

FEATURE

Color LED Topography (CLT): Towards more accurate corneal surface measurements.....1

ABSTRACTS

Corneal surface reconstruction algorithm that uses Zernike polynomial representation.....4

Pseudo forward ray-tracing: a new method for surface validation in cornea topography.....4

Stimulator Pattern Density and Precision in Next Generation Corneal Topography.....5

Forward ray tracing for image projection prediction and surface reconstruction in the evaluation of corneal topography systems.....6

Image Processing of Irregular Corneas in Color-coded Multiple-point-source Corneal Topography (cmct).....7

Color LED Topography (CLT): Towards more accurate corneal surface measurements.

Cornea specialists share their perspectives and clinical experiences using the Cassini, a corneal topographer based on CLT technology.

Applications in refractive surgery



Michel Zaal MD, PhD VU University Medical Center, Amsterdam

topography gives an image that is qualitatively helpful we have observed that this topographic system does not properly reflect corneal irregularities.

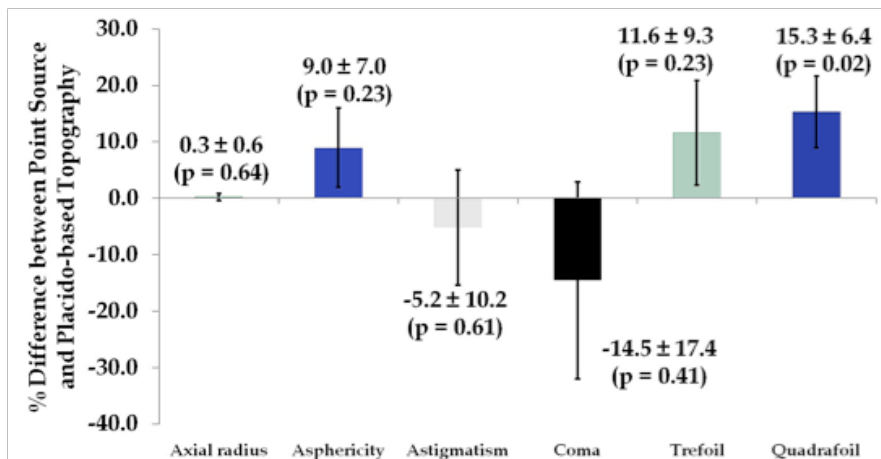
Penetrating keratoplasty is a procedure to replace diseased parts of the cornea with viable donor tissue. The trephination is usually 8-9 mm in diameter. In this procedure it is critical to minimize post operative astigmatism and other refractive aberration. In order to achieve this goal, proper management of suture revision, based on accurate assessment of the corneal shape, is necessary. Although Placido based

between Placido based topography measurements and PSCT in measuring non-spherical corneal aberrations. This was statistically significant for quadrafoil aberration. With PSCT a correct diagnosis of all relevant corneal aberrations can be made.

“Although qualitatively helpful Placido-based topography does not reveal all corneal irregularities” - MZ

For this reason we advocate Point Source Corneal Topography (PSCT). A corneal topographer using a multiple points stimulator, composed of small boxes in various colors, was developed at the VU University Medical Center. In a recent study¹, we found differences

This PSCT was further developed by i-Optics (The Hague, Netherlands). They improved the technology by implementing Color LED



Technology (CLT) and integrating it into a compact and portable medical diagnostic device: the Cassini Corneal Topographer. The first clinical trial is taking place in the OMC Zaandam in patients with irregular corneal surface such as keratoconus or after a corneal transplant.

Figure 1. Percentage Difference between Point Source and Placido-based Topography measurements of different corneal parameters.

Theoretical considerations



Victor Arni DP Sicam, PhD, Rotterdam Ophthalmic Institute, i-Optics, The Hague

Placido-based topographers

reconstruct the corneal shape based on specular reflections of a ring pattern. The advantage of using specular reflections is that measurement time is nearly instant and therefore is not affected by motion artifacts due to eye movements. However, the Placido ring technique suffers from inaccurate reconstruction of the irregular shape features of the cornea. This problem was already documented in the 90s^{2,3}. The affected shape

features are the rotationally non-symmetric ones such as those responsible for astigmatism, trefoil and quadrafoil aberrations. These shape features have a characteristic surface curvature along a circular direction. Ring reflections are hardly deformed by these features and therefore will be difficult to detect.

“Color LED Topography (CLT), like the Cassini, solves the issue of Placido based topography” - VS

shown in Figure 2. Reconstruction based on PSCT reproduced a topography close to the actual shape of the cornea while the Placido based reconstruction introduced large edge artifacts, induced astigmatism and induced quadrafoil-like shape. The Cassini has a unique source pattern of color LEDs to ensure one to one correspondence between source and image points. This eliminates artifacts due to shadows caused by object obstruction such as the eye lashes, nose

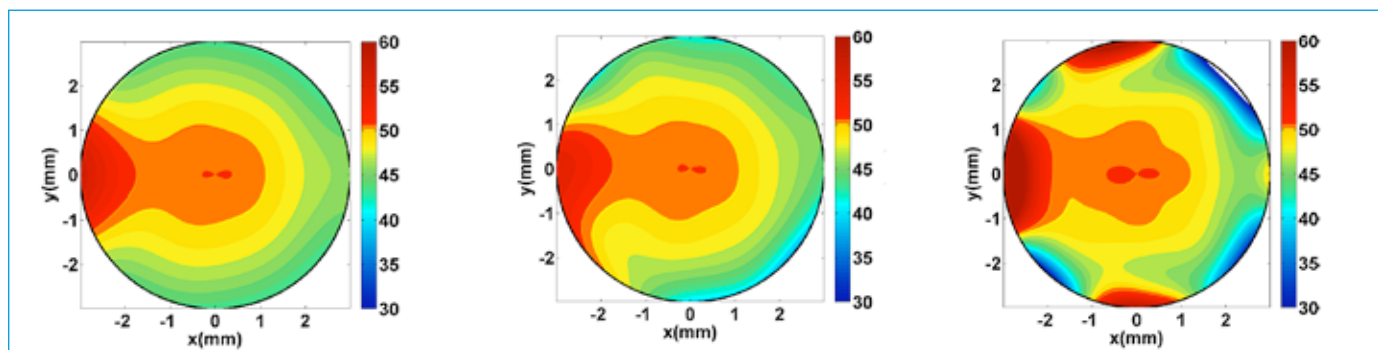


Figure 2 From left to right: Simulated Cornea; Point to point surface reconstruction; Placido based reconstruction

PSCT, also a specular reflection type solves this problem. As an example, the results of a comparison study between a Placido based surface reconstruction algorithm and that of a PSCT is

and other facial features. This makes the Cassini an accurate corneal topographer, producing precise and highly repeatable measurements.

Screening for keratoconus



Annette Geerards MD, PhD, Rotterdam Eye Hospital.

The cornea as seen by the naked eye seems to be a smooth curved surface but in reality irregularities in the surface exist with sizes of a few microns 10x smaller than the typical width of a human hair. These features can be “seen” by a corneal topographer. Corneal topography has many clinical applications. It can be used for screening purposes of laser surgery patients or detection and follow-up of keratoconus patients.

Keratoconus at an early stage can be treated with collagen crosslinking (CXL) with Riboflavin. This technique has been shown to be safe and effective⁵. CXL halts the progression of keratoconus, thus preventing visual loss and the need for surgical intervention. This makes early detection of keratoconus particularly relevant. A typical example of a patient with Keratoconus is shown in Figure

“With Cassini we foresee improvements in early detection of Keratoconus” - AG

3. We also did measurements on an artificial octafoil surface and results show a clear advantage of using the Cassini compared to a Placido based Topographer (Figure 4). The Placido based topographer fails to “see” the peripheral irregularities of the artificial surface while the Cassini was able to accurately detect the correct surface feature. Placido based measurements are one of the most sensitive detectors for keratoconus. However, with the aid of the new technology of Cassini, we can make further progress.

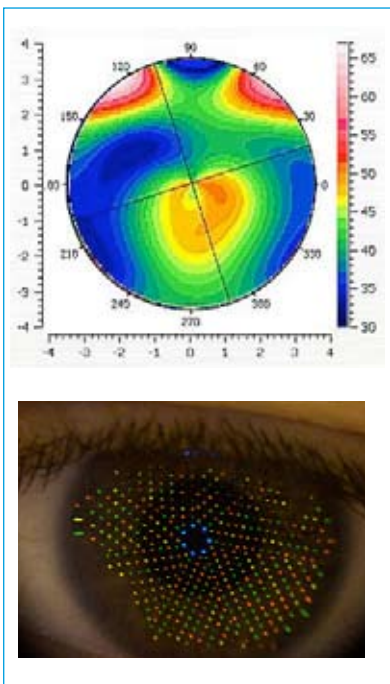


Figure 3. Photo (top left) obtained by the Cassini on a patient with Keratoconus with the corresponding curvature map (bottom left).

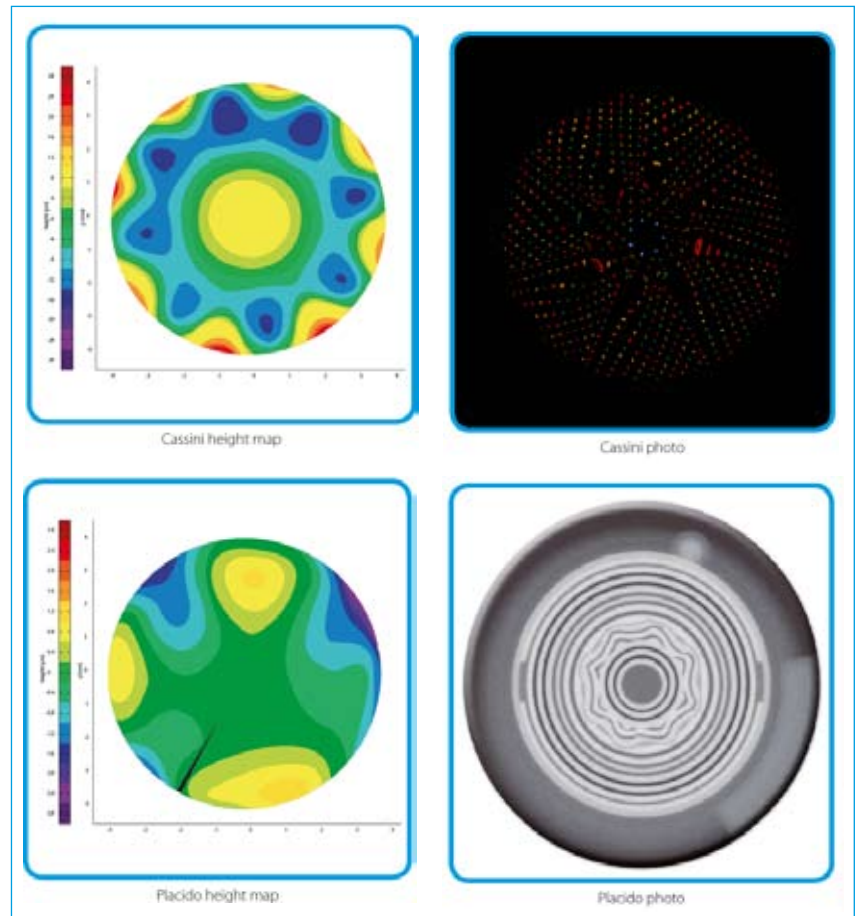


Figure 4. Comparative measurement of an artificial octafoil surface.

“Cassini’s technique and algorithm ensure submicrometer accuracy in corneal topography”

J Opt Soc Am A Opt Image Sci Vis. 2004 Jul;21(7):1300-6.

Corneal surface reconstruction algorithm that uses Zernike polynomial representation.

Sicam VA, Coppens J, van den Berg TJ, van der Heijde RG.

SOURCE

Department of Physics and Medical Technology (FMT), Vrije University Medical Centre, De Boelelaan 1118, 1081 HV Amsterdam, The Netherlands.

ABSTRACT

We developed an algorithm that directly determines Zernike coefficients for the corneal anterior surface derived from the reflection image of a stimulus with pseudorandom encoding. This algorithm does not need to include calculation of corneal height maps. The numerical performance of the algorithm is good. It has the potential of determining corneal shape with submicrometer accuracy in obtaining Zernike coefficients. When applied to real eye measurements the accuracy of the procedure will be limited by the topographer that is used.

“Corneal topography capturing radial distortions”

Optom Vis Sci. 2007 Sep;84(9):915-23.

Pseudo forward ray-tracing: a new method for surface validation in cornea topography.

Sicam VA, Snellenburg JJ, van der Heijde RG, van Stokkum IH.

SOURCE

Department of Physics and Medical Technology, VU University Medical Center, Vrije Universiteit, Amsterdam, The Netherlands. va.sicam@vumc.nl

ABSTRACT

Purpose

A pseudo forward ray-tracing (PFRT) algorithm is developed to evaluate surface reconstruction in corneal topography. The method can be applied to topographers where one-to-one correspondence between mire and image points can be established.

Method

The PFRT algorithm was applied on a corneal topographer designed and constructed at the VU University Medical Center, Amsterdam, The Netherlands. Performance of the algorithm was evaluated using artificial test surfaces and two sample eyes. The residual output of the PFRT algorithm is displayed as pixel displacements of actual feature points on the corneal image. Displacement of 1 pixel indicates submicrometer corneal height accuracy.

Results

PFRT residual increases with complexity of the measured surface. Using Zernike radial order 6, the mean residual for the artificial surfaces is subpixel. The mean residual for the regular cornea and the irregular cornea is 1.16 and 2.94 respectively. To some extent, increasing the Zernike radial order improves the accuracy. The improvement from order 6 to 20 is factor 2.3 for the irregular cornea. Using the residuals to further improve the accuracy brought local changes as high as 0.28 D in some areas of the reconstructed corneal power map.

Conclusion

PFRT can be used to evaluate how close a reconstructed corneal surface is to the actual one. The residue information obtained from this algorithm can be displayed simultaneously with the corneal image. This provides accurate information about the corneal shape that is useful for application in laser refractive surgery.

“Proof of principle: surface reconstruction in severe pathologies and extreme artificial surfaces”

ARVO Meeting Abstracts April 11, 2009 50:5081—D1027

Stimulator Pattern Density and Precision in Next Generation Corneal Topography

V. D. Sicam⁶; K. A. Vermeer⁷; J. J. Snellenburg⁸ and M. Mensink⁷

Purpose

Recent developments in customized laser refractive surgery and customized contact lens applications demand more accurate corneal topography measurements (Curr Opin Ophthalmol 2007; 18:325-333.) At the VU University Amsterdam in the Netherlands a skew ray error free corneal topography method was developed over the past 10 years to address this issue, especially in improving higher order aberration measurements (Optom Vis Sci. 2006; 83(12):910-8.) . This method uses a grid pattern instead of concentric circles. In this study, the minimum number of stimulator points in skew ray error free corneal topography that will produce sufficient precision in reconstructing the anterior corneal surface is determined. Methods Source and image points are simulated for different surface types encountered in corneal topography (sphere, toric, human eye with no corneal abnormality). A new

raytracing method based on forward raytracing has been applied in order to evaluate the precision for the three test surfaces. This is an upgrade of a method previously developed (OptomVis Sci2007; 84(9):915-23). This is better than previous methods because it uses no approximations in the underlying equations used for derivation. Gaussian noise (20 μm s.d.) was added to the image points to simulate actual experimental noise. This was applied to different number of source points (ranging from 100 to 800) that will produce an equal spread of image points over a 10 mm corneal zone. The precision for central radius of curvature and refractive corneal aberrations were assessed over a 7 mm corneal zone (Zernike convention - rms values up to order 8).

Results

A minimum number of about 700 stimulator points covering a 10 mm corneal zone is enough to achieve a precision of better than 0.125 Equivalent Diopter central radius of curvature. For this configuration the precision in corneal astigmatism, trefoil, coma and quadrafoil aberrations is 0.08, 0.05, 0.04 and 0.05 Equivalent Diopter respectively.

Conclusions

Although it appears that 700 stimulator points will give good performance in reconstructing the corneal surface this is only applicable to skew ray error free corneal topography.

“Submicron accuracy and improved precision of point-source corneal topography”

Optics Express, Vol. 18, Issue 18, pp. 19324-19338 (2010) doi:10.1364/OE.18.019324

Forward ray tracing for image projection prediction and surface reconstruction in the evaluation of corneal topography systems

Joris J. Snellenburg, Boy Braaf, Erik A. Hermans, Rob G. L. van der Heijde, and Victor Arni D. P. Sicam

ABSTRACT

A forward ray tracing (FRT) model is presented to determine the exact image projection in a general corneal topography system. Consequently, the skew ray error in Placido-based topography is demonstrated. A quantitative analysis comparing FRT-based algorithms and Placido-based algorithms in reconstructing the front surface of the cornea shows that arc step algorithms are more sensitive to noise (imprecise). Furthermore, they are less accurate in determining corneal aberrations particularly the quadrafoil aberration. On the other hand, FRT-based algorithms are more accurate and more precise showing that point to point corneal topography is superior compared to its Placido-based counterpart.

“Proof of principle: Color LED Topography (CLT)”

ARVO Meeting Abstracts April 22, 2011 52:4189 - D933

Image Processing of Irregular Corneas in Color-coded Multiple-point-source Corneal Topography (CMCT)

*Victor A. Sicam; Harry de Vries; Maarten Huijbregtse and Michiel Mensink
i-Optics, The Hague, The Netherlands*

Purpose

Color-coded Multiple-point-source Corneal Topography (CMCT) is a new technique which is validated to be superior to Placido based corneal topography in reconstructing irregular corneal surfaces (Sicam et. al. OVS 2006 & Snellenburg et. al. Optics Express 2010). In extreme cases, image processing of CMCT taken for irregular corneas present some difficulties because of smearing and deformation of reflection patterns. In this investigation, an image processing algorithm is developed to enable a reasonable detection of feature points in the reflection pattern of irregular corneas.

Methods

The prototype topographer uses 672 LEDs as stimulator for corneal reflection. The LED pattern has a color code involving the variation in arrangement of three LED colors: RED, YELLOW and GREEN LEDs. This ensures that there is no mismatch in source and image points. A photo of an octafoil artificial surface made from PMMA (SUMIPRO BV, Almelo, The Netherlands) is obtained. To deal with the smearing and deformation of points in the reflection pattern an appropriate algorithm involving filtering techniques was applied to locate feature points in the corneal reflection. Surface reconstruction which is described in literature (Sicam et. al. JOSA A 2004) was applied and the amplitude of the peripheral modulations of the octafoil is measured and compared with manufacturer's specifications. A preliminary test on the robustness of the algorithms were applied on three normal eyes. The resulting corneal curvature were compared for surface reconstruction with and without the application of the filtering algorithm.

Results

The reconstructed octafoil surface has an amplitude of 10.4 ± 0.5 micrometer compared to the manufacturer's specification (tolerance based on Talysurf measurements) of 10.0 ± 0.3 micrometer. There was a slight decrease (s.d. of 0.02 mm) in the corneal curvature measured when the algorithm was applied for normal eyes.

Conclusions

The developed image processing algorithm succeeded in detecting feature points on an irregular artificial corneal surface. This enabled surface reconstruction of the surface with submicron elevation height accuracy. The algorithm systematically reduced the measured curvature of the cornea. This can be easily corrected with proper calibration.

Cassini Highlights is offered to you by i-Optics.



i-Optics pioneers smart and superior eye diagnosis solutions that are affordable, fast and easy to use by care providers worldwide to serve their patients best. Our innovations include EasyScan, Cassini and EyePrevent. EasyScan is a breakthrough zero-dilation retinal imaging system that uses Scanning Laser Ophthalmoscope technology to diagnose diabetic retinopathy, age-related macular degeneration, and glaucoma. Cassini is a first-of-its-kind corneal topographer based on Color LED Topography. It supports superior contact lens fitting, earlier detection of Keratoconus, and could help improve the outcomes of corneal transplants and refractive surgery. EyePrevent is a retinal-disease screening service for diabetic and other patients.

WE SEE THINGS **DIFFERENTLY.**

www.i-optics.com

Notes

¹Vrijling AC, Braaf B, Snellenburg JJ, de Lange F, validation of point-source corneal topography in keratoplasty. *Optom Vis Sci.* 2011 Jul;88(7):E837-42.

²Tripoli NK, Cohen KL, Obla P, Coggins JM, Holmgren DE. Height measurement of astigmatic test surfaces by a keratoscope that uses plane geometry surface reconstruction. *Am J Ophthalmol.* 1996 Jun;121(6):668-76.

³Rand RH, Howland HC, Applegate RA. Mathematical model of a Placido disk keratometer and its implications for recovery of corneal topography. *Optom Vis Sci.* 1997 Nov;74(11):926-30.

⁴Snellenburg JJ, Braaf B, Hermans EA, van der Heijde RG, Sicam VA. Forward ray tracing for image projection prediction and surface reconstruction in the evaluation of corneal topography systems. *Opt Express.* 2010 Aug 30;18(18):19324-38

⁵Kolli S, Aslanides IM. Safety and efficacy of collagen crosslinking for the treatment of keratoconus. *Expert Opin Drug Saf.* 2010 Nov;9(6):949-57.

⁶Rotterdam Ophthalmic Institute, The Rotterdam Eye Hospital, Rotterdam, The Netherlands

⁷i-Optics BV, Rijswijk, The Netherlands

⁸VU University, Amsterdam, The Netherlands