RESEARCH PAPER

Comparative Analysis of Corneal Densitometry, Higher-Order Aberrations, and Biomechanical Indices (CBI & TBI) in LASIK and SMILE

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Received: 2nd Mar, 2026 | **Revised:** 14th Mar, 2026 | **Accepted:** 4th Apr, 2026 | **Available Online:** 20th Apr, 2026

ABSTRACT

Purpose: To evaluate postoperative changes in corneal densitometry, higher-order aberrations (HOA), and corneal biomechanics, including the Corvis Biomechanical Index (CBI) and Tomographic Biomechanical Index (TBI), in patients undergoing laser-assisted in situ keratomileusis (LASIK) or small incision lenticule extraction (SMILE).

Methods: In this prospective, comparative study, 120 eyes from 60 patients were randomly assigned to LASIK or SMILE groups. Corneal densitometry and HOA were measured using the Pentacam HR, while CBI and TBI were assessed with the Corvis ST at baseline, and at 1 and 6 months postoperatively. Paired and two-sample t-tests were used to analyze intra- and intergroup differences, with significance set at $p < 0.05$.

Results: SMILE resulted in a significant increase in corneal densitometry (mean change: +2.6 ± 0.7; $p = 0.015$), whereas LASIK showed no significant change ($p > 0.05$). HOA increased significantly in both groups (LASIK: $p = 0.005$; SMILE: $p = 0.0238$). Although CBI and TBI values increased in both procedures, these changes did not reach statistical significance.

Conclusions: SMILE was associated with increased densitometry and lower HOA induction, indicating better preservation of optical quality. LASIK yielded greater CDVA improvement and maintained stable densitometry but induced more HOA. Both techniques demonstrated trends toward biomechanical weakening, underscoring the need for comprehensive preoperative assessment to guide individualized surgical planning.

Keywords: LASIK, SMILE, Corneal Densitometry, Higher-Order Aberrations, Corneal Biomechanics, CBI, TBI.

How to cite this article: Anand P, Prajapat MK, Koul A. Comparative Analysis of Corneal Densitometry, Higher-Order Aberrations, and Biomechanical Indices (CBI & TBI) in LASIK and SMILE. Int J Drug Deliv Technol. 2026;16(33s):858-865. DOI: 10.25258/ijddt.16.33s.102

Source of support: Nil.

Conflict of interest: The authors declare no conflict of interest.

Introduction

Refractive surgery has advanced significantly, with LASIK and SMILE established as primary methods for myopia correction. LASIK utilizes a microkeratome or femtosecond laser to create a hinged corneal flap, exposing the stromal layer for precise excimer laser ablation to achieve desired refractive outcomes. In contrast, SMILE is a minimally invasive, flapless technique that involves extracting a refractive lenticule through a small incision, thereby reducing the extent of stromal disruption and potentially minimizing wound-related complications. [1,2]

Although both techniques achieve good visual outcomes, their impacts on corneal biomechanics, optical quality parameters such as higher-order aberrations, and overall structural integrity required detailed evaluation.[3,4] In particular, assessing corneal densitometry provides insight into wound healing and subclinical haze formation related to keratocyte activation of corneal tissue following refractive surgery. The Pentacam HR generates tomographic and densitometric analyses, whereas the Corvis ST evaluates dynamic biomechanical properties, enabling the computation of indices such as CBI and TBI.[5,6]

This research seeks to evaluate LASIK and SMILE by examining the changes in corneal densitometry, encompassing light scattering and wound healing processes, Higher-order aberrations (HOA) influencing optical quality, Biomechanical indices, specifically CBI and TBI, reflecting corneal strength. The study focuses on assessing postoperative changes in these metrics over a six-month period to identify the procedure that more effectively maintains corneal integrity.

Material and Methods

Sample Size and Outcomes: The sample size of 120 eyes (60 patients) was determined based on an a priori power analysis assuming an expected difference of 0.1 logMAR in CDVA between LASIK and SMILE, with $\alpha = 0.05$ and 80% power. Primary outcome measure: CDVA. Secondary outcomes: corneal densitometry, HOA, and biomechanical indices (CBI, TBI). These were chosen to provide a comprehensive evaluation of both optical and biomechanical effects post-refractive surgery.

This prospective comparative study involved 60 patients of 120 eyes, equally divided into two groups, who underwent either SMILE or LASIK procedures. Participants met the following inclusion criteria: ages between 18 and 40 years, myopia and myopic astigmatism ranging from −1.00D to −10.00D, stable refraction for a minimum of one year, and no prior history of ocular disease or surgery. Exclusion criteria encompassed the presence of keratoconus or risk factors for ectasia, severe dry eye symptoms, and systemic conditions that could adversely affect the healing process.

The study utilized distinct surgical techniques for LASIK and SMILE procedures, highlighting the role of advanced technology and meticulous execution in achieving superior refractive results. For SMILE, the VisuMax femtosecond laser system (Carl Zeiss Meditec) was used to create an intrastromal refractive lenticule, which was then extracted through a minimal incision of 2-4 mm. Parameters such as cap thickness and lenticule diameter were standardized to ensure consistency. In the LASIK group, a corneal flap with a thickness ranging from 90 to 120 microns was created using femtosecond laser technology, followed by stromal ablation with the Wavelight EX500 excimer laser. This flap-based technique enables precise tissue removal for refractive correction.

Measurements of corneal densitometry and higher-order aberrations were obtained with the Pentacam HR, and corneal biomechanical properties (via CBI and TBI) were measured using the Corvis ST, both preoperatively and at 1-month and 6-month postoperative intervals. Paired t-tests were performed for within-group comparisons, and two-sample t-tests were used for between-group comparisons, with a significance threshold set at $p<0.05$.[6]

Ethical approval for the study was obtained from the Institutional Ethics Committee, and informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

Results

This study evaluates Postoperative outcomes at 1-month and 6-months, focusing on changes in Corrected Distance Visual Acuity [CDVA], Corneal Densitometry [CD], Higher-Order Aberrations [HOA], and the corneal biomechanical indices: Corvis Biomechanical Index [CBI] and Tomographic Biomechanical Index [TBI] (see Table 1).

Postoperative CDVA improved in both groups, although the improvement reached statistical significance only in the LASIK group. In LASIK patients, CDVA decreased from a preoperative mean of 0.01188 ± 0.0326 to 0.005 ± 0.021978 at both 1 and 6 months postoperatively ($p = 0.005$), indicating enhanced visual acuity. The SMILE group also showed an improvement from 0.01133 ± 0.01440 to 0.0033 ± 0.0081, but the change was not statistically significant ($p = 0.081$) (see Fig.1).

Significant changes in corneal densitometry were observed predominantly in the SMILE group. Mean densitometry values increased from a baseline of 14.77333 ± 1.2133 to 15.2845 ± 1.1636 at 6 months post-op, reflecting a statistically significant increase ($p = 0.015$). This suggests enhanced stromal remodeling and keratocyte activity, likely leading to increased light scatter. In contrast, the LASIK group exhibited no significant change in densitometry, with values moving slightly from 14.8833 ± 1.491 to 14.8285 ± 1.2890 over the same period ($p = 0.7348$), suggesting that the flap-based LASIK procedure might preserve corneal clarity more effectively (see Fig.2).

A significant postoperative increase in HOA was noted in both surgical groups. For LASIK, mean HOA values rose from 0.41503 ± 0.1257 preoperatively to 0.7496 ±

0.3326 at 6 months post-op (*p = 0.005*). Similarly, SMILE patients experienced an increase from 0.38893 ± 0.0893 to 0.6590 ± 0.2938 (*p = 0.0238*). While both groups exhibited degradation in optical quality due to increased aberrations, the increase was slightly less pronounced in the SMILE group, reflecting its advantage in preserving anterior corneal structure due to the absence of flap creation (see Fig.3).

Corneal biomechanical changes, as measured by CBI and TBI, showed a general upward trend in both groups, reflecting biomechanical weakening after surgery. However, these changes did not reach statistical significance within the 6-month follow-up period.

- CBI in the LASIK group rose from **0.18133 ± 0.21567** to **0.1933 ± 0.2667** (*p = 0.8133*), while the SMILE group increased from **0.0825 ± 0.1977** to **0.7866 ± 0.2562** (*p = 0.2488*). (see Fig.4)

- TBI followed a similar trend: LASIK increased from **0.18766 ± 0.22042** to **0.2392 ± 0.2592** (*p = 0.6596*), and SMILE from **0.1976 ± 0.1826** to **0.2554 ± 0.2488** (*p = 0.5778*). (see Fig. 5)

These results suggest that both LASIK and SMILE result in measurable biomechanical weakening of the cornea, though the degree and clinical relevance of this weakening require further investigation in long-term studies. SMILE demonstrated a trend toward better biomechanical preservation, aligning with its flapless technique, but the differences were not statistically significant within the study duration.

In summary, SMILE led to a significant increase in corneal densitometry and a moderate increase in HOA, while maintaining relatively better biomechanical integrity. LASIK, on the other hand, showed significant improvement in visual acuity and less increase in densitometry, but induced more HOA and biomechanical weakening. These findings highlight trade-offs between optical quality and biomechanical preservation, with neither technique being superior in all evaluated aspects.

Discussion

Interpretation of Findings: While SMILE demonstrated increased densitometry (suggestive of subtle haze), it also induced fewer HOAs than LASIK. This indicates that densitometry changes may reflect stromal remodeling that does not directly impair optical quality. Meanwhile, LASIK produced statistically significant CDVA improvement, though preoperative values were already excellent (0.01 logMAR). Thus, the clinical significance of this improvement is limited. We emphasize that both procedures offer trade-offs, with SMILE favoring biomechanical preservation and LASIK favoring short-term visual recovery.

In this study, corneal densitometry significantly increased in the SMILE group (p = 0.015), suggesting heightened stromal remodeling and keratocyte activation. These findings are consistent with previous studies that have reported increased light scatter following SMILE due to subtle wound healing responses and extracellular matrix changes in the posterior stroma.[7,8] Conversely, LASIK showed no significant change in densitometry values ($p > 0.05$), indicating that its flap-based approach while disrupting the anterior corneal layer minimizes deeper stromal alteration and better preserves corneal transparency.[9,10] This difference has important clinical relevance, as excessive densitometry may correlate with transient haze and delayed visual clarity.

Both LASIK and SMILE were associated with significant postoperative increases in HOA. However, the increase was more pronounced in the LASIK group. The likely cause is the creation of a corneal flap, which introduces anterior surface irregularities and optical distortions. [13,14] In contrast, SMILE being a flapless procedure better preserves the anterior corneal curvature, leading to fewer induced aberrations. [15,16] These findings reinforce the evidence that SMILE may offer superior visual quality in low-light conditions by minimizing HOA-related symptoms such as halos and glare. [17,18]

Postoperative biomechanical indices (CBI and TBI) exhibited an upward trend in both groups, indicating some degree of corneal biomechanical weakening. However, these changes did not reach statistical significance in this study's 6-month follow-up. This aligns with literature noting that while both procedures impact corneal integrity, LASIK tends to produce greater weakening due to flap creation and anterior stromal disruption. [19–21] SMILE, by preserving more of the anterior stromal architecture, may offer better biomechanical resilience. [22,23] Nevertheless, the absence of statistically significant findings here may be due to limited follow-up duration or the sensitivity of current biomechanical assessment tools. It is recommended that future studies employ advanced modalities like Brillouin imaging or ultra-high-speed Scheimpflug analysis for more nuanced detection.

Limitations of Biomechanical Assessment: Although CBI and TBI were included as biomechanical indices, these tools were originally developed for keratoconus screening and may not be optimal for detecting subtle post-refractive biomechanical changes. Parameters like SP-A1, DA ratio, or IR may offer more sensitive assessment and should be incorporated in future research. The findings suggest that surgical selection should be guided by individual patient needs:

- SMILE may be preferable for patients prioritizing long-term visual quality and biomechanical preservation, as it induces fewer aberrations and may better maintain corneal strength.
- LASIK remains advantageous for patients seeking faster recovery and superior short-term CDVA outcomes, given its more predictable ablation profile and less densitometric alteration.

Importantly, neither procedure fully prevents biomechanical compromise. This underscores the necessity of comprehensive preoperative evaluation—including CBI and TBI—to identify patients at elevated risk for postoperative ectasia, especially those with borderline pachymetry or abnormal topography. [24–26]

Conclusion

This study demonstrates that both LASIK and SMILE produce significant postoperative alterations in corneal optical and biomechanical properties. SMILE results in increased densitometry and a more moderate rise in HOA, while providing a trend toward superior biomechanical preservation. LASIK, on the other hand, achieves greater improvement in corrected distance visual acuity and maintains stable densitometry but induces more HOA and biomechanical changes. These findings highlight the need for personalized surgical planning based on anatomical, biomechanical, and visual quality considerations. Further studies with extended follow-up and more sensitive biomechanical markers are essential to refine patient selection criteria and optimize long-term refractive outcomes.

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Figures & Tables

Table 1: Pre-Operative Parameters

Parameter	LASIK (Mean ± SD)	SMILE (Mean ± SD)	P-value (t-test)
Age (years)	27.2 ± 5.4	27.83 ± 2.815	~0.28 (p > 0.05)
Pre-op Sphere (Sph)	-3.8667 ± 2.6487	-3.725 ± 1.4982	~0.67 (p > 0.05)
Pre-op Cylinder (Cyl)	-1.666 ± –1.6542	-0.9416 ± –0.8762	~0.10 (p > 0.05)
Pre-op SE	-4.5923 ± 2.7376	-4.6083 ± 2.238	~0.98 (p > 0.05)
Thinnest Pachymetry (µm)	535.35 ± 26.9826	545.87 ± 25.9528	~0.19 (p > 0.05)
Ablation Depth/ Lenticule Thickness	68.1805 ± 26.2789	93.4 ± 23.225	**< 0.01**
CDVA	0.01188 ± 0.0326	0.01133 ± 0.0440	~0.90 (p > 0.05)
Pre-operative HOA	0.41503 ± 0.1257	0.3893 ± 0.0893	~0.29 (p > 0.05)
Pre-operative CD	14.8833 ± 1.491	14.7733 ± 1.2133	~0.57 (p > 0.05)
Mean Keratometry	43.80166 ± 1.335429	44.1016 ± 1.282	~0.30 (p > 0.05)
CBI	0.18133 ± 0.21567	0.0825 ± 0.1977	**~0.04** (p < 0.05)
TBI	0.18766 ± 0.22042	0.1976 ± 0.1826	~0.79 (p > 0.05)

Table 2. Preoperative vs Postoperative Changes in CDVA, Corneal Densitometry, HOA, CBI, and TBI in LASIK Group

Parameter	Pre-op	Post-op (1 mo)	Post-op (6 mo)	P-value
CDVA	0.01188 ± 0.0326	0.005 ± 0.021978	0.005 ± 0.021978	0.005

HOA	0.41503 ± 0.1257	0.75870 ± 0.3366	0.7496 ± 0.3326	0.005
CD	14.8833 ± 1.491	14.4321 ± 1.422294	14.8285 ± 1.2890	0.7348
CBI	0.18133 ± 0.21567	0.2567 ± 0.2293	0.1933 ± 0.2667	0.8133
TBI	0.18766 ± 0.22042	0.2596 ± 0.2325	0.2392 ± 0.2592	0.6596

Table 3. Preoperative vs Postoperative Changes in CDVA, Corneal Densitometry, HOA, CBI, and TBI in SMILE Group

Parameter	Pre-op (Mean ± SD)	Post-op 1 Month	Post-op 6 Months	P-value
CDVA	0.01133 ± 0.01440	0.0033 ± 0.0081	0.0033 ± 0.0081	0.081
HOA	0.38893 ± 0.0893	0.6419 ± 0.3085	0.6590 ± 0.2938	0.0238
Corneal Densitometry	14.77333 ± 1.2133	14.7865 ± 1.0549	15.2845 ± 1.1636	0.0877
CBI	0.0825 ± 0.1977	0.8473 ± 0.3552	0.7866 ± 0.2562	0.2488
TBI	0.1976 ± 0.1826	0.2554 ± 0.2488	0.2554 ± 0.2488	0.5778

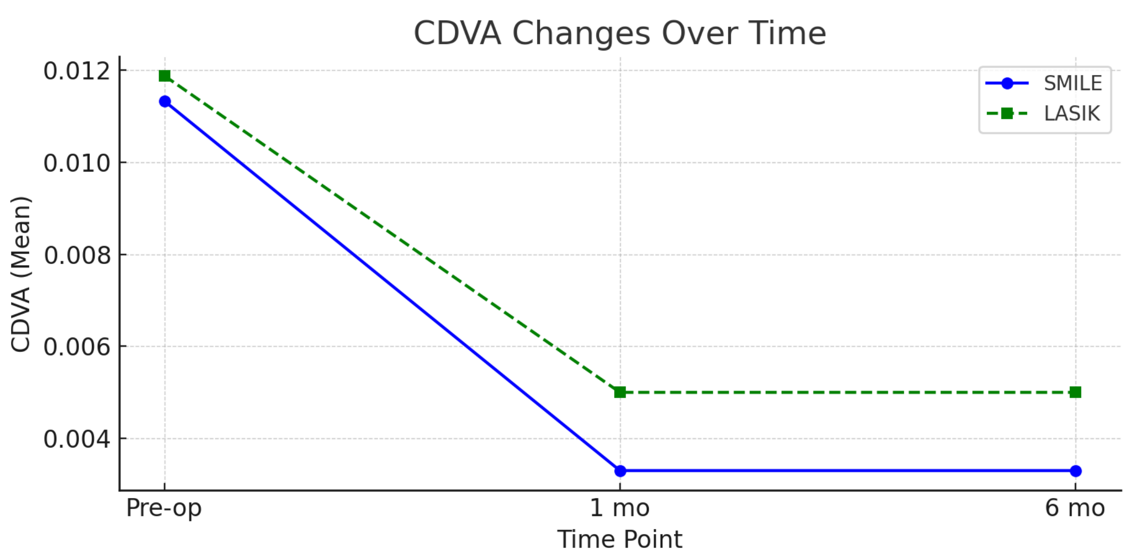

Figure 1 Pre-operative and Post-Operative Change in the Corrected Distance Visual Acuity between LASIK and SMILE Group

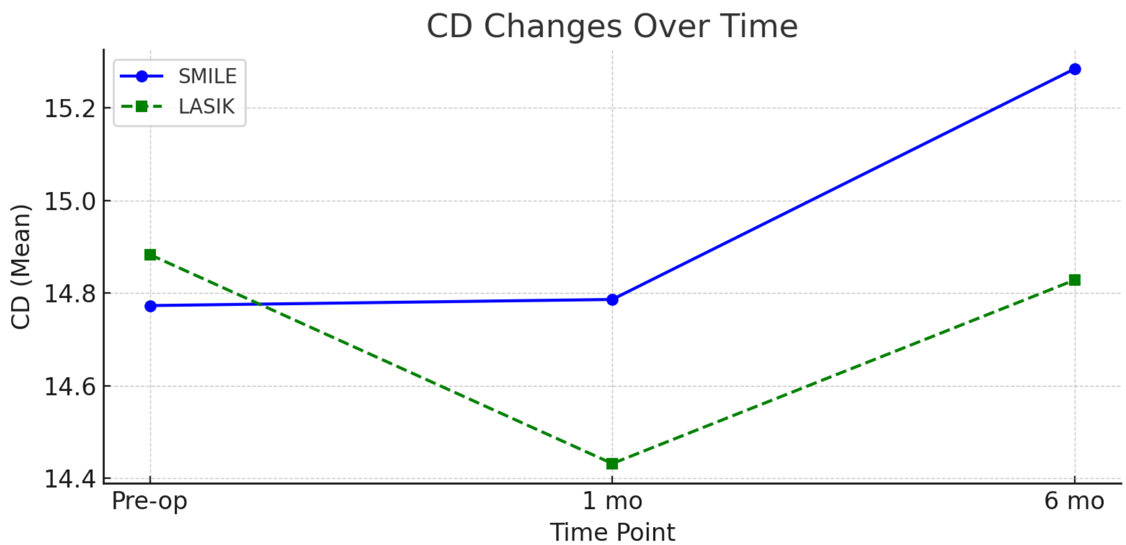

Figure 2 Pre-operative and Post-Operative Change in the Corneal Densitometry between LASIK and SMILE Group

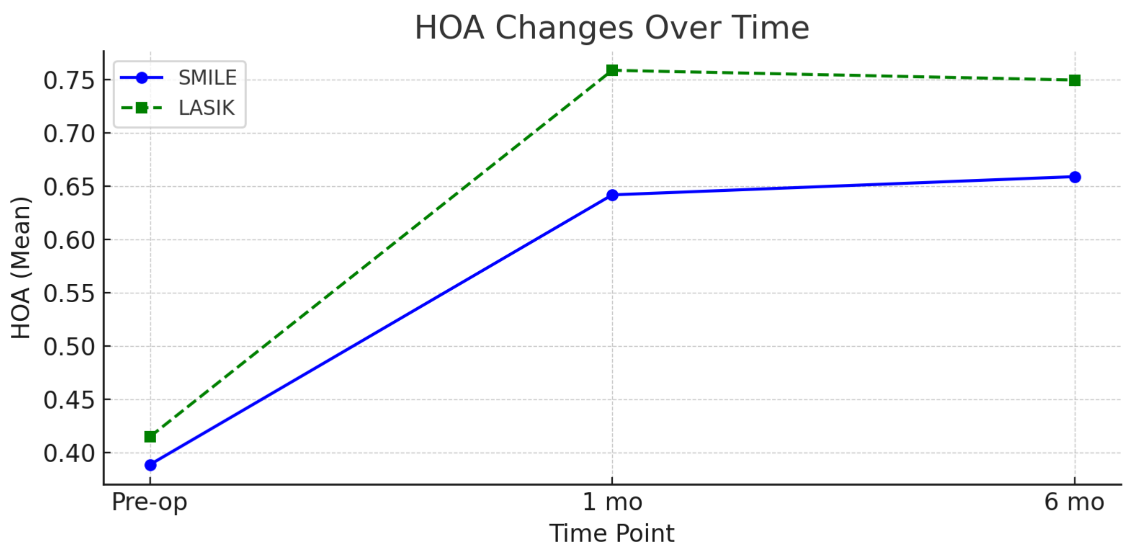

Figure 3: Pre-operative and Post-Operative Change in the HOAs between LASIK and SMILE Group

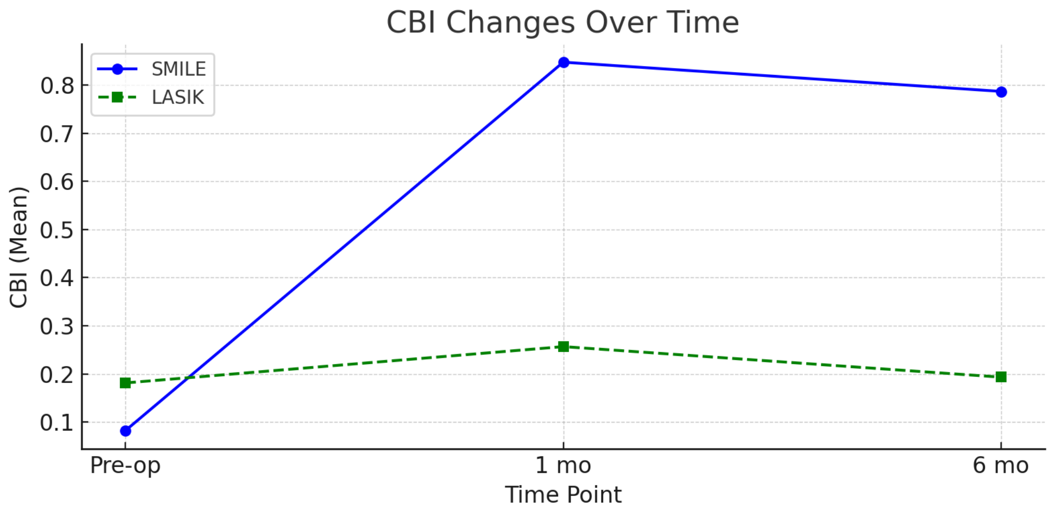

Figure 4: Pre-operative and Post-Operative Change in the Corvis Biomechanical Index between LASIK and SMILE Group

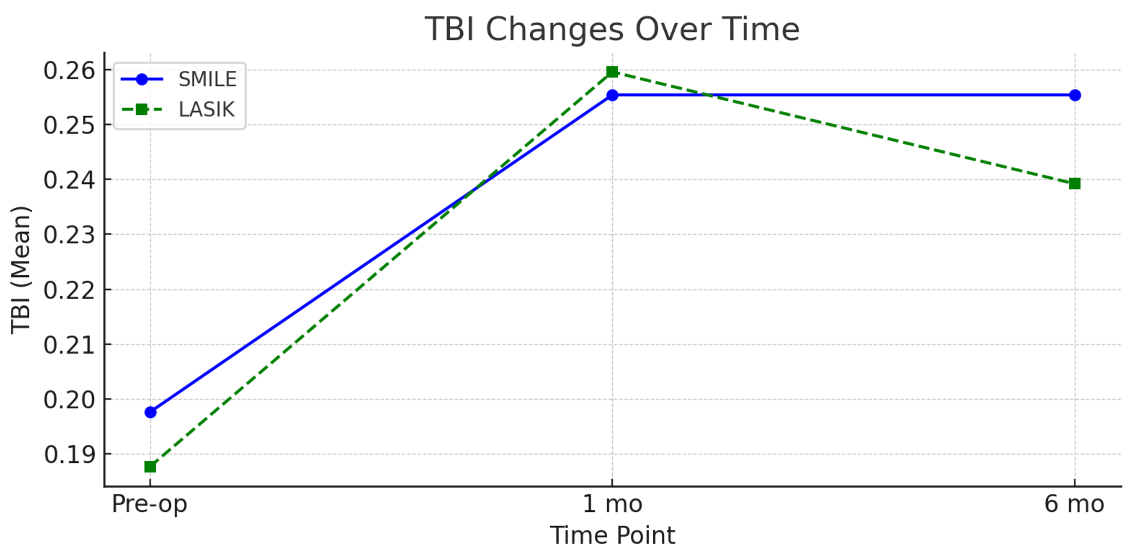

Figure 5: Pre-operative and Post-Operative Change in the TBI