# Dysfunctional Lens Index: A New Indicator in Lens Based Refractive Surgeries and Cataract Surgeries

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ABSTRACT

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| Lens-based refractive surgeries including Phakic IOLs and Refractive Lens Exchange are the procedure of choice when corneal ablative surgeries are contraindicated and in presbyopes. These procedures are gaining popularity over ablative procedures due it’s reversible nature. Dysfunctional Lens Index (DLI) in i-Trace aberrometer serves as an objective indicator of the lenticular quality of vision particularly useful in presbyopes for identifying and counselling patients with clinically clear lenses but dysfunctional. DLI complement other diagnostic measurements to assess lens function. Here, a comprehensive review has been presented regarding the applications of DLI in lens based refractive- cataract surgeries. Precise surgical planning is necessary when DLI is taken into account, as it is altered by factors other than lenticular causes of higher- order aberrations.

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***Keywords:*** *Dysfunctional Lens Syndrome(DLS), Dysfunctional Lens Index (DLI), “Refractive Lens Exchange(RLE), Ray trace aberrometer”, “Wavefront aberrometer”, “iTrace”, “Phakic IOLs”, “ICL”, “Implantable Collamer Lens”, “Higher order aberrations”, and “Lens Based Refractive Surgeries.”*

1. INTRODUCTION

Corneal ablative procedures like LASIK and PRK are the popular refractive surgeries. LASIK being flap based refractive procedure is prone for flap related intraoperative complications like an irregular flap, free cap and button-holes, and postoperative complications like interface infectious keratitis, flap striae, flap dislocation, diffuse lamellar keratitis, pressure-induced stromal keratitis, central toxic keratopathy, and epithelial ingrowth. (Schallhorn SC et al., 2006; Melki SA & Azar DT, 2001; Randleman JB & Shah RD, 2012). Dry eyes due to the transection of corneal nerves during flap creation is another potential complication associated with this procedure. (Shtein RM, 2011; Toda I, 2018) PRK being the surface ablative procedure, has a lesser incidence of dry eyes and no other flap-related complications mentioned above, but complications due to de-epithelization like post-operative pain, delayed epithelial healing, corneal haze due to abnormal healing response, sterile corneal infiltrates and so on. PRK has delayed visual recovery as compared to LASIK. (Kaiserman I et al., 2017; Ang BCH et al., 2006 to 2013; Wong AK et al. 1997; Talamo JH et al., 2013)

Then SMILE came into line, being an ablation-free, small incisional lenticular extraction procedure with minimal transection of corneal nerves, this procedure was indicated in patients with pre-operative dry eyes, higher magnitude of refractive error (up to -10D), those involved in contact sports and those who had large pupils due to less induction of aberrations (Sekundo W et al., 2011; Shah R, Shah S, & Sengupta S, 2011) but had limitations of cap and lenticule related complications and steep learning curve. (Ang M et al., 2014; Titiyal JS, Kaur M, 2018; Titiyal JS et al., 2017; Ramirez-Miranda A et al., 2015) Potential complications like glares and halos due to induction of aberrations, infective keratitis, diffuse lamellar keratitis, decentered treatment, under-correction, overcorrection, regression, and post-operative ectasia can occur in corneal ablative and lenticule-based procedures. (Schallhorn SC et al., 2006; Melki SA & Azar DT, 2001; Randleman JB & Shah RD, 2012; Kaiserman I et al., 2017; Ramirez-Miranda A et al., 2015 Webber SK et al., 1996; Randleman JB et al., 2008; Bohac M et al., 2018; Wolle MA, Randleman JB & Woodward MA, 2016; Tatar MG et al., 2014)

Kerato-refractive procedures are limited by corneal thickness, degree of refractive error, and corneal curvature. Minimum residual stromal bed thickness (RSBT) post-procedure is needed to minimize the risk of ectasia, with higher refractive error, more amount of tissue being ablated, increases the chances of ectasia, induces aberrations, increases the risk of post-operative haze and regression. Extremes of corneal curvature (pre-operative K values less than 41.00 D and more than 48 D) can lead to LASIK flap-related complications, free flaps, and flap button-holes. Patients with age less than 40 years, myopia <14 D, hyperopia <6 D, astigmatism <6 D, minimum post-procedural RSBT of 250 to 300 microns, post-operative K values of 34 to 50 D are ideal candidates for all kerato-refractive procedures (PRK/ LASIK/ SMILE). ([Jeewan S. Titiyal](https://openlibrary.org/authors/OL3865167A/Jeewan_S._Titiyal), [Manpreet Kaur](https://openlibrary.org/authors/OL8832520A/Manpreet_Kaur)& [Sridevi Nair](https://openlibrary.org/authors/OL9933803A/Sridevi_Nair), 2021)

Patients who are poor candidates for corneal procedures like age more than 40 years, with high degrees of refractive error, inadequate RSBT, stable keratoconus, lens-based refractive surgeries come into the role. (Nanavaty MA & Daya SM, 2012) Lens-based procedures involve Phakic IOLs (Guell JL et al., 2010; Lovisolo CF et al., 2005) and Refractive Lens Exchange (RLE) with Multifocal (MF) or Extended Depth of Focus (EDOF) IOLs. Phakic IOLs can be considered in patients with anterior chamber depth (ACD) of at least 3 mm, with an iridocorneal angle aperture of at least 30 degrees and horizontal white-to-white (WTW) distance between 10.5 mm to 13 mm. (Reinstein DZ et al., 2013) Phakic IOLs are contraindicated in ACD or WTW distance violates this range. (Huang D et al., 2009; Pesando PM et al., 2007) Phakic IOL implantation with inadequate measurements of ACD or WTW distance can lead to lower (<250 Microns) or higher vaulting (>750 Microns) causing cataract formation or pupillary block and endothelial decompensation respectively. (Lim DH et al., 2014)

For patients in whom kerato-refractive surgeries are contraindicated and phakic IOL can’t be implanted like high hyperopes due to small axial length and shallow anterior chamber, RLE with MF/ EDOF IOLs is useful. (Packard R, 2005) Moreover, this procedure is useful for presbyopes between 50 to 60 years not interested in using near glasses, because they have early lens changes and eventually need cataract surgery. RLE and cataract surgery differ as the surgery is performed on a clear crystalline lens as opposed to an opacified lens. (Packer M et al., 2005; Hoffman RS et al. 2004; Alio JL et al. 2014)

The first clear lens extraction was performed by Vincenz Fukala in high myopic patients. (Schmidt D, Grzybowski A, 2013) This gained popularity among surgeons worldwide (Colin J, Robinet A. 1994; Pucci V. et al., 2001) but due to intra-operative and post-operative complications related to cataract surgery including posterior capsular opacification, cystoid macular edema, and particularly late-onset retinal detachment due to untreated peripheral retinal degenerations in high myopes, made surgeons to abandon this technique. (Rodriguez A et al., 1987; Ravalico G et al., 2003; Javitt JC et al., 1991; Fritch CD. 1998) With newer advances in phacoemulsification with multifocal and accommodating IOLs, RLEs are creating a significant impact as a refractive surgery to provide spectacle/contact lens independence in patients with high myopia and presbyopia. (Packer M et al., 2002; Alio JL et al., 2012; Dhital A et al., 2013; Perez‑Merino P *et al*., 2014; Alio JL et al., 2004)

Contraindications to RLE include pre-existing ocular pathologies like corneal disease, age-related macular degeneration, diabetic retinopathy, lacquer cracks, and inflammatory diseases of the eye as the image quality causes poor post-operative vision. (Ruiz‑Moreno JM et al., 2008; Javitt JC et al., 1992; Gris O, Guell JL et al., 1996; Srinivasan B et al. 2016)

“Dysfunctional lens syndrome (DLS) is a term to use to describe the physiological aging process of crystalline lens. This process is categorized into 3 stages. Stage 1 is nothing but presbyopic changes after 40 years due to loss of accommodation. Stage 2 starts from 50 years with progressive loss of accommodation, increase in light scattering, and early changes in the transparency of the lens may be noted with an increase in higher-order aberrations. Stage 3 starts around 65 years or more with opacification of the lens (clinically significant cataract). The limitation of this staging is the overlapping of symptoms between stages. Those subjects in stages 2 and 3 experience a visual quality deterioration” (Waring G O, Rocha K M. 2018; Fernández et al., 2018; 2018, Kaweri, L et al., 2020, Mercer, R N et al., 2021) This staging is used in clinical practice for assessing the patients who can benefit from lens-based surgeries and also for a better understanding of the lens aging process. In the last two stages, there are algorithms and AI tools to help the clinician for the same. (Goh J et al., 2020). There are several platforms for objective measurement of lens dysfunctionality and opacity (Artal P et al., 2011; Mello G R et al., 2012), one such indicator is the Dysfunctional Lens Index (DLI). DLI and Opacity grade are objective lens outcomes provided by the i-Trace Visual Function Analyzer. The Dysfunctional Lens Index (DLI), part of the i-Trace wavefront aberrometer system, provides a quantitative and objective measure of lens performance. (Molebny VV et al., 2000; Rozema JJ et al., 2005)

The purpose of this review article is to describe the novel role of DLI in lens-based refractive surgeries including phakic IOLs and RLEs, also in cataract surgeries.

2. material and methods

This systematic review included studies that were observational studies, which correlated the DLI with lens function and internal ocular optical functions including aberrations. The studies that analyzed the role of DLI in various refractive surgeries were reviewed. Systematic review 3 databases including PubMed, Medline, and Cochrane central register of controlled trials from inception to December 2024 with the following keywords “Dysfunctional Lens Syndrome”, Dysfunctional Lens Index”, “DLS”, “DLI”, “Refractive Lens Exchange”, “RLE”, “Ray trace aberrometer”, “Wavefront aberrometer”, “iTrace”, “Phakic IOLs”, “ICL”, “Implantable Collamer Lens”, “Higher order aberrations”, Presbyopic Refractive Surgeries” and “Lens Based Refractive Surgeries.”

**3. THE i-TRACE RAY TRACING TECHNOLOGY AND DYSFUNCTIONAL LENS INDEX**

The i-Trace Visual Function Analyzer (Tracey Technologies, Houston, TX, USA) combines a Placido disk-based corneal topography and a ray tracing aberrometer which measures ocular aberrations, according to the varying levels of pupil dilation. From wavefront analysis, a colour-coded wavefront map depicting corneal, internal, and total ocular aberrations can be evaluated. This analysis is also depicted as bar graphs of Zernike polynomials (0 order to 6th order, 27 terms) along with Chang analysis. Quality of the image, measured in terms of contrast sensitivity, called Modulation Transfer Function, Point Spread Function, and Strehl Ratio also displayed. The i-Trace software also calculates the corneal curvature (sim K- steep and flat, axis and average), inferior–superior index, corneal asphericity), corneal refractive power (sphere, cylinder, and axis), and angles related to visual axes (angle kappa and angle alpha). With all this information, the i-Trace software calculates the DLI and opacity grade. In addition, the suitability of premium IOLs (based on the angle kappa and aberrations), Toric planner-power, and axis of toric IOL are also displayed. The imaging of limbal landmarks is done for intraoperative toric IOL alignment, thereby compensating cyclotorsion. Postoperatively, the i-Trace software also checks the accuracy of toric IOL alignment. The calculation of DLI on the i-Trace is based on the internal higher-order aberrations, contrast sensitivity, and pupil size dynamics. The appropriate time to plan RLE for the clinically appearing clear but dysfunctional lens can be objectively assessed. It can be used as an objective tool to counsel the patients.

The representation of DLI is simple and patient-friendly. A Snellen’s E chart is used to display the quality of vision. Poor DLI score is represented by blurred and distorted “E” which becomes well-defined and clear with improvement in DLI score. Poor DLI indicates a dysfunctional lens. Clear lens extraction improves visual symptoms in these patients. (Molebny VV et al., 2000; Rozema JJ et al., 2005, Mello G R et al., 2012; Castillo A et al., 2012)

Based on the manufacturer guidelines, DLI values range from 0 to 10, and the lower the value more dysfunctional is the lens, while an increasing number indicates better performance. The values are graded as DLI <5 suggests severely impaired lens function, between 5-7 means moderate impairment and >7 is considered normal.

On the other hand, the opacity grade is based on statistical analysis, the amount of light energy from the first 128 beams that enter the pupil during the exam creating an opacity map, which is then graded. Both parameters could be considered to assist in the optimal timing to proceed with a lens exchange. (Faria-Correia F et al., 2016; Li, Z. et al., 2019)

**4. DYSFUNCTIONAL LENS INDEX VALUES IN NORMAL POPULATION**

Martínez-Plaza et al., conducted “a study to describe normal DLI and opacity grade values in a healthy population (<50 years and >50 years) and analyzed the relationship between DLI, opacity grade, and wavefront aberrations obtained with the i-Trace device”. They found both indexes presented a weak-to-moderate although statistically significant correlation, and both correlated as well with ocular and internal higher order aberrations. In their study, 75% of the subjects in the younger group showed DLI values between 8 and 10 points with less percentage of subjects obtaining lower values. For subjects more than 50 years, the mean DLI value was significantly lower. They found an inverse correlation between DLI and age, supporting the findings above mentioned. A lower DLI value is associated with a more dysfunctional lens. (Martínez Plaza E et al., 2022)

 Few other works of literature have reported mean values previously for slightly older populations. (Faria-Correia F et al., 2016, Faria-Correia F et al., 2017, Li Z et al., 2019) “Although DLI is considered a useful indicator for DLS assessment, the variability observed implies the necessity of combining other diagnostic measurements. The opacity grade values did not correlate with age. In addition to DLI, factors such as lens dimensions and anterior chamber assessment, are required for considering any lens-based procedure”. (Nguyen P & Chopra V, 2013). “An inverse significant correlation was also found between DLI and opacity grade. Lower DLI values are associated with higher root-mean-square values of higher order aberrations, as increased higher order aberrations appear in visual-deteriorated optical systems” (Applegate R A et al., 2003; Rocha K M et al., 2007; Lombardo M et al., 2010; Sachdev N et al., 2004)

**5. ROLE OF DYSFUNCTIONAL LENS INDEX IN REFRACTIVE LENS EXCHANGE**

“A prospective cross‑sectional study correlated DLI, visual quality, and lens density changes in presbyopes (40‑60 years) with best‑corrected distance and near visual acuity 20/20 and N6. This study assessed lens density clinically using the lens opacity classification system (LOCS III) and scheimpflug imaging (Pentacam HR; Oculus Optokgerate, Germany). I-Trace was used to assess DLI, Area under Curve for Modulation Transfer Function, Strehl’s ratio, and internal aberrations. They found a significant positive correlation of DLI with the Area under Curve for Modulation Transfer Function, and Strehl’s ratio, and a negative correlation with internal higher-order aberrations. Thereby, concluded that DLI is an indicator of visual quality. DLI correlated well with average lens density obtained from Pentacam Nucleus Staging but not with maximum density and clinical LOCS III grading. Hence, we should focus on average lens density changes in presbyopes to plan RLE rather than clinical changes. (Kaweri L et al., 2020) Faria‑Correia *et al.* showed that a reduction in corrected distance visual acuity is strongly correlated with DLI than LOCS or Pentacam grading. “This proves that DLI is a reliable quality performance indicator of the crystalline lens. There are patients with best‑corrected distance and near visual acuity 20/20 and N6 who complain of reduced visual quality with normal acuity quantitatively” (Faria-Correia F et al., 2017) Patients who underwent corneal laser vision correction surgery in the past may complain that their correction has decreased as time proceeds. Though various aetiologies like exaggerated corneal epithelial healing response, stromal remodeling (Moshirfar M et al., 2018), cataract formation, progression, post laser vision correction corneal ectasia have been implicated as the pathogenesis in refractive regression, (Radhika Natarajan & Raj S Paul, 2020) one of the most important etiology can be an increase in internal higher-order aberrations due to a dysfunctional lens.(Lombardo M & Lombardo G, 2010; Sachdev N et al., 2004) DLI is a tool that can be used as a biomarker for identifying and counseling patients having clear lenses but exhibiting symptoms of dysfunctional lens syndrome.

**6. ROLE OF DYSFUNCTIONAL LENS INDEX IN PHAKIC IOL IMPLANTATION**

One of the most widely-used types of Phakic IOL is the Implantable Collamer Lens (ICL; STAAR Surgical Inc., Monrovia, CA, USA). It’s model V4c with a 0.36-mm central hole has been gradually accepted for making iridectomies or iridotomies unnecessary and allowing for adequate aqueous flow physiologically through the anterior segment. (Igarashi A, Shimizu K & Kamiya K, 2014; Gomez-Bastar A et al., 2014) The ICL V4c was first implanted by Kimiya Shimizu in 2007. (Shimizu K et al., 2012) Hole ICL implantation offered favorable outcomes in all measures of safety, efficacy, predictability, and stability in middle-aged patients. (Igarashi A et al., 2022) ICL V4c incorporated a 0.36-mm central port, making iridotomies unnecessary and allowing adequate aqueous flow to avoid anterior subcapsular cataracts. (Montés-Micó R et al., 2021)

A study conducted by [Weifang Cao](https://pubmed.ncbi.nlm.nih.gov/?term=%22Cao%20W%22%5BAuthor%5D), et al., established the relationship between DLI and ICL implantation outcomes in eyes with myopia. This was the first study that found the preoperative and postoperative DLI values of patients with high myopia who underwent ICL surgery were significantly different, which was statistically significant. The DLI values improved post-ICL surgery, even though the surgery didn’t involve the crystalline lens. This is because the DLI is not only the indicator of the functional status of the crystalline lens but also the refractive state and visual quantification of the inner optical system. Through this process of research, they found that DLI is not only limited to the lens' function but overall internal ocular optics and explored its new meaning. The DLI is presented on a continuous scale, allowing a more precise assessment for clinical and research purposes. (Cao W et. al., 2023)

**7. ROLE OF DYSFUNCTIONAL LENS INDEX IN CATARACT SURGERY**

Cataract is a leading cause of reversible visual impairment and blindness globally. Early detection of cataracts is critical for effective management and prevention of vision loss. Traditional methods for cataract diagnosis, including visual acuity testing, pinhole testing, and slit-lamp examination, are foundational but limited in detecting early lens changes. The pinhole test is effective for refractive errors but less reliable for early cataracts. The DLI, in the iTrace aberrometer system, provides a quantitative and objective measure of lens performance. (El-Haddad M. and Nguyen T., 2023; Patel A. et al., 2022; Carter J R and Singh A., 2023; Lewis S et al., 2022)

The previous studies demonstrated correlations between the DLI and LOCS III score, which was a subjective assessment, and Scheimpflug-based average lens density which was an objective assessment *(*Faria-Correia F et al., 2016; *Li Z. et al., 2019) “*Both the quantification parameters derived from Scheimpflug densitometry and the functional status of the crystalline lens based on ray-tracing aberrometry in eyes with mild nuclear cataracts might help in preoperative counseling and patient education” *(*Faria-Correia F. et al., 2016*) “*Some studies reported sensitivity and specificity values of 83.6% and 72.4%, respectively for DLI value < 5 in early cataract detection, but a Moroccan cohort study, demonstrated 100% sensitivity for DLI value < 5 in detecting cataracts at early stages” (Rifay Y., 2025) “Though traditional methods such as slit-lamp examination remain the gold standard for cataract diagnosis, they rely on subjective clinical expertise and may miss early-stage changes” (Browning C.J. et al., 2023) “The DLI offers a quantitative, objective approach and complements these methods. The Moroccan cohort study also addressed the challenges such as variability in DLI due to axial length and keratoconus which becomes erroneously high due to induced aberrations despite a normally functioning lens”. (Prasad N. et al., 2023; Singh, M., et al., 2022) Furthermore, a study reported that the DLI was also useful for the phacoemulsification dynamics prediction in terms of cumulative dissipated energy in age-related nuclear cataracts, even better than Scheimpflug-derived density and LOCS III opalescence (Faria-Correia F et al., 2017)

**8. CONCLUSION**

DLI in i-Trace aberrometer is an objective indicator of the lenticular quality of vision in presbyopia, for identifying and counseling patients with clinically clear lenses but dysfunctional. DLI can complement other diagnostic measurements, to assess lens function. Opacity grade does not serve as an accurate indicator. Very few studies were done on this parameter and its role in refractive-cataract surgery. The limitations of the above-reviewed study were the cross‑sectional nature, lack of modest sample size, and lack of long‑term follow‑up to see DLI changes. Also, these studies didn’t consider the age-related changes in the anterior segment other than lenticular changes. The algorithms used by the aberrometer calculate DLI taking pupil diameter and other factors causing internal and ocular higher-order aberrations in addition to lenticular factors. Furthermore, studies of prospective nature with larger number of patients, avoiding selection bias and including other factors causing aberrations are recommended to evaluate the potential of DLI.

**DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

I declare that no generative AI technologies and text-to-image generators have been used during the writing or editing of this manuscript.

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Abbreviations

LASIK- Laser Assisted Insitu Keratomileusis

PRK- Photorefractive Keratectomy

smile- Small Incisional Lenticule Extraction

dls- Dysfunctional Lens Syndrome

dli- Dysfunctional Lens Index

RSBT- Residual Stromal Bed Thickness

RLE- Refractive Lens Exchange

MF- Multifocal IOLs

EDOF- Extended Depth of Focus iol

ACD- Anterior Chamber Depth

WTW- White-To-White Distance

LOCS- Lens Opacity Classification System

ICL- Implantable Collamer Lens