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ORIGINAL PAPER

Vector Analysis of Visual Acuity and Refractive Outcomes of Astigmatic Corrections After T-PRK and Fs-LASIK

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ABSTRACT

Introduction: T Transepithelial photorefractive keratectomy (T-PRK) and femtosecond laser in situ keratomileusis (Fs-LASIK) are reftactive surgery methods for treating myopia and myopic astigmatism. Although T-PRK obtains similar results to Fs-LASIK with spherical myopia, it has differences in astigmatism correction. Vector analysis is a perfect tool to see the real difference between these two methods regarding astigmatic refraction and visual acuity.**Aim:** The aim of the study is to investigate changes in astigmatism and visual acuity following treatment of myopia and myopic astigmatism above -5.00DS and up to -2.00DC after either T-PRK or Fs-LASIK. **Methods:** Patients (30 eyes per group) underwent unremarkable T-PRK (group I) or Fs-LASIK (group II) using Schwind Amaris 750S laser. Astigmatic data acquired by subjective refraction were subjected to vector analysis to determine the association between surgically (SIA) and target induced (TIA) astigmatic powers and differences in axes(θ). **Results:** Key results at 6 months were: i) Mean astigmatism changed from -0.92 DC (sd ±0.49,95%CI-1.10to-0.75) to -0.38 DC (sd ±0.40,95% CI-0.52 to -0.24) in group I and -0.93DC (sd±0.55,95%CI -1.07 to -0.67) to -0.14DC (sd±0.31,95% CI-0.25 to -0.03) in group II (P=0.005 at 6 months). ii) Mean (±sd) θ was +9.7° (±19.0°) in group I and -2.2° (±15.5°) in group II (P=0.005).**Conclusion**: There was a greater mismatch between SIA and TIA powers and axes after T-PRK. T-PRK tends to induce more unwanted astigmatism. The predictability of the refractive and optical changes is better following Fs-LASIK.

Key words: Cornea, Astigmatism, Surgery, Visual acuity.

1. INTRODUCTION

Transepithelial photorefractive keratectomy (T-PRK) is regarded as a safe, efficacious, procedure for correcting myopia and myopic astigmatism (1-6). In this procedure, the corneal epithelium is removed by photo-ablation, and this is regarded as a less painful more efficient procedure compared with the more traditional techniques involving either manual scraping or alcohol rub associated with PRK (1-3,5-9). More precise hands-free control over the removal of the epithelium coupled with more sophisticated tracking systems, and ablation beam profiles, should lead to better optical and refractive outcomes after T-PRK. It has been claimed, T-PRK leads to better visual outcomes compared with LASIK. However, residual astigmatism can still be encountered following complication-free T-PRK(4,5,10,11). The introduction of femtosecond lasers for creating the flap during LASIK has reduced the incidence of complications during, and after, LASIK. Femtosecond assisted laser in situ keratomileusis (Fs-LASIK) is more predictable compared with LASIK (6). Therefore, Fs-LASIK is expected to produce better optical and refractive outcomes compared with more traditional LASIK. The efficacy and safety of both Fs-LASIK and T-PRK procedures have been reported by many groups. Other than studies by Ghadfan et al. (1), Luger et al. (2) and Aslanides et al. (3), there is a paucity of longitudinal studies directly comparing the outcomes of T-PRK with Fs-LASIK for, unexpected residual astigmatism.

2. AIM

This study aimed to compare, and contrast, the changes in the magnitude and orientation of astigmatism after routine uncomplicated T-PRK and Fs-LASIK.

3. METHODS

Patient population

This was a retrospective observational case-control study based on 30 patients that underwent T-PRK and 30 that underwent Fs-LASIK. All surgical procedures were performed with the Schwind Amaris 750S excimer laser on patients with moderate to high myopia or myopic astigmatism at University Eye Hospital Svjetlost, Zagreb Croatia, between January 2016 and January 2017. The inclusion criteria were: preop refractive error between -5.00DS and -7.00DS with astigmatism no greater than -2.00DC and no previous history of either refractive surgery or anterior segment conditions known to affect the outcome of any corneal refractive procedure. Follow-up time of 6 months with full refractive data are available. All patients gave their informed consent by the tenets of the Declaration of Helsinki. .

Clinical Examination

Complete preoperative ophthalmological examinations were performed. Visual acuity was measured using a standard Snellen acuity chart at 6m and presented in decimal format. Patients were directed to discontinue contact lens wear for up to 4 weeks depending on the type of lenses.

Postoperative examinations

All eyes were checked at the slit lamp at all postop visits. In T-PRK cases checks were made to ensure that the bandage contact lens was in position and to remind the patients to follow the postoperative protocol. Patients receiving Fs-LASIK were examined after 1 day and 1 week, and those receiving T- PRK after 1, 4 days (depending on the epithelial healing and when the contact lens was removed) and 1 week. Thereafter, follow-up visits were scheduled for 1, 3, and 6 months.

Data and Statistical Analysis

Data were entered on Microsoft office excel 2007 spread sheet for statistical analysis and separated into two groups as follows: Group 1, myopia and myopic astigmatism treated with T-PRK; Group 2, myopia and myopic astigmatism treated with Fs-LASIK.

Data were analyzed to determine the significance of changes in the uncorrected distance visual acuity (UDVA), corrected visual acuity (CDVA), spherical correction, astigmatism, within each group and between groups. The t-test, 2 sample assuming unequal variances, was applied when data were normally distributed. Appropriate non-parametric tests were applied when data were not normally distributed. Changes and differences were considered statistically significant when P▮0.05. Astigmatic data were subjected to vector analysis using the methods proposed by Thibos et al. (12) and Alpins (13). The former requires the calculation of J0 and J45 vectors as described fully in our previous work. The latter requires the calculation of the surgically induced astigmatism (SIA) using the target induced astigmatism (TIA) and the astigmatic component of residual refractive error. The TIA is zero when the correction is purely spherical and SIA equals TIA when the residual refractive error is either plano or purely spherical. We also calculated the difference (Δθ) between the angles of TIA and SIA, sometimes referred to as the angle of error. This would indicate if there was a systematic misorientation as a source of any unexpected residual astigmatism.

The data were further analyzed as follows: 1.) to determine the correlation between the change (ΔJ) in each astigmatic vector (J0 and J45) and pretreatment astigmatic vector value within each of the two groups (Pearson correlation), and to estimate the significance of any intergroup differences in the correlation coefficients (Fischer's 'r' to 'z' transformation); 2.) to determine the correlation between ΔC (the difference between TIA and SIA powers) and the TIA within each of the two groups (Pearson correlation), and to estimate the significance of any intergroup differences in the correlation coefficients (Fischer's 'r' to 'z' transformation); 3.) to determine the correlation between individual pairs of the Δθ values and the TIA angle within each of the two groups (Pearson correlation), and to estimate the significance of any intergroup differences in the correlation coefficients (Fischer's 'r' to 'z' transformation). The significance level was initially set at $P<0.05$. This was adjusted to $P<0.009$ using the Bonferroni correction for the number of parameters under consideration.

4. RESULTS

Thirty patients underwent T-PRK and 30 patients underwent the Fs-LASIK (30 right eyes in bilateral cases). No major complications associated with surgery were encountered. This paper is centered on the refractive outcomes as noted from the outset. A summary of the main results of refraction are shown in table 1.

4.1. VISUAL ACUITY

In the T-PRK group, there was a significant ($P<0.001$) improvement in postoperative UDVA and CDVA. UDVA improved from a mean of 0.031 (sd ±0.019, 95% CI 0.023 to 0.038) to 0.968 (sd, ±0.118, 95% CI 0.952 to 0.985) and CDVA improved from a mean of 0.933 (sd ±0.036, 95% CI 0.920 to 0.946) to 0.981 (sd ±0.036, 95% CI 0.968 to

T-PRK				
	Pre-op	1 month	3 months	6 months
Sphere (D)	-5.89(0.60) -6.11, -5.68	-0.11(.55) -0.31, 0.09	-0.33(0.51) -0.52, -0.15	-0.38(0.38) -0.52, -0.24
Cylinder (D)	-0.92(0.49) -1.10, -0.75	-0.67(0.58) -0.88, -0.46	-0.47(0.50) -0.65, -0.29	-0.38(0.40) -0.52, -0.24
Axis (°)	86.1(71.1) 60.6, 111.5	104(60.1) 82.5, 125.5	96.6(63.6) 73.8, 119.4	93.9(64.8) 70.7, 117.1
Fs-LASIK				
	Pre-op	1 month	3 months	6 months
Sphere (D)	-5.75(0.57) -5.95, -5.55	-0.55(0.35) -0.68, -0.43	-0.42(0.28) -0.52, -0.32	-0.22(0.24) -0.31, -0.13
Cylinder (D)	-0.93(0.55) -1.07, -0.67	-0.21(0.28) -0.31, -0.11	-0.28(0.25) -0.37, -0.19	-0.14(0.31) -0.25, -0.03
Axis(°)	59.6(54.4) 40.1, 79.1	75.5(55.1) 55.8, 95.2	98.7(60.4) 77.1, 120.3.	104.4(47.9) 87.3, 121.5

Table 1. Mean values for the spherocylindrical refraction for the T-PRK and Fs-LASIK groups

	T-PRK	FS-LASIK
1-month J_0	ΔJ_0=0.257-1.644J_0, r=0.818	ΔJ_0=0.024-1.020J_0, r=0.936
1-month J_{45}	ΔJ_{45}=0.047-1.448J_{45}, r=0.894	ΔJ_{45}=-0.026-1.008J_{45}, r=0.943
3 months J_0	ΔJ_0=0.243-1.421J_0, r=0.853	ΔJ_0=0.060-1.113J_0, r=0.969
3 months J_{45}	ΔJ_{45}=0.069-1.139J_{45}, r=0.888	ΔJ_{45}=0.005-0.797J_{45}, r=0.800
6 months J_0	ΔJ_0=0.190-1.328J_0, r=0.902	ΔJ_0=-0.056-0.964J_0, r=0.953
6 months J_{45}	ΔJ_{45}=0.063-0.973J_{45}, r=0.875	ΔJ_{45}=-0.017-1.023J_{45}, r=0.913

Table 2. Change in J0 and J45 post-op vector values in cases treated with Trans epithelial PRK and Femtosecond LASIK procedure after 1,3 and 6 months

0.994) by 6 months postop. In the Fs-LASIK group, there was a significant (P<0.001) improvement in postoperative UDVA. This increased from a mean of 0.044 (sd ±0.028, 95% CI 0.034 to 0.054) to 0.980 (sd ±0.025, 95% CI 0.971 to 0.989) by 6 months postop. There was no significant change in postoperative CDVA in comparison to preop values. At 6 months postop mean CDVA = 0.983 (sd ±0.024, 95% CI 0.974 to 0.992, P=0.11). Comparing the two groups, there was no significant difference in UDVA and CDVA at either pre- or postop after applying the Bonferroni correction.

4.2. VECTOR ANALYSIS

The chief results of this analysis are shown in table 2 and figures 1 and 2.

Intergroup comparison of the J0 vector

In the T-PRK group mean (±sd) preop J0 vector was 0.323 (±0.264) and in the Fs-LASIK group, it was 0.190 (±0.399). The difference was not statistically significant (P=0.132). At 6 months postop, the mean J0 vector in the T-PRK group was 0.084 (±0.189) and in the Fs-LASIK group, it was -0.049 (±0.123). This difference was statistically significant (P=0.002). Intergroup differences at 1 and 3 months postop were not significant.

Comparing mean pre- with mean post-op J0 values within each group

In the T-PRK group there was a statistically significant fall in mean (±sd) J0 at 1 (J0=0.049, sd=±0.350, P=0.001), 3 (J0=0.102, sd=±0.255, P=0.002) and 6 (J0=0.084, sd=±0.189, P<0.001) months postop. In the Fs-LASIK group there was no significant change in mean J0 at 1 (J0=0.021, sd=±0.153, P=0.034) or 3 months (J0=0.039, sd=±0.255, P=0.085) postop. A significant change was found at 6 months postop (J0 =-0.049, sd=±0.123, P=0.003).

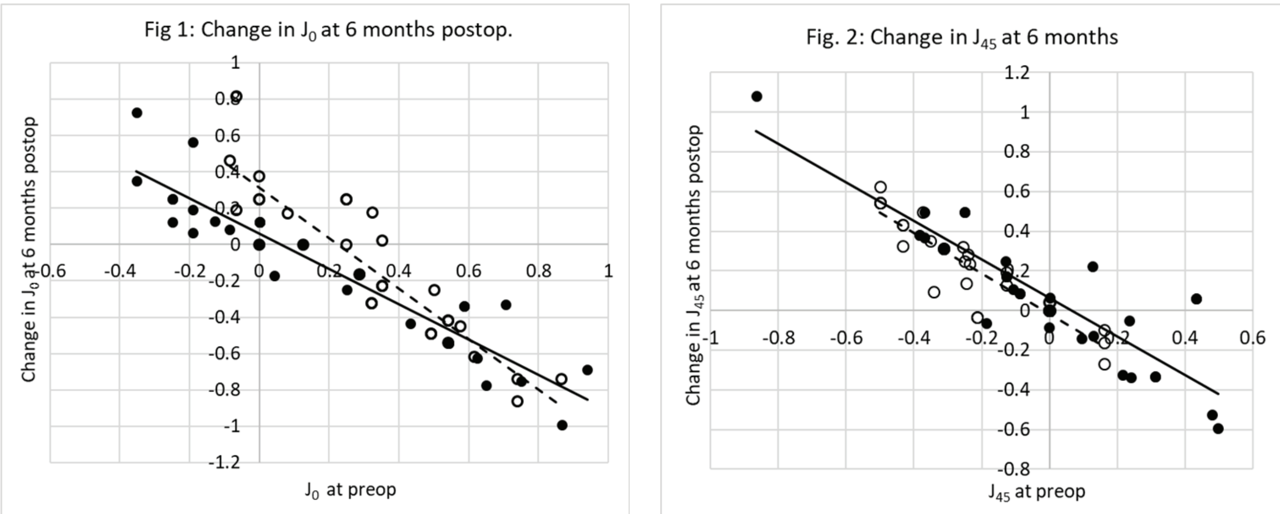

Figure 1. Change in J0 & J45 vector value in each case treated at 6 months postop.

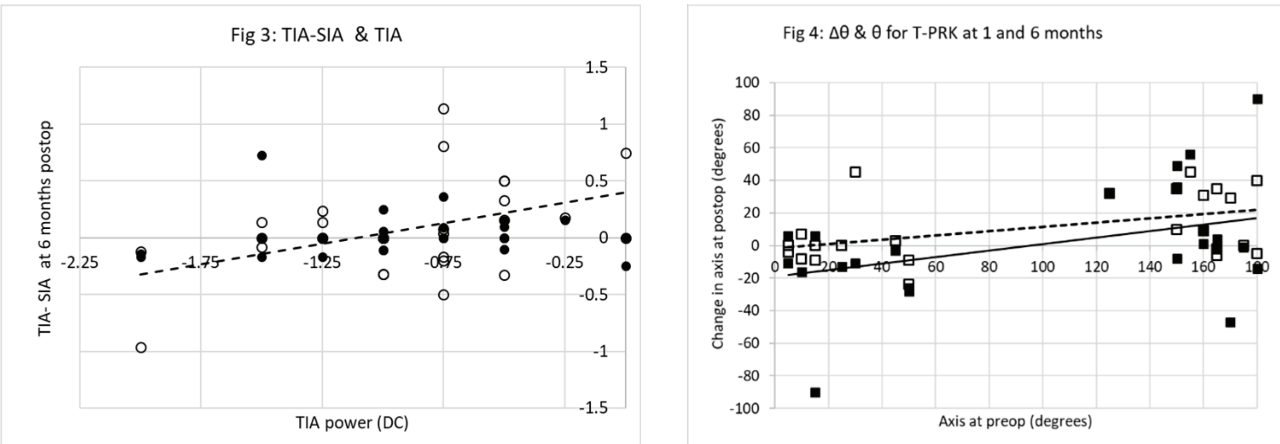

Figure 2. Difference beween target induced astigmatism (TIA) and surgically induced astigmatism (SIA) and preop target induced astigmatism at 6 months postop; and difference between TIA and SIA axes compared with TIA axis at 1 and 6 months postop for T-PRK cases.

Intergroup comparison of the J45 vector

In the T-PRK group, the mean (±sd) preop J45 vector was -0.018 (±0.315) and in the Fs-LASIK group, it was -0.214(±0.209). The difference was statistically significant (P =0.006). There were no significant differences between the two groups at 1,3 and 6 months postop.

Comparing mean pre- with mean postop J45 values within each group

There were no statistically significant differences between the pre- and postop J45 values in the T-PRK group. The mean (±sd) J45 values were 0.055(±0.269), 0.071(±0.191), 0.062(±0.170) at 1, 3 and 6 months postop respectively. The differences between the pre- and postop J45 values were significant in the Fs-LASIK group. The mean (±sd) J45 values were -0.024(sd=±0.071, P<0.001), -0.038(sd=±0.0132, P<0.001) and -0.012(sd=±0.096, P<0.001) at 1,3 and 6 months post respectively.

Correlation between i) ΔJ0 and preop J0 values, ii) ΔJ45 and preop J45 values

Significant associations were encountered between changes in each vector and preop vector values in both groups at 1, 3 and 6 months postop. The indices of the least-squares regression lines equating Δ J0 & preop J0 values, and Δ J45 & preop J45 values are shown in Table 2. Compared with the T-PRK group, the correlation coefficients in the Fs-LASIK group are closer to unity. The difference between matched pairs of correlation coefficients was significant only at 3 months post-op for the Δ J0 & preop J0 values (Z=-2.954, P=0.002) after applying the Bonferonni correction.

Comparing mean target and surgically induced astigmatism in each group

In the T-PRK group, mean (±sd) TIA was -0.92DC (±0.49) and the SIA was -1.30D (±0.75), -1.09D (±0.65) and -0.98D (±0.45) at 1, 3 and 6 months respectively. In the Fs-LASIK group, the respective values were -0.93DC (±0.50), -0.97DC (±0.45), -0.98DC (±0.50) and -0.94DC (±0.52). After applying the Bonferonni correction, there were no significant differences between mean TIA and SIA values in each group.

Correlation between ΔC and TIA values

The only significant associations between ΔC and TIA occurred at 1 (Fs-LASIK group) and 6 (T-PRK group) months postop. The least-squares regression lines equating ΔC and TIA were as follows:

T-PRK group at 6 months postop ΔC = 0.36TIA + 0.40 (R=0.442, N=30, P=0.007) eq.1

Fs-LASIK group at 1-month postop ΔC = 0.28TIA + 0.29 (R=0.461, N=30, P=0.005) eq.2

Intergroup comparison of the Δθ values

In the T-PRK group mean (±sd) Δθ values were -0.9° (±32.0°), -1.1° (±24.9°), 9.7° (±19.0°) at 1,3 and 6 months postop. And in the Fs-LASIK group, the values were -1.3° (±15.5°), 5.0° (±10.5°), -2.2° (±15.5°) at 1, 3 and 6 months postop. A negative Δθ value indicates an anti-clockwise rotational misorientation of the intended correction. Within each group, the changes in mean Δθ were deemed insignificant after applying the Bonferonni correction. Intergroup differences were significant only at 6 months postop (p=0.005).

Correlation between Δθ and target induced astigmatic axis (θ)

In the Fs-LASIK group, there was no significant association between Δθ and θ at any of the three postop periods. In the T-PRK group, a significant association was found at 1 and 6 months postop. The least-squares regression lines equating Δθ and θ were as follows:

At 1 month postop Δθ = 0.20θ − 19.14 (R =0.444, N=30, P=0.007) eq.3

At 6 months postop Δθ = 0.13θ − 1.50 (R =0.544, N=30, P<0.001) eq.4

5. DISCUSSION

Both procedures were safe and there was no loss of corrected distance visual acuity (CDVA). There was no significant difference in either means UDVA or CDVA between the two groups at 6 months postop. This was in keeping with the conclusions reached by others (6,18). However, compared with the preop value, there was an improvement in CDVA in the T-PRK cases but not in the Fs-LASIK cohort. Regarding astigmatism, there was no significant difference between the T-PRK and Fs-LASIK groups in the magnitude of sphero-cylindrical corrections before surgery. However, at six months postop there was a small, though significant, difference in the magnitude of mean astigmatism. There was significantly more unwanted astigmatism in the T-PRK group compared with the Fs-LASIK group. Vector analysis revealed there was no significant difference in mean values of J0 between the two groups at the preop stage. By 6 months postop the mean value J0 reduced in both groups but was still greater in the T-PRK group. Regarding the J45 vector, there was a significant difference between groups at preop but not at any point during the postop period. Within the T-PRK group, there was no change in the J45 but this was not the case in the Fs-LASIK group in which, the mean value J45 reduced towards zero by 6 months postop. Figure 1 , and the equations noted in table 2, indicate that changes in the value of J0 and J45 vectors can be predicted on a case-by-case basis. The equations indicate the levels of precision that can be attributed to the T-PRK and Fs-LASIK procedures. Nevertheless, the changes in the Fs-LASIK group are more predictable at 3 months postop, because the intergroup differences in the correlation coefficients for the J0 vector were highly significant (P=.002). Turning to eq 1, for a TIA of zero the magnitude of unwanted astigmatism after T-PRK is 0.40DC at 6 months postop. De Ortueta et al. (14) reported similar findings at 3 months postop. On average, the SIA encountered after traditional PRK ranges from 0.47 to 0.58D (19-21). The predicted residual astigmatism after T-PRK is slightly lower and, as noted in table 1, the actual mean astigmatism was -0.70DC at 1month post-op reducing to -0.40DC by 6 months. However, the indices of eqs 3 and 4 signal the relevance of the axis of the TIA correction. When the axis of the TIA is with-the-rule (WTR), eqs 3 and 4 predict the angle of error (Δθ) is 19° at 1-month postop reducing to less than 2° by 6 months postop. For an against-the-rule (ATR) TIA axis, Δθ shifts from 1° to 10° between 1 and 6 months postop. With time, Δθ reduces in WTR astigmatism but increases in ATR astigmatism. The dynamics and exact mechanism of epithelial regeneration may be the source of this difference between WTR and ATR cases. However, this is purely speculative. The majority of astigmatic corrections were WTR and any residual astigmatism prevalent at the 1-month post, due to the difference in the axis between TIA and SIA, which was expected to reduce by 3 months postop. However, in ATR cases residual astigmatism at 1-month postop is predicted to increase by 3 months. Jun et al. (13) proposed that a thinner preop epithelium was linked to a more predictable relationship between TIA and SIA. However, this does not explain the differences between eqs 3 and 4. Pokroy et al. (15) asserted that correcting astigmatism by T-PRK carries a high risk for an enhancement procedure. At 6 months postop we found seven (23%) of T-PRK cases and three (10%) of Fs-LASIK cases presented with astigmatism of -0.75DC or more. None opted for an enhancement. For the Fs-LASIK cases, eq 2 predicts the magnitude of residual astigmatism at 1-month postop is not expected to exceed 0.30DC. Furthermore, by 6 months postop the mean angle of error was -2.2° (±15.5°) implying there was a tendency towards a small anti-clockwise misorientation of the correction. However, in the T-PRK cases, the mean angle of error was +9.7° (±19.0°) suggestive of a clockwise misorientation of the correction. All treatments were performed using the same laser platform and data were harvested primarily from the right eyes. Nevertheless, the significant intergroup difference in mean angle of error at 6 months postop op is a signal pointing to intergroup differences in postoperative response. This gulf between the angles of error could be related to the very different modes of healing prevalent in T-PRK and Fs-LASIK. There may be an element of torque during the reconstruction of, and distribution of bulk within, the epithelium after T-PRK contributing to the angle of error that is not, or minimally, occurring present after Fs-LASIK. Luger et al. (2) showed that T-PRK and Fs-LASIK result in very similar postop refractive outcomes. Our results do not concur with their findings.

6. CONCLUSION

T-PRK can be described as quasi-robotic refractive surgery. Nevertheless, the refractive and optical outcomes are less predictable compared with Fs-LASIK. There is a greater risk of unwanted residual astigmatism, particularly in cases where the correction veers towards against-the-rule, and degradation of the overall optical quality of the eye after T-PRK compared with Fs-LASIK..

- **Author's Contribution:** All authors gave substantial contributions to the conception or design of the work in acquisition, analysis, or interpretation of data for the work, had a part in article preparing for drafting or revising it critically for important intellectual content, and gave final approval of the version to be published and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.
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