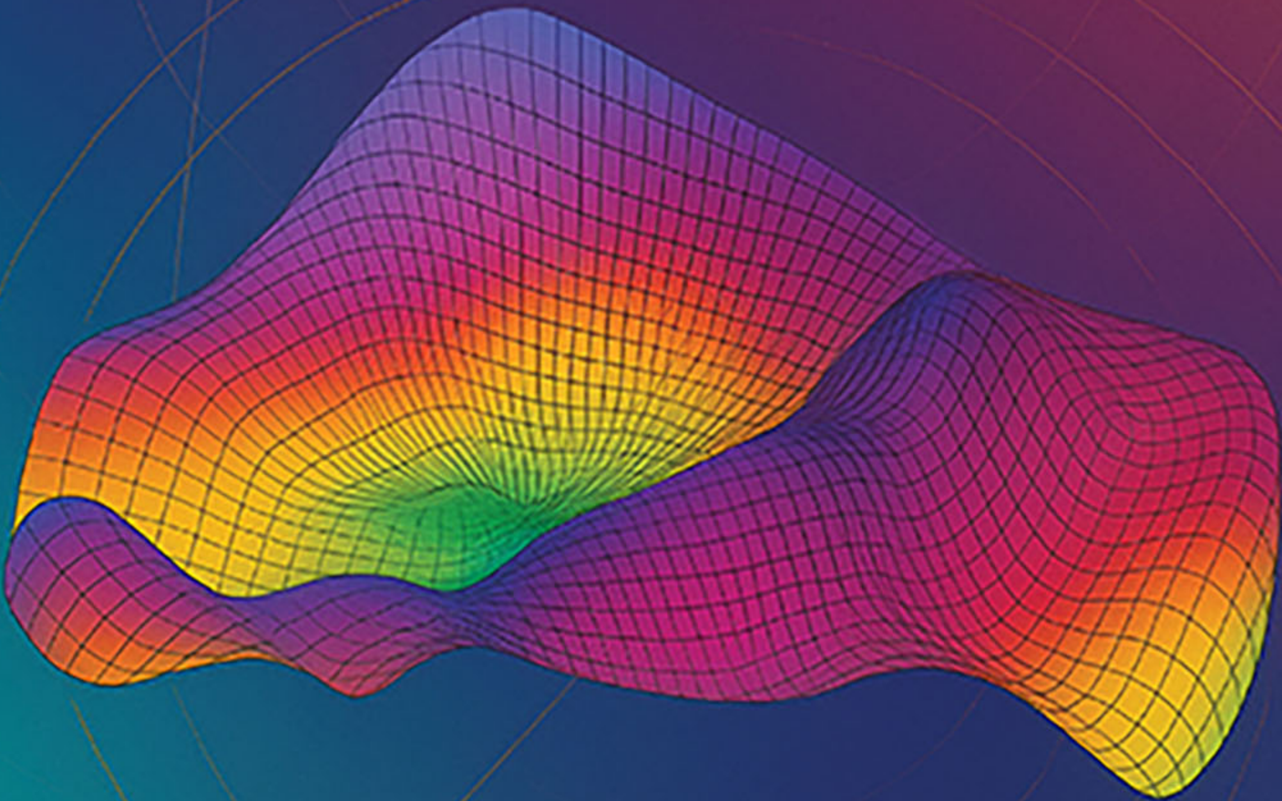
Vol. 1

# Corneal Tomography in Clinical Practice

## Basics & Clinical Interpretation



Mazen M Sinjab

5th Edition

# Contents


Preface to the fifth edition v
Preface to the first edition vii
Dedication ix
A message from the other world xi
Abbreviations xv
Bibliography xvii

## VOLUME 1: BASICS AND CLINICAL INTERPRETATION

### SECTION 1: Introduction

**Chapter 1**
Corneal optics and geometry 5

**Chapter 2**
Measuring corneal geometry 9

**Chapter 3**
Screening guidelines 15

### SECTION 2: Corneal maps and displays

**Chapter 4**
Overview 27

**Chapter 5**
Corneal power maps 29

**Chapter 6**
Elevation maps 43

**Chapter 7**
Belin/Ambrósio enhanced ectasia display 53

**Chapter 8**
Corneal thickness maps and profiles 63

**Chapter 9**
Geometric tomography and corneal topometry 73

**Chapter 10**
The Holladay report 79

### SECTION 3: Understanding corneal astigmatism

**Chapter 11**
Astigmatism 95

**Chapter 12**
Astigmatic disparity 107

## SECTION 4: The systematic interpretation of corneal tomography

**Chapter 13**
Validating capture quality 113

**Chapter 14**
Factors of false findings 117

**Chapter 15**
Enantiomorphism 125

**Chapter 16**
The practical subjective scoring system 131

## SECTION 5: Wavefront analysis

**Chapter 17**
Basics of wavefront analysis and measurements 145

**Chapter 18**
Zernike analysis 151

**Chapter 19**
Corneal asphericity and related functions 165

## SECTION 6: Corneal tomography in ectatic corneal diseases

**Chapter 20**
Tomographic characteristics of ectatic corneal diseases 179

**Chapter 21**
Tomographic grading systems of ectatic corneal diseases 187

**Chapter 22**
Progression criteria 191

**Chapter 23**
Entities misdiagnosed as ectasia 197

## SECTION 7: Tomographic toolkit

**Chapter 24**
Cataract and clear lens extraction surgery toolkit 213

**Chapter 25**
The practical subjective IOL selection algorithm 215

**Chapter 26**
Phakic IOL implantation toolkit 217

**Chapter 27**
Keratoconus and ectatic corneal diseases toolkit 221

Index 229

# Chapter 8 Corneal thickness maps and profiles

Corneal thickness map, relative thickness map (relative pachymetry), corneal thickness spatial profile (CTSP), and percentage thickness increase (PTI) are used for:

- Diagnosis of ectatic corneal diseases (ECDs).
- Diagnosis of previous corneal refractive surgeries.
- Raising suspicion about Fuchs' endothelial dystrophy and cornea guttata.
- Thickness calculations in laser vision correction (LVC), including residual stromal bed (RSB) and percent of tissue altered (PTA).
- Planning for ICRs in the management of ECDs in terms of location of the ring and the depth of the tunnel.
- Planning for the best type of corneal crosslinking (CXL) in ECDs.

## CORNEAL THICKNESS MAP (PACHYMETRY MAP)

### Principle

The software measures corneal thickness at all points based on the difference between the anterior and posterior elevation maps.

### Patterns

The shape of the normal cornea is a negative meniscus lens (back surface radius of curvature is steeper than the front), thin at its optical center, and thickens by the square of the distance from the center. The total positive power is a result of the air in front and the aqueous behind. The normal pattern is usually disciform. **Figure 1** illustrates the disciform pattern, characterized by pachymetry zones that are almost central, circular, concentric, and symmetric. However, this pattern can also be encountered in keratoconus (KC). Abnormal pachymetry patterns include:

- *Horizontal displacement pattern* (**Figure 2**): This pattern may occur due to misalignment, large-angle kappa, and rarely due to ECDs.
- *Vertical displacement pattern* (**Figure 3**): It is also known as "dome shape." It is usually encountered in ECDs. However, it can be seen in patients with constant rubbing, in whom the dome will be inferior-temporal due to the direction of band rubbing. When ICRs implantation is planned in this pattern, a special precaution to the tunnel's depth is fundamental because the thinnest location (TL) will be very close to the tunnel, bearing the risk of introducing the ICR into the anterior chamber during insertion. When calculating the tunnel's depth in this pattern, it is recommended to consider the thickness at the TL rather than the thinnest point along the tunnel.
- *Bell pattern* (**Figure 4**): This pattern is a hallmark of pellucid marginal degeneration (PMD). It is characteristic of inferior band thinning. In this pattern, the risk of corneal perforation during ICR implantation is very high due to two reasons: (1) the inferior area is usually very thin, and the proper place to insert the ICR is usually

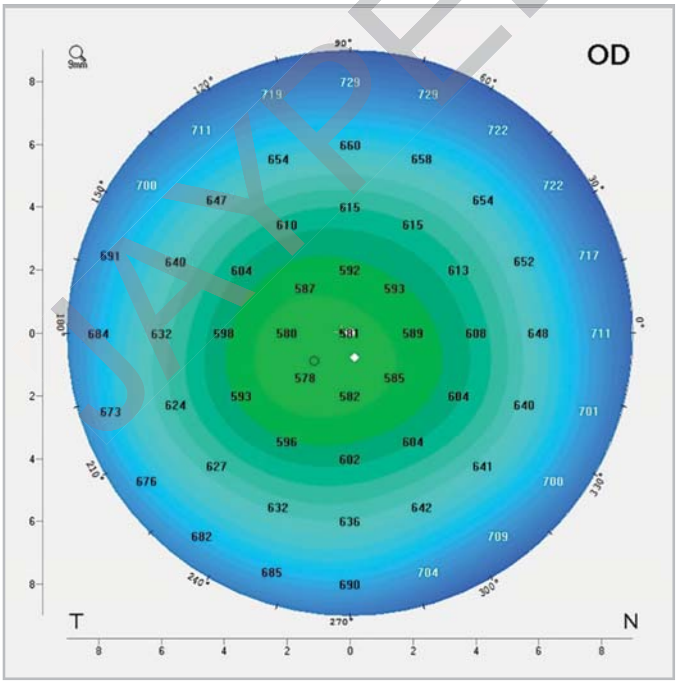



**Figure 1** The disciform pattern.

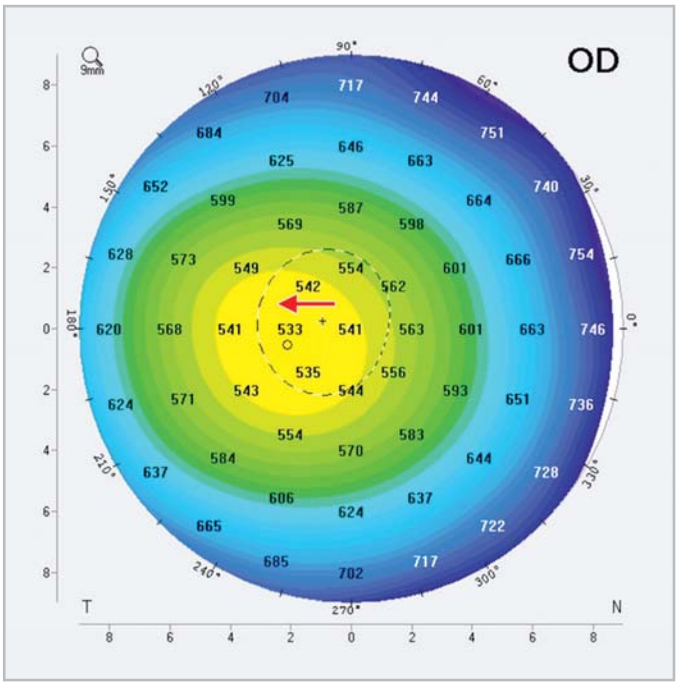



**Figure 2** The horizontal displacement pattern.

inferior; (2) due to highly distorted cornea in PMD, the inferior part is usually extrapolated as shown in the figure (black dots), so the thickness of the cornea at that part is not realistic. In such cases, OCT-based tomography is strongly recommended because it is much more accurate than Scheimpflug-based tomography.

- *Droplet pattern* (**Figure 5**): It is usually encountered in KC, but might be a sign of early PMD.
- *Globus pattern* (**Figure 6**): It is a hallmark of keratoglobus (KG). It is characterized by generalized thinning extending to the limbus. In this pattern, ICR implantation and traditional corneal transplantation are contraindicated.

## Limitations

One limitation of the corneal thickness map is corneal opacities. The Scheimpflug beam light is susceptible to scattering in areas of scars, resulting in artifacts, extrapolated data, and misinterpretation. The area of the scar is usually displayed as a flat area, which is real but exaggerated. Additionally, scarred areas are often interpreted as thin, which is not always accurate. The OCT-based tomography is more reliable in such cases. **Figures 7 to 12** represent a typical corneal scar.

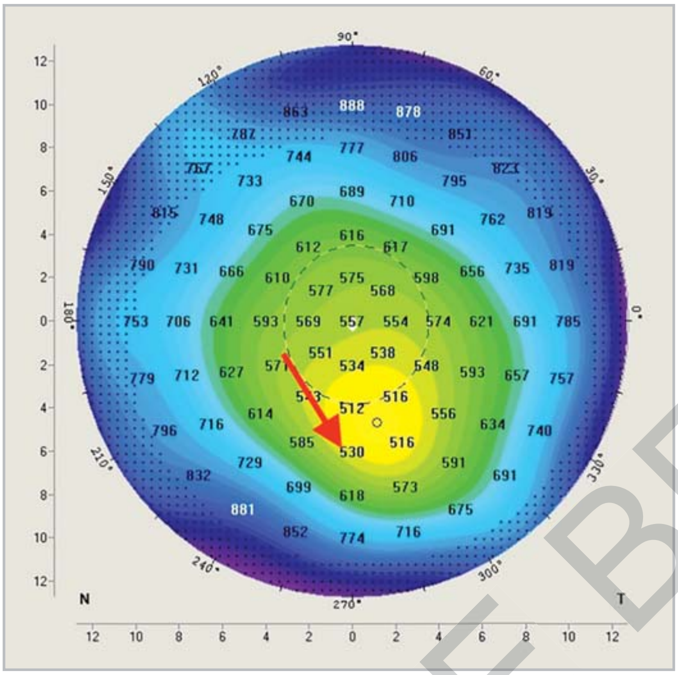



**Figure 3** The vertical displacement pattern.

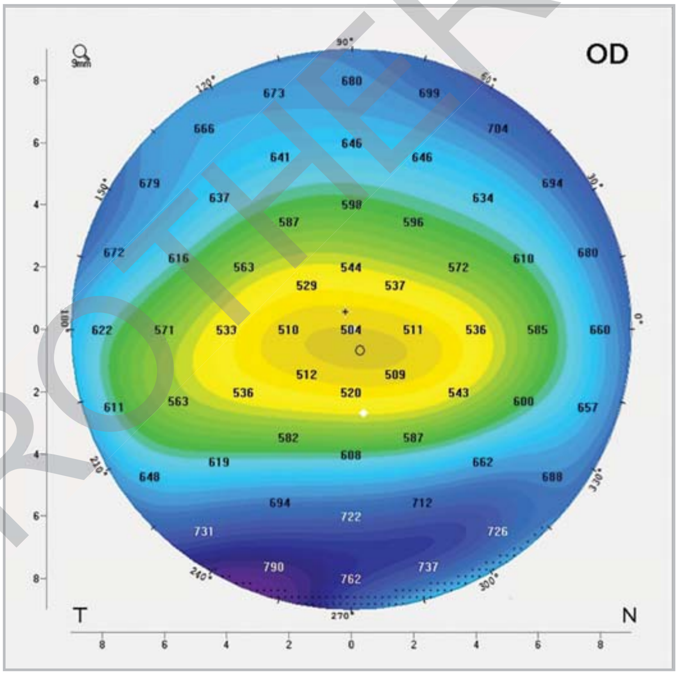



**Figure 5** The droplet pattern.

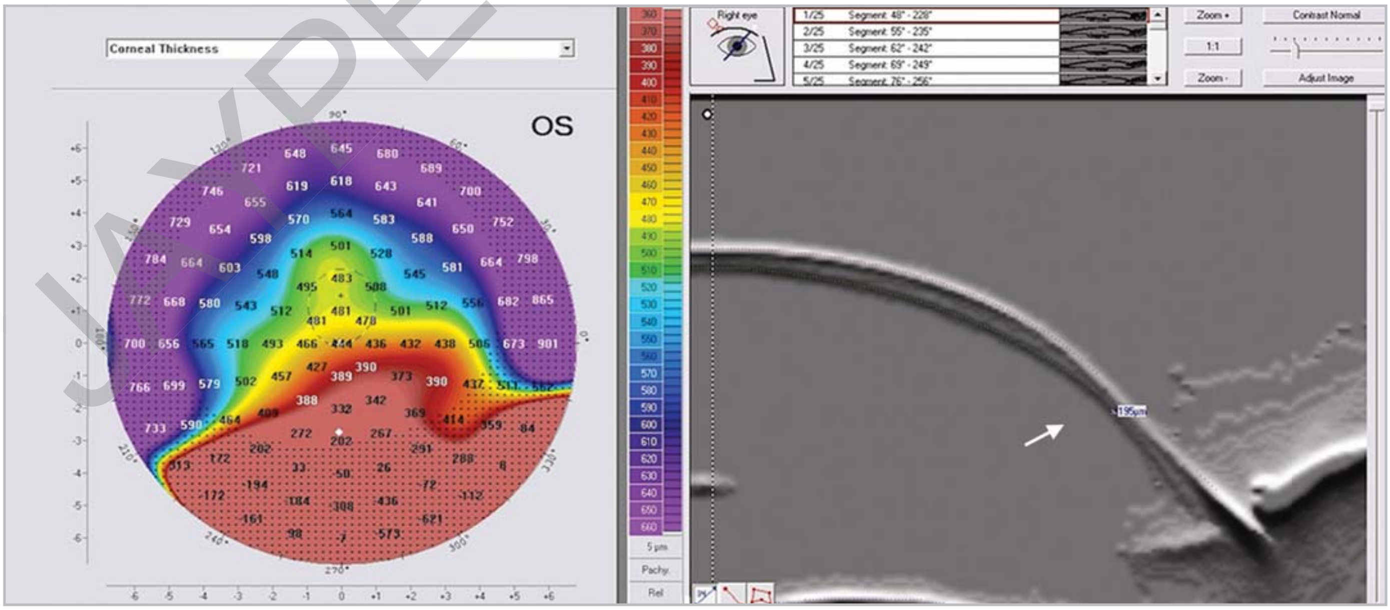



**Figure 4** The bell pattern.

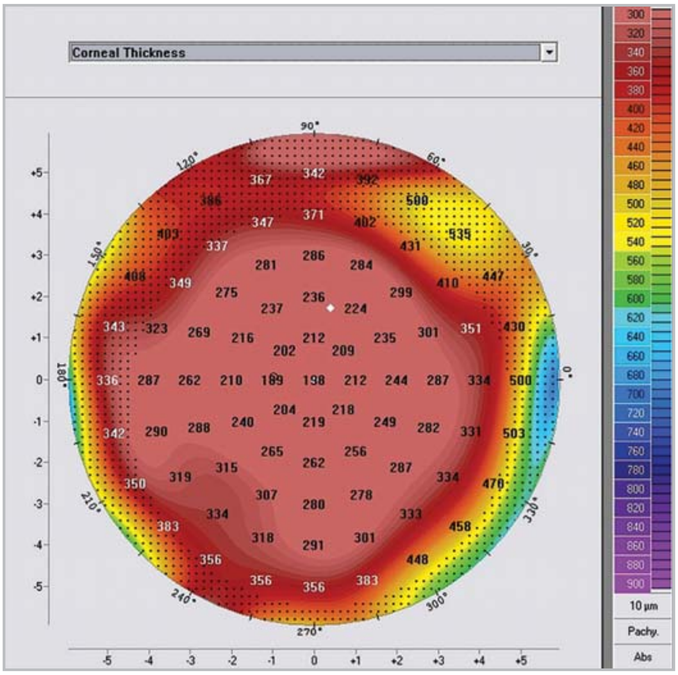



Figure 6 The globus pattern.

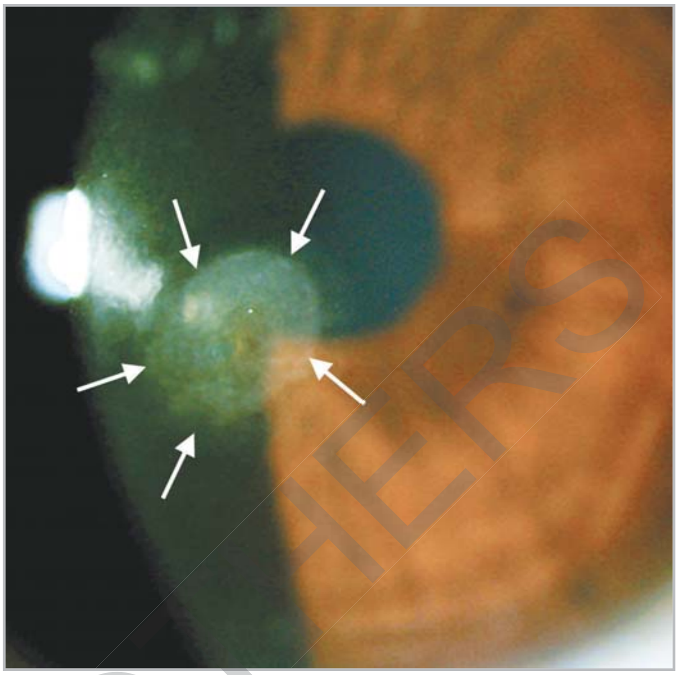


Figure 7 Corneal scar: The slit-lamp view.

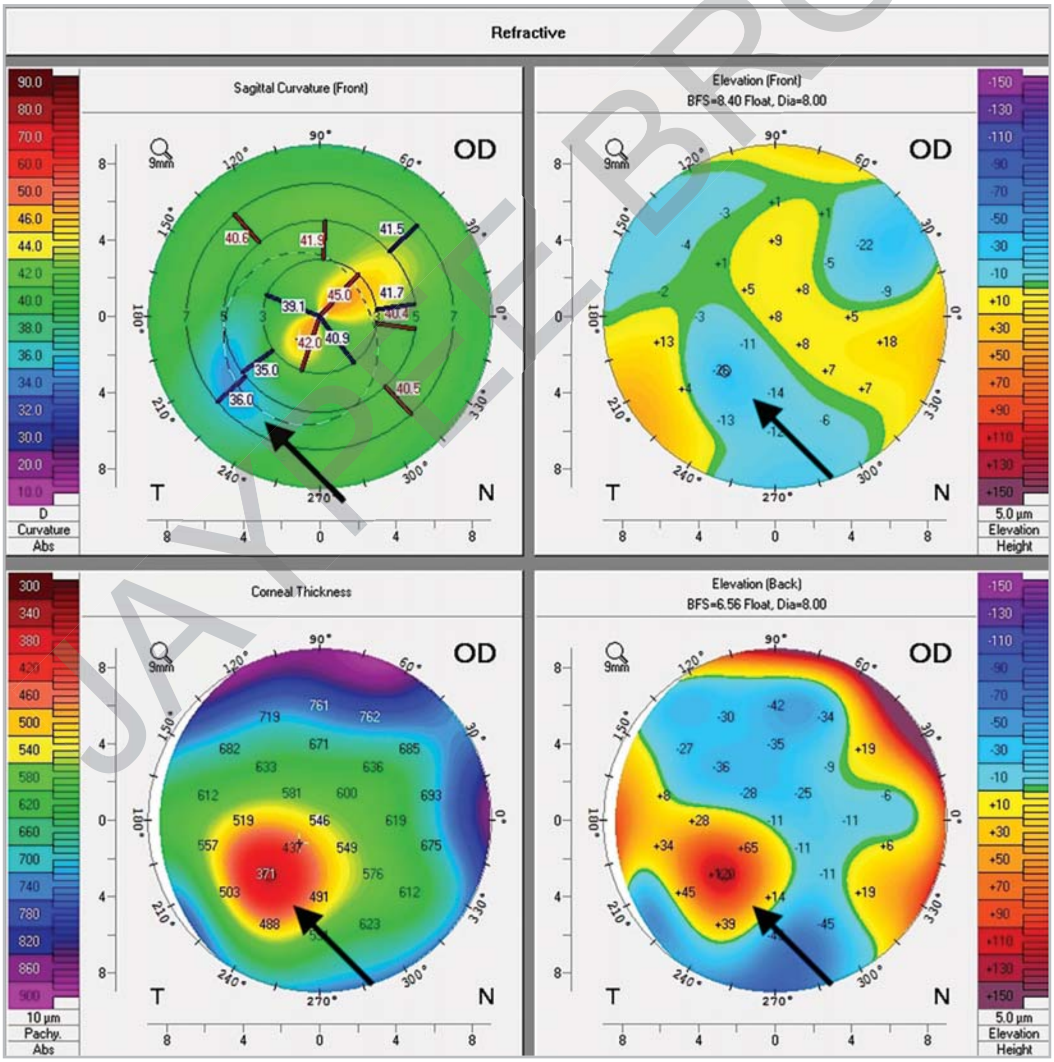



Figure 8 Corneal scar: The four-composite refractive map.

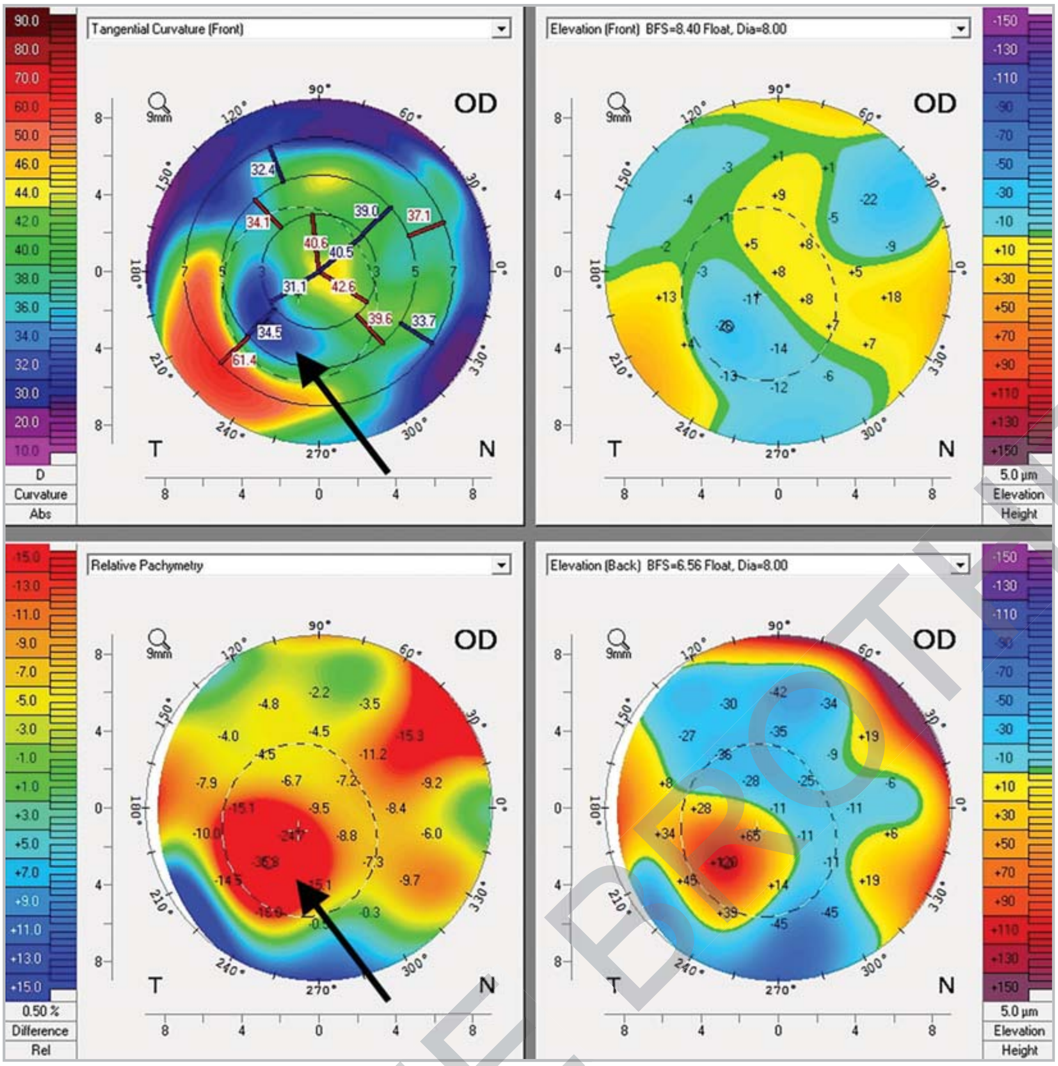



**Figure 9** Corneal scar: The four-composite selective map.

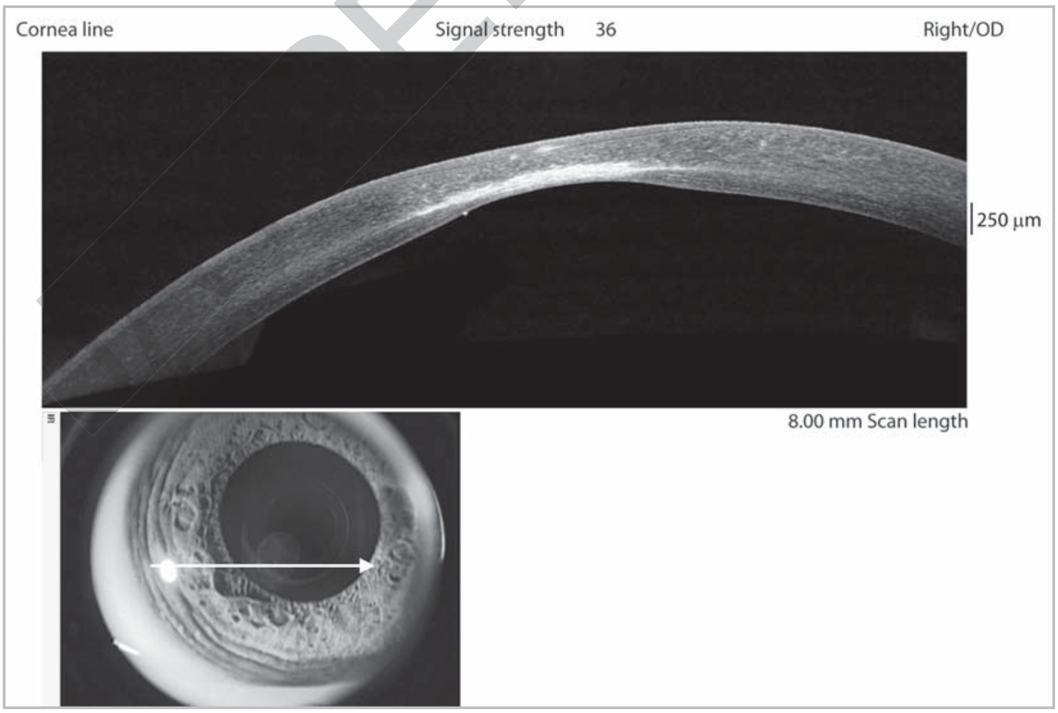



**Figure 10** Corneal scar: The AS-OCT cross-section view.

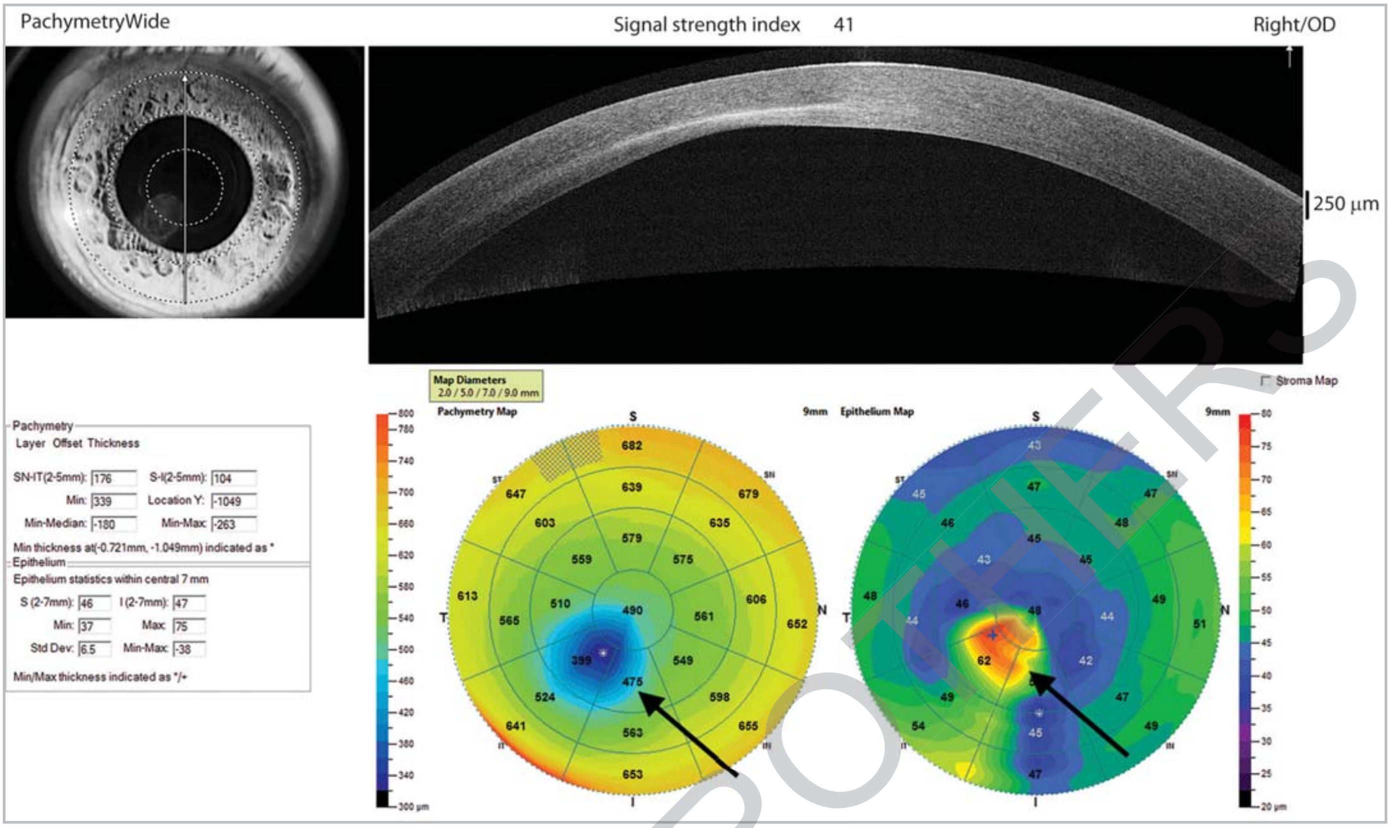



Figure 11 Corneal scar: The pachymetry map and the epithelial map by the AS-OCT.



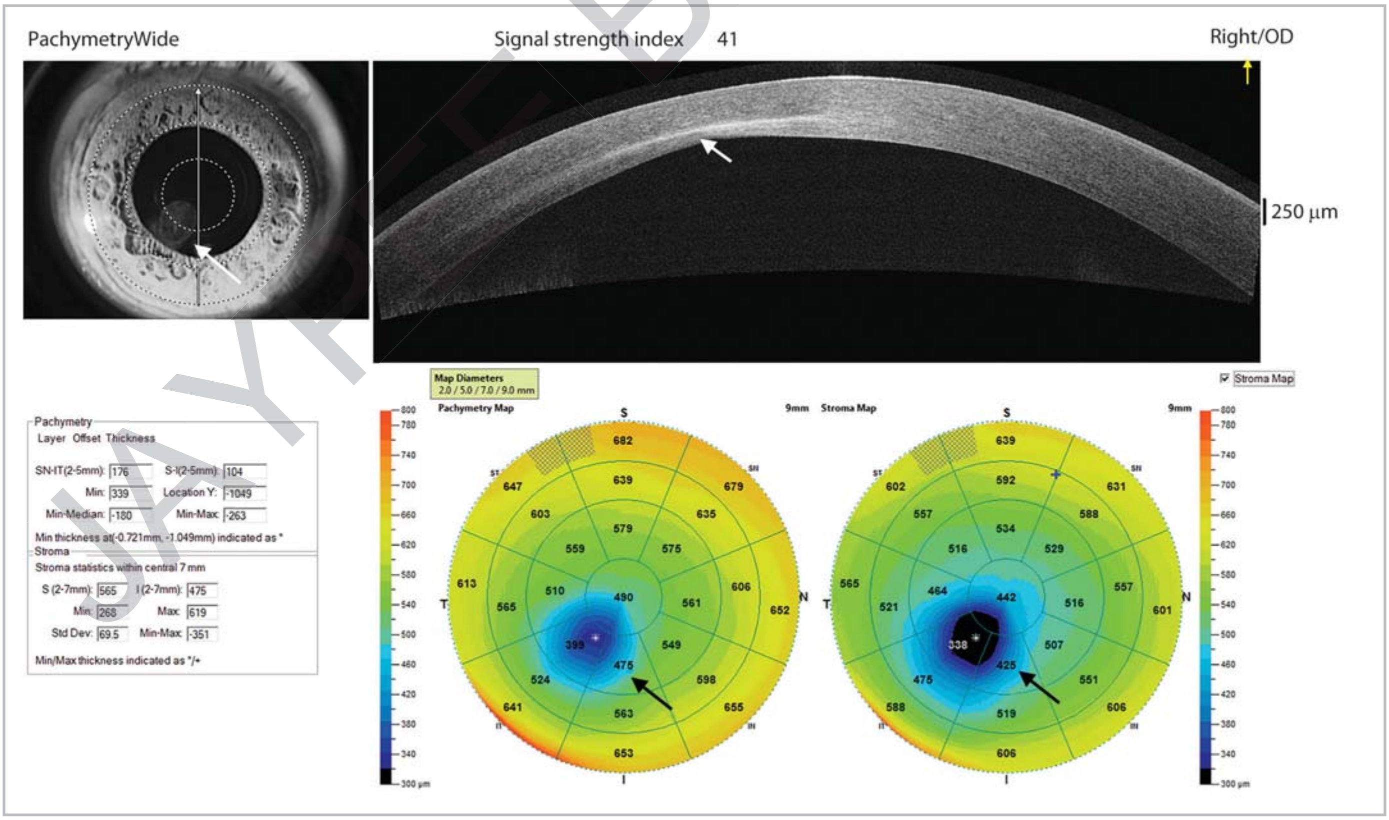



Figure 12 Corneal scar: The pachymetry map and the stromal map by the AS-OCT.

**Figure 7** is the slit lamp view—the scar is oval. It partially interferes with the pupillary zone, thereby affecting vision.

**Figure 8** is the four-composite refractive map—a flat area on the anterior curvature map and anterior elevation map, a corresponding steep area on the posterior elevation map, and a corresponding thin area on the pachymetry map. Many surgeons may misinterpret this case as ectasia or KC. The important sign that differentiates this case from ectasia and KC is the corresponding flat area on the anterior curvature map rather than a hot spot (steep area) found in ectasia and KC.

**Figure 9** shows the four-composite selective map—the flat area is more prominent on the anterior tangential map and the relative pachymetry map.

**Figure 10** is the anterior segment (AS-OCT) view—a horizontal linear cross-section along the scar shows the real thinning of the cornea over and under the scar. Since the epithelium has a filling effect (remodeling), it thickens over the scar to smooth the anterior surface and therefore masks the real flattening caused by the scar **(Figure 11)**. Look at the outward-bulging outward bulge on the posterior surface under the scar. It explains the very high elevation values on the posterior elevation map.

**Figure 11** is the AS-OCT pachymetry map with epithelial thickness map—look at the thinning in the pachymetry map on the left side and the corresponding thickening of the overlying epithelium in the epithelium map on the right. **Figure 12** is the AS-OCT pachymetry with the stromal map on the right. It shows a larger zone of thinning in the stroma compared to the thinning seen on the pachymetry map on the left. That is because the pachymetry map is the algebraic sum of the epithelium remodeling effect and stromal changes.

## CORNEAL THICKNESS SPATIAL PROFILE AND PERCENTAGE THICKNESS INCREASE

### Principle

The corneal thickness spatial profile (CTSP) describes the progression of corneal thickness in relation to corneal zones. In contrast, the percentage thickness increase (PTI) describes the percentage of this progression **(Figure 13)**. The horizontal axis represents concentric corneal zones of 2, 4, 6, 8, and 10 mm, centered on the TL. The vertical axis represents corneal thickness in the CTSP and the percentage of thickness increment in the PTI. The red curve represents the captured cornea. The black dotted curves represent the normative data for the normal population, with a confidence interval (CI) of 95% and two standard deviations.

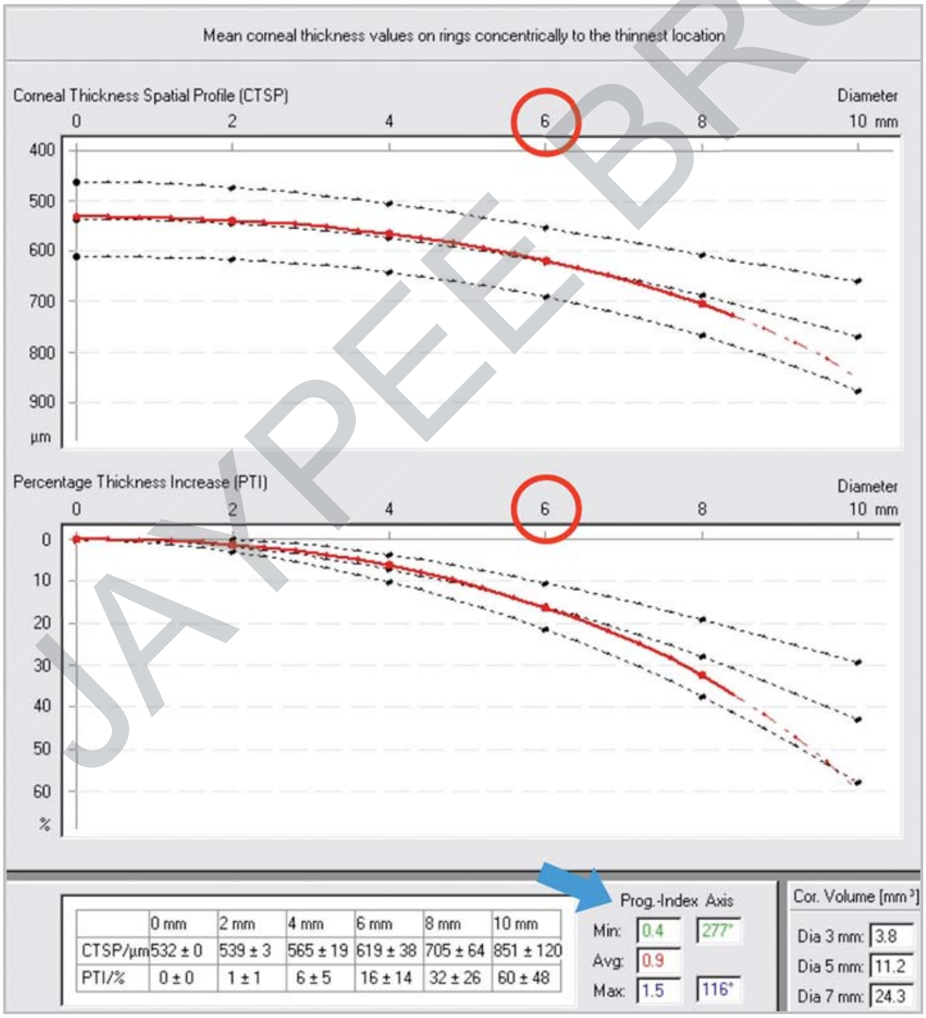



**Figure 13** The corneal thickness spatial profile, percentage thickness increase, and pachymetric progression index.

## Patterns

The normal pattern of both CTSP and PTI is a curved line plotted in red, following (but not necessarily within) the course of the normative black dotted curves, with an average < 1.20. In other words, the shape of the curve should show a gradual increment. The reference in this regard is the 6-mm zone **(Figure 13: red ellipses)**. Abnormal patterns include:

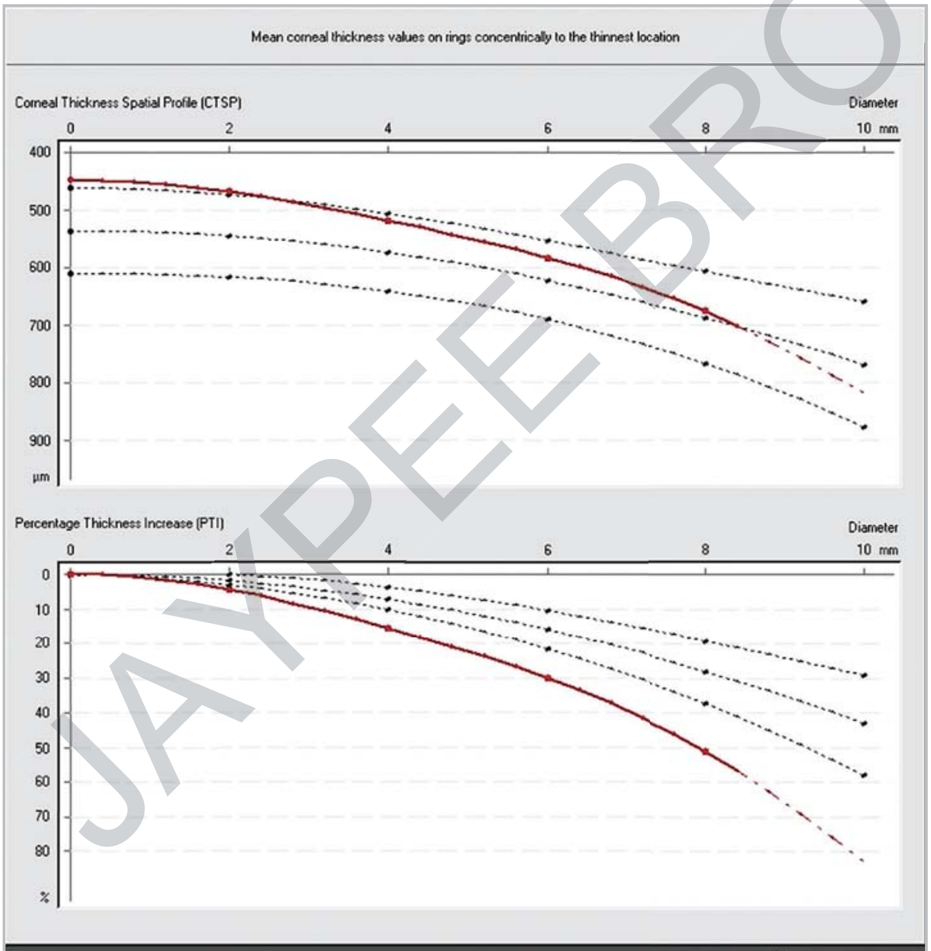
- *The quick slope* **(Figure 14)**: The red curve declines before the 6-mm zone. It is encountered in ECDs and corneas with high potential **(Chapter 20)**.
- *The S-shape*: The red curve descends before the 6-mm zone and then ascends **(Figure 15)**.
- *The lazy S-shape*: The red curve follows the slope and ascends after the 6-mm zone **(Figure 16)**.
- Both S-shape patterns are usually seen in ECDs and corneas with high potential **(Chapter 20)**.
- *The flat slope* **(Figure 17)**: It is seen in diseased thickened corneas, such as Fuchs' endothelial dystrophy and cornea guttata.
- *The inverted slope* **(Figure 18)**: It is a hallmark of PMD. However, not every PMD shows this pattern.

## PACHYMETRIC PROGRESSION INDEX

The thickness/location relationship can be introduced as an index known as the pachymetric progression index (PPI) **(bottom of Figures 13 to 18)**. This index represents the maximum, minimum, and average progression of the captured cornea compared with the normative data. The normal average value of the PPI is 0.8–1.1 **(Figure 13)**. When the average is <0.8, the cornea is usually diseased and thickened as in corneal edema, cornea guttata, and Fuchs' endothelial dystrophy **(Figure 17)**. When the average is ≥1.2, the cornea is usually abnormal **(Figures 14 and 15)**. In some cases of high corneal astigmatism, the average might be ≥1.2 despite a normal cornea. In the S-shape patterns, the average is usually normal when the ascending is after the 6-mm zone **(Figure 16)**.

## THE RELATIVE PACHYMETRY

Jack Holladay was the first to describe this map. Its principle is very similar to that of the elevation map. In the elevation map, the




| | 0 mm | 2 mm | 4 mm | 6 mm | 8 mm | 10 mm |
|---|---|---|---|---|---|---|
| C. Thickness / µm | 448 ± 0 | 468 ± 5 | 518 ± 17 | 583 ± 30 | 677 ± 54 | 819 ± 104 |
| Progression / % | 0 ± 0 | 4 ± 1 | 16 ± 6 | 30 ± 14 | 51 ± 26 | 83 ± 49 |

| | Prog.-Index | Axis |
|---|---|---|
| Min: | 1.3 | 23° |
| Avg: | 2.1 | |
| Max: | 3.2 | 281° |

| Cor. Volume [mm³] | |
|---|---|
| Dia 3 mm: | 3.4 |
| Dia 5 mm: | 10.2 |
| Dia 7 mm: | 22.5 |

**Figure 14** The quick slope.

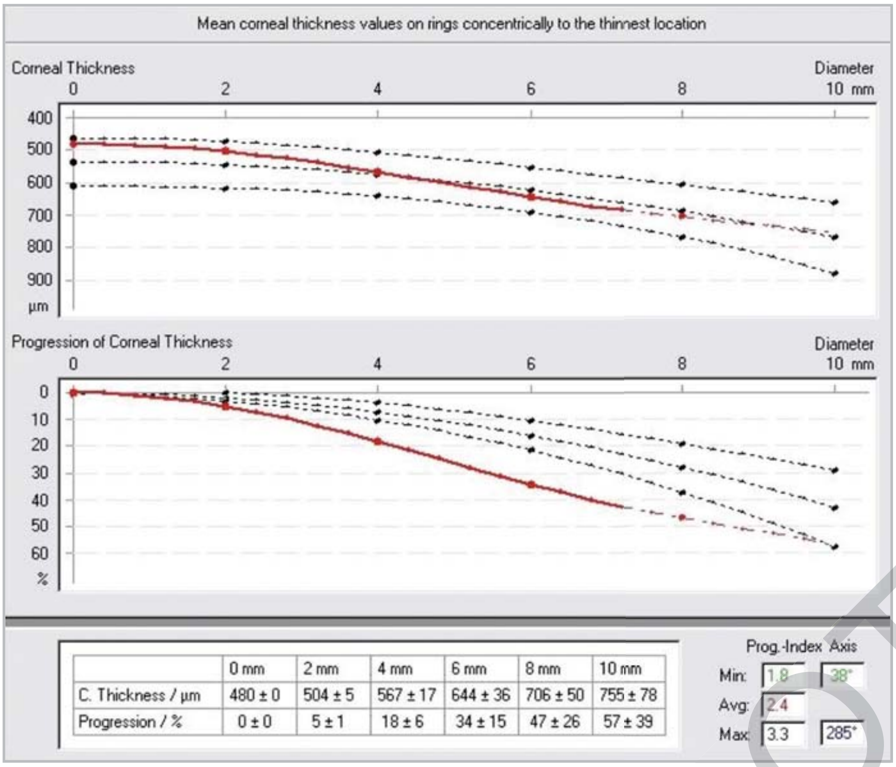



**Figure 15** The S-shape pattern.

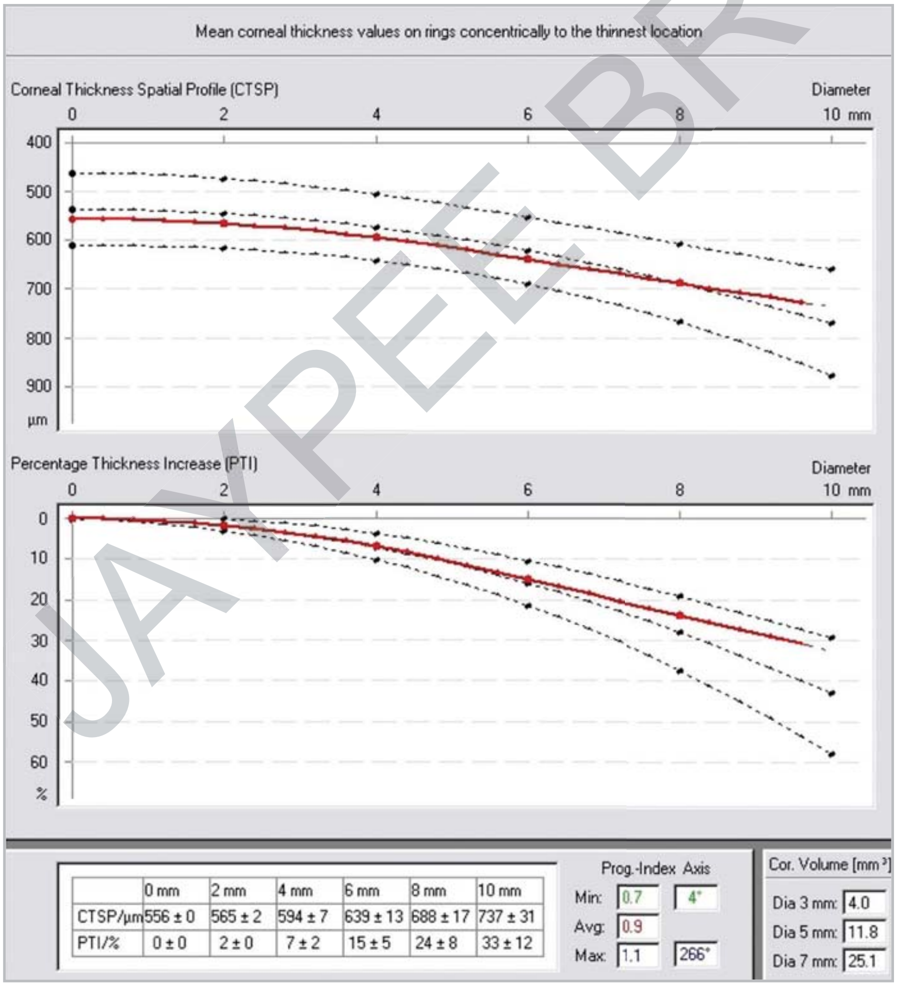
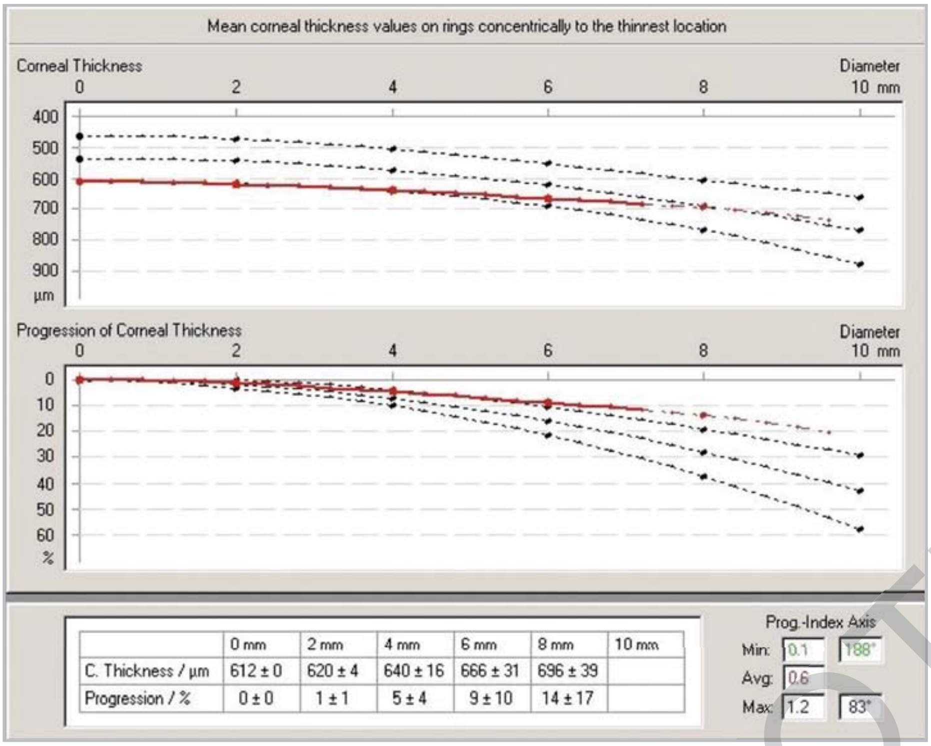
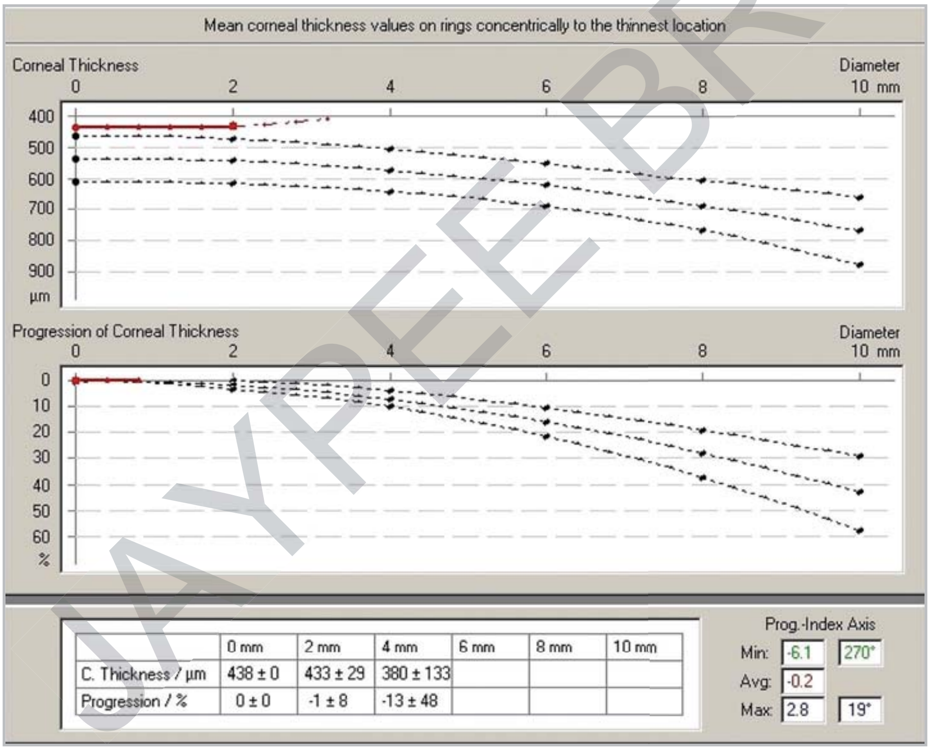



**Figure 16** The lazy S-shape pattern.




| | 0 mm | 2 mm | 4 mm | 6 mm | 8 mm | 10 mm |
|---|---|---|---|---|---|---|
| C. Thickness / µm | 612 ± 0 | 620 ± 4 | 640 ± 16 | 666 ± 31 | 696 ± 39 | |
| Progression / % | 0 ± 0 | 1 ± 1 | 5 ± 4 | 9 ± 10 | 14 ± 17 | |

**Figure 17** The flat slope.




| | 0 mm | 2 mm | 4 mm | 6 mm | 8 mm | 10 mm |
|---|---|---|---|---|---|---|
| C. Thickness / µm | 438 ± 0 | 433 ± 29 | 380 ± 133 | | | |
| Progression / % | 0 ± 0 | -1 ± 8 | -13 ± 48 | | | |

**Figure 18** The inverted slope.

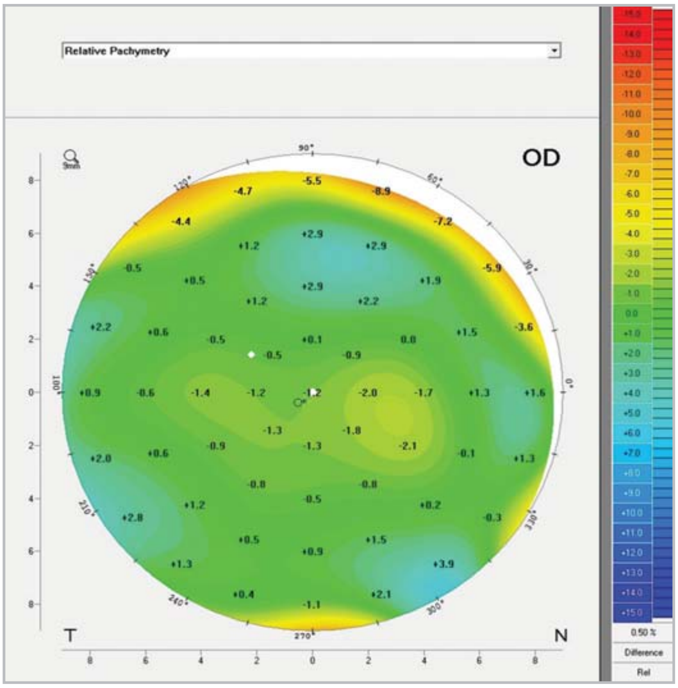



Figure 19 The relative thickness map.

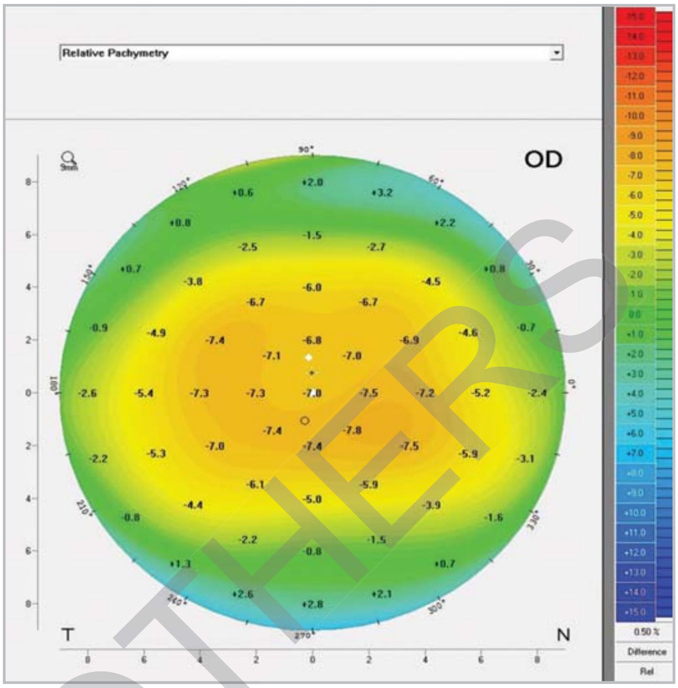



Figure 20 A suspicious relative thickness map.

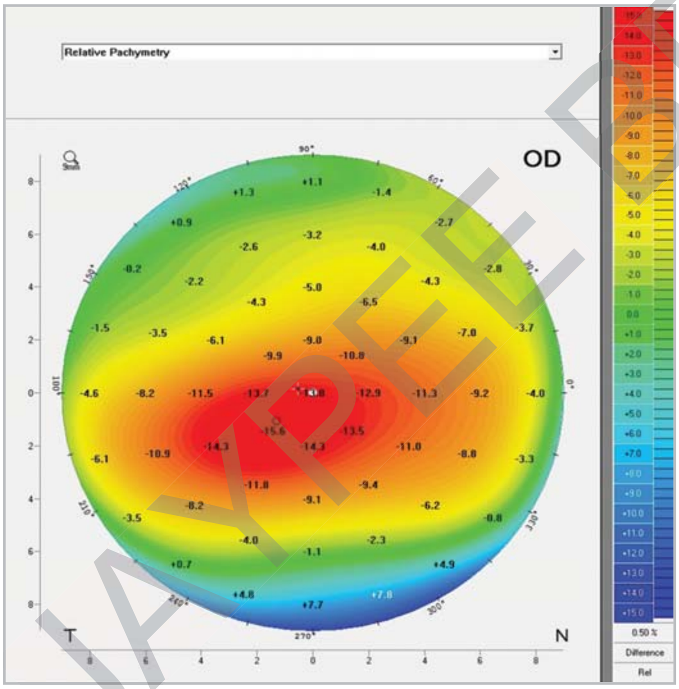



Figure 21 An abnormal relative thickness map.

captured cornea is measured in relation to a reference surface. In relative pachymetry, the thickness map of the captured cornea is compared with a standard normative thickness map of the normal population.

The relative pachymetry is displayed as percentage values **(Figure 19)**. Areas thicker than the similar areas in the standard map will be displayed in positive values, and vice versa. For example, +7 and +9 values are thicker than the standard map by 7 and 9%, respectively, and vice versa when the values are negative. Based on the Holladay report, the map is:

- *Normal*: If all values all over the cornea are > –5 (e.g., –2), as in **Figure 19**.
- *Suspicious*: If any value all over the cornea is –5 to –8, as in **Figure 20**.
- *Abnormal*: If any value all over the cornea is < –8 (e.g., –10), as in **Figure 21**.

In general, this map has three applications:

- In the workup for refractive surgery **(Chapter 14)**.
- In differentiating ECDs from entities mimicking ECDs, especially after laser-based refractive surgery **(Chapter 23)**.
- In the Holladay report **(Chapter 10)**.

# Corneal Tomography in Clinical Practice
## Basics & Clinical Interpretation

This landmark 5th edition of *Corneal Tomography in Clinical Practice* is presented in t*wo comprehensive volumes,* offering a unique and unparalleled resource in the field of anterior segment imaging.

**Volume 1: Basics & Clinical Interpretation**
This volume provides a solid foundation in corneal optics, topography, and tomography, following the renowned *Sinjab's step-by-step methodology*. Richly illustrated with clinical examples, figures, and interpretation guidelines, it is designed to guide clinicians through every aspect of tomographic analysis and its clinical applications.

*Key topics include:*

- Clinical basics of corneal optics and geometry
- Core principles of topography and tomography
- In-depth analysis of Pentacam HR maps and displays, including:
    - All maps and profiles
    - Belin-Ambrósio enhanced ectasia display
    - Holladay reports
    - Corneal topometry
    - ABCD Belin Keratoconus Staging
- Wavefront analysis and its clinical relevance
- Novel tomographic definitions for ectatic corneal diseases
- Comprehensive grading systems, including the Belin ABCD grading
- Sinjab's PS3 in laser-based and lens-based refractive surgery
- Sinjab's PSIS algorithm for IOL selection
- Sinjab's tomography toolkit for:
    - Modern cataract surgery
    - Phakic IOL implantation
    - Keratoconus

*Groundbreaking Features of this Edition*
This is the *first and only book worldwide* to offer:

- A *two-volume structure* spanning from foundational theory to real-life cases and MCQs
- *Volume 2* for Self-Assessment in MCQs and Clinical Cases
- The *Sinjab's Tomographical Toolkits* for Cataract, Phakic IOL Implantation, and Keratoconus
- The updated *Sinjab PS3 Algorithm* for Subjective Tomographic Scoring
- The updated *Sinjab PSIS Algorithm* for personalized IOL selection

**Mazen M Sinjab** MD MSc ABOphth PhD FRCOphth(London) CertLRS(London) FRCSEd is a Senior Ophthalmic Surgeon and Consultant Practicing in Dubai, UAE. He is also a Past Professor of Ophthalmology at Damascus University, Syria. Professor Sinjab is a Fellow and Board Examiner in the Royal College of Ophthalmologists in London and the Royal College of Surgeons of Edinburgh. The main field of speciality of Professor Sinjab is cataract, refractive surgery, and keratoconus in addition to particular interest in the workup diagnostics, such as tomography, wavefront, and biometry.

Professor Sinjab has made significant contributions to ophthalmology education through thousands of lectures, instructional courses, masterclasses, research, and books, as well as his YouTube Channel (Sinjab Academy). He founded the Sinjab Academy platform for ophthalmology education (sinjabacademy.org), a global platform with >12 K members so far, conducting physical and virtual scientific activities with a central vision to take ophthalmology education to a higher level. Due to his scientific and educational influence in the field, he received several honours and awards, such as FRCO from the Royal College of Ophthalmologists in London, FRCSEd from the Royal College of Surgeons of Edinburgh, the shield of appreciation from His Highness Prince Abdulaziz Bin Ahmed Al Saud, the president of the Saudi Ophthalmology Society in Saudi Arabia, the honorary Ambassador Golden Medal from The Light For Sight Foundation in Switzerland, the honorary Esteemed Scientific Faculty Membership from The Light For Sight Foundation in Switzerland, The 'Ibn Umaira' International Award from the Oman Ophthalmology Society, and the recognition award from the Emirates Society of Ophthalmology from His Highness the Minister of Tolerance and Coexistence, Sheikh Nahyan bin Mubarak Al Nahyan, in addition to many golden medals from international societies.

JP medical publishers

www.jpmedpub.com

ISBN 978-1-78779-192-3

9 781787 791923