REVIEW ARTICLE

Scheimpflug Principle in Ophthalmology: A Deep Dive into Its Utility

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Abstract

The Scheimpflug principle, a geometric rule for capturing sharp, focused images of non-parallel objects, has been effectively utilized in ophthalmology. Initially described by Jules Carpentier in 1901 and later applied by Theodor Scheimpflug for aerial photographs, the principle was adapted for ophthalmic imaging in the 1970s by Professor Otto Hockwin. By aligning the object, lens, and image planes at a common intersection point, the principle allows for detailed imaging of curved structures like the cornea. Modern ophthalmic devices, such as the Pentacam, leverage this principle to provide high-resolution cross-sectional images of the anterior segment, enhancing diagnostic accuracy in clinical practice.

Keywords: Scheimpflug principle, pentacam, Ophthalmology, Imaging

INTRODUCTION

The Scheimpflug principle is a geometric rule that allows for capturing sharp, focused images of objects that are not parallel to the camera and lens. It enables an enhanced depth of focus without distorting the image and is commonly used in photography. Originally described by Jules Carpentier in 1901, the principle is named after Austrian army Captain Theodor Scheimpflug, who used it to devise a method for correcting perspective distortion in aerial photographs. However, it was not until the 1970s that a group of researchers led by Professor Otto Hockwin developed a Scheimpflug slit-imaging device for ophthalmological use.

The principle describes the orientation of the plane of focus of an optical system when the object plane, lens plane, and image plane are not parallel but intersect at a common point in space. Ideally, the lens and the image plane are parallel, allowing a linear object to form a plane of focus parallel to the lens plane, resulting in a completely focused image. When the object is not parallel to the image plane, it becomes impossible to focus the entire image on a plane parallel to the image plane, leading to image blur and distortion. By applying the Scheimpflug principle, an oblique tangent can be drawn from the image, object, and lens planes, and their point of convergence is called the Scheimpflug intersection. Careful movement of the image and lens planes can lead to a focused and sharp image of the entire non-parallel object. This has obvious advantages and uses for imaging a curved object such as the cornea. The images taken during the study are digitized in the main unit and all image data are transferred to the computer interface bus. Scheimpflug's principle [Figure 1] has been particularly useful in ophthalmic imaging over the past decades. Several devices were used to obtain cross-sectional images of the anterior segment using a Scheimpflug camera perpendicular to the slit beam. The most commonly used Scheimpflug device in ophthalmology is currently the pentacam (Oculus Wetzlar, Germany).

APPLICATIONS OF THE SCHEIMPFLUG PRINCIPLE

In Corneal and Refractive Surgery

Scheimpflug-based topographers play a vital role as an anterior segment diagnostic and interventional modality. At present, the topographers using Scheimpflug-based imaging are Pentacam, Galilei, and Sirius.

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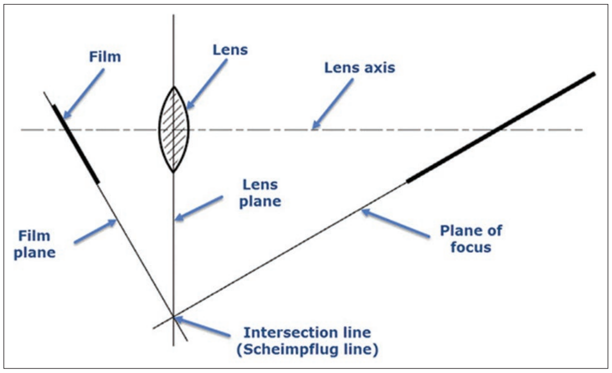

Figure 1: This figure illustrated the intersection of the film, subject and the lens plane to obtain Scheimpflug image

Advantages of using Scheimpflug-based imaging systems

1. Precise measurement of the central cornea
2. Ability to correct for small eye movements
3. Easy fixation for patient
4. Short examination time.

The Scheimpflug device does not appear to be as limited as the slit scanning in terms of post-refractive measurement.

Variations in Scheimpflug-based systems

Single Scheimpflug imaging

Pentacam™ (Oculus GmbH) utilizes a single Scheimpflug imaging camera. It rotates around the central axis and captures 50 meridian images, each passing through the same point in the center of the cornea. Pentacam software analyzes each image to generate 25,000 precise elevation measurements, obtained by extracting 500 points each from the entire corneal surface. A measurement takes <2 s, and the system can adjust the center of each image before reconstructing the corneal image, reducing any movement. Pentacam's software adds a ray-tracing algorithm to build and calculate a three-dimensional mathematical image of the entire anterior segment. Image analysis is performed by linear densitometry and correlates density with a layer of the cornea and lens.

Corvis® ST (Oculus) uses a high-speed Scheimpflug camera to take over 4300 images per s to capture the cornea's deformation in response to a defined air pulse. The acquired Scheimpflug pictures enable accurate determination of intraocular pressure (IOP) and corneal thickness. The cornea's biomechanical properties can be investigated in greater detail and have important implications for the treatment of corneal pathologies and keratorefractive surgery.[1]

Dual Scheimpflug imaging

Two Scheimpflug cameras (used in Galilei Dual Scheimpflug Analyzer, Ziemer Ophthalmology) oriented at 90° are used, which rotate around a shared central axis housing the slit beam light source. Upgradation to dual imaging systems enables the comparison and averaging of related corneal data from each channel to account for inadvertent misalignment and eye movement. It is unaffected by angular surfaces, enabling correct pachymetry to be determined even when the degree of decentration from the corneal apex is unknown. In contrast to single Scheimpflug systems, which must estimate the changing surface inclination before calculating the correct thicknesses or posterior heights, it is possible to place each averaged thickness and posterior height value in the cornea to its suitable location using dual cameras. Due to the reciprocal dual-camera views, any inaccuracy resulting from the misalignment can be fixed by averaging these corresponding data. This technique makes it easier to map the cornea and anterior section with more accuracy because of how naturally human eyes move in real life. The latter can obtain an accurate and reliable pachymetric analysis compared to the single imaging system.

Incorporation of placido topography

Scheimpflug devices would give erroneous data while processing the anterior and posterior curvature of the cornea on moving toward the periphery, as the curvature is only a small part of the anterior segment imaging. This can be voided by combining dual Scheimpflug imaging with infrared placido topography. Several devices combine the two approaches to improve precision in readings (CSO Sirius Topographer® [CSO, Firenze, Italy]).

In Fuchs endothelial dystrophy (FECD)

The FECD tomographic patterns that are indicative of the presence of edema can be found using Scheimpflug imaging. These recurring patterns, which may be detected in the posterior elevation and pachymetry maps, can be utilized to forecast how FECD will progress. An objective, quantitative index for evaluating the optical health of the cornea in FECD can be provided by corneal backscatter (Two spiking humps in densitogram)[3] detected by the Pentacam.

Comparison of three Scheimpflug topographers[2]

Topographer	Pentacam	Galilei	Sirius
Principle	Single scheimpflug	Dual scheimpflug with placido	Single scheimpflug with placido
Acquisition speed	25 scan images in 2 s	25–50 scan images in 2 s	25 scan images in 2 s
Points mapped	25,000 points	122,000 points	21632 anterior and 16000 posterior points
Principle	Single scheimpflug	Dual scheimpflug with placido	Single scheimpflug with placido

Topographic indices in various Scheimpflug topographers[2]

Topographer	Notable indices
Pentacam (Oculus, Wetzlar, Germany)	• Belin-Ambrósio enhanced ectasia display total deviation value (BAD-D) • The Belin/Ambrósio Enhanced Ectasia Display I - enhanced visualization of the cone by enhancing the reference surface • Furthermore, gives the corneal thickness spatial profile (CTSP) and (Percentage thickness index) PTI – plot points outside the outlier are suggestive of keratoconus • Belin/ambrósio enhanced ectasia display II - calculated final D using 5 parameters ([Df (front), Db (back), Dp (pachymetry progression), Dt (thinnest value), and Da (thinnest displacement)]) • BAD III - added an additional 4 parameters to the latter • Pachymetric progression index • Ambrósio relational thickness (ART) - 412 µm is the cut-off value for ART max • Keratoconus index - reliable screening parameter
Sirius (Costruzione Strumenti Oftalmici, Florence, Italy)	• Root mean square (RMS) lower the RMS, the more regular the surface. Belin/Ambrosio enhanced ectasia total derivation (BAD-D) similar to the 4.5 mm RMS per unit area. • Symmetry index of curvature - measures vertical asymmetry • Baiocchi-Calossi-Versaci front and back index (BCVf) (highly specific for keratoconus) and (BCVb) analyze the coma and trefoil components of elevations in the zones
Galilei (Ziemer, Biel, Switzerland)	• Asphericity asymmetry index, or Kranemann-Arce index - denotes asymmetry in the asphericity of the cornea • The Center/surround index - sensitive index for identification of central steepening • Surface regularity index - useful for forme fruste keratoconus comparable to BAD - D • Opposite sector index - reliable screening index • Keratoconus prediction index - 20 to 30% = keratoconus or suspicious corneas, >30% indicates pellucid marginal degeneration • Keratoconus Probability (Kprob) - • Percentage probability of keratoconus - > 45% suggestive of Keratoconus

In phakic intraocular lens (IOL) surgery

During the pre-operative evaluation, the 3D chamber analyzer is useful for surgeons implanting phakic IOLs. Pentacam uses a rapid, reproducible, non-contact approach to show where implantable contact lenses should be placed in reference to the cornea and crystalline lens. This enables the ophthalmologist to monitor these patients' cataract risk.

In Corneal Pathologies

Scheimpflug imaging adds value to the management of post-penetrating keratoplasty patients (planning suture removal). It is also useful for the planning and screening of Intacs in patients with keratoconus. It is beneficial for monitoring corneal haze that may develop after surface photorefractive keratectomy procedures, as well as opacities that can occur in patients who have suffered from adenoviral conjunctivitis. High-resolution Pentacam can aid in delineating the flap—bed interface, allowing for the visualization of diseases present at the interface, such as Interface Fluid Syndrome, which may develop in post-LASIK steroid responders.

In Cataract Surgery

It has been demonstrated that Scheimpflug's calculation of lens density correlates with the Lens Opacities Classification System III grading, enabling it to identify the progression of cataractogenesis more subtly.

A recently introduced software (using densitometry) called Pentacam nucleus staging offers an accurate and exact evaluation of lens density based on features providing a nuclear cataract score in five stages (0–5).[4] In cases of posterior capsular opacification (PCO), Pentacam tomograms offer an advantage over slit-lamp retro illumination images. Due to the absence of flash reflections in Pentacam tomograms, they enable a more straightforward and objective quantification of PCO compared to the traditional slit-lamp retro illumination imaging technique.

In Glaucoma

The anterior chamber volume is an effective screening method for identifying eyes with narrow angles, which is highly sensitive and specific. Based on the central corneal thickness, various IOP correction formulas are built within the Pentacam software. In contrast to the anterior segment OCT, it is inefficient in assessing the anterior chamber angle. This is because the scleral surface's reflectivity makes it difficult to see the sclera spur.

LIMITATIONS/DISADVANTAGES OF SCHEIMPFLUG IMAGING DEVICE

- Confusion in data interpretation may arise when comparing color-coded maps between Scheimpflug and placido-based imaging systems, as in Scheimpflug systems, red depicts the higher location, whereas, in placido systems, the steepest area is marked red.
- It is impossible to compare the precision of the many Scheimpflug devices. As each machine extrapolates and calculates data based on a separate set of algorithms and systems. Galilei (Ziemer, Biel, Switzerland) reduced the corneal power's value by around 3% compared to earlier versions by moving the optical reference plane to the anterior corneal surface. With respect to the posterior corneal surface, Pentacam determines the total corneal refractive power.
- Care must be taken when cross-comparing the variables between each system as they aren't mutual.
- Epithelial abnormalities and defects in corneal clarity may influence Scheimpflug imaging, leading to false-positive alterations in the posterior corneal surface and pachymetry.

Using additional placido-based systems may be able to negate some of the earlier mentioned issues.

CONCLUSION

The Scheimpflug principle has revolutionized ophthalmic imaging by enabling the capture of sharp, focused images of non-parallel objects. Its application in devices like the Pentacam has significantly improved the accuracy of diagnosing and managing various ocular conditions, particularly those involving the cornea and anterior segment. This principle facilitates precise measurements and imaging, offering detailed insights into the structure and pathology of the eye. While there are some limitations, the integration of Scheimpflug imaging with other technologies, such as Placido topography, enhances its utility and accuracy, making it an indispensable tool in modern ophthalmology.

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