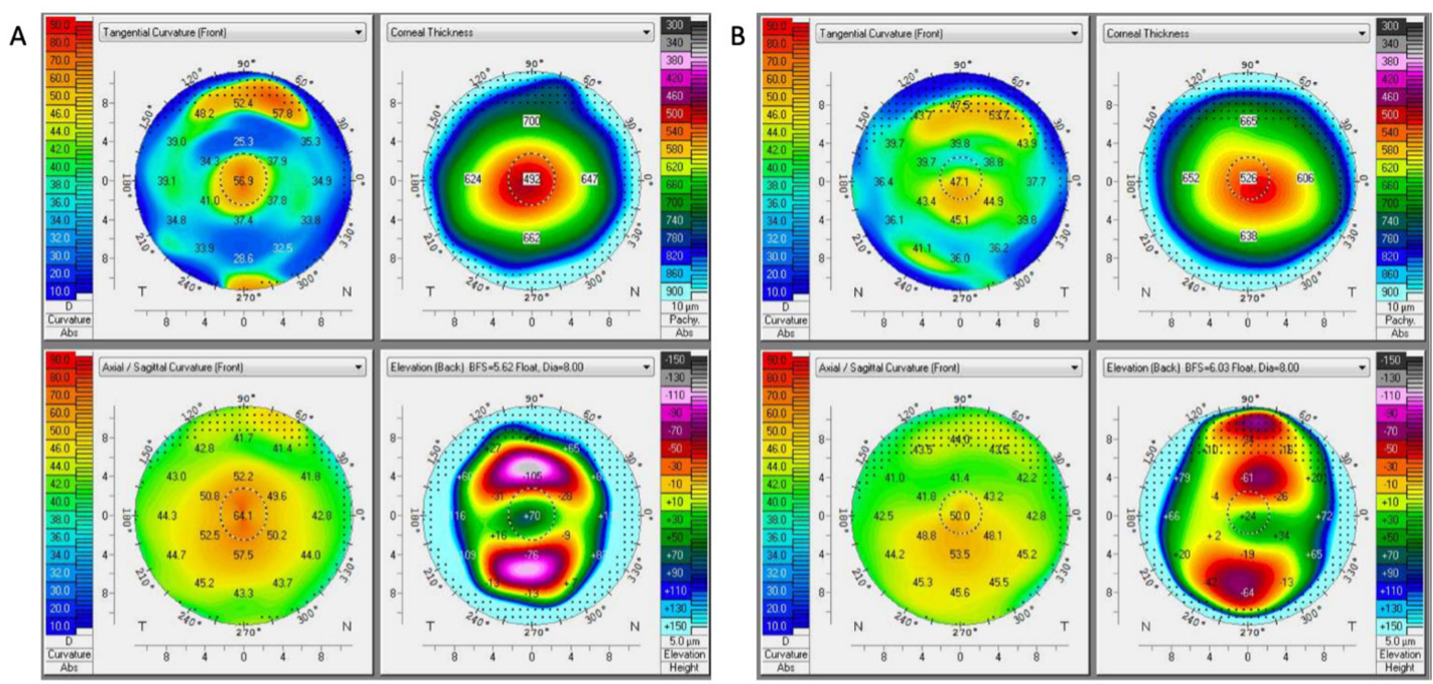

__Figure 8:__ 20-year-old man with keratoconus. Manifest refraction was of -10.25D with a best corrected distance acuity of 20/100 OD, and of -5.25 +6.00 x 35 yielding 20/25 OS. Four-map composite Pentacam images of OD (A) and OS (B) are shown. OD images show presence of a prominent central cone with significant surrounding flattening and a difference in curvature from center to periphery of over 20D. Although combined CXL-PRK could be considered in this eye, better results are likely to be obtained with a combined CXL-ICRS procedure. OS images display superior-inferior asymmetry, with relative inferior steepening and around 10D difference in curvature across the cornea. Considering the preserved visual acuity, combined CXL-PRK could be a good option to stop keratoconus progression and increase corneal regularity in this eye.

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