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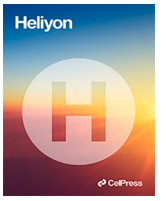

Implantation of a toric intraocular lens after repeated radial keratotomy procedures: A case report

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A B S T R A C T

Corneal alterations due to radial keratotomy (RK) complicate intraocular lens calculations, which may explain why there have been few reports of toric intraocular lens (TIOL) implantation after excessive or multiple operations. A 71-year-old male with a history of repeated RKs and at least 30 corneal incisions in each eye was referred for cataract surgery. Preoperatively, the best-corrected distance visual acuity was 0.7 decimal (0.15 logMAR) in the right eye and 0.9 decimal (0.05 logMAR) in the left eye. The refractive errors were −8.00 −3.00 × 80 and −6.00 −3.50 × 80, respectively. The total corneal cylindrical powers (real power; anterior and posterior) were, respectively, −0.90 D and −3.60 D at 9 a.m., compared to −1.60 D and −3.80 D at 1 p.m. Corneal astigmatism in the left eye was considered symmetric and diurnally stable; therefore, an XY1AT6 TIOL (Hoya, Tokyo, Japan; cylindrical power at the plane, +3.75 D) was implanted. A non-toric intraocular lens, the XY1 (Hoya), was implanted in the right eye. Six-month postoperative best-corrected distance visual acuities were 1.2 decimal (−0.08 logMAR) and 1.0 decimal (0.00 logMAR) in the right and left eyes, respectively. Post-operative manifest refractions were +0.00 −3.00 × 70 and −1.00 −2.00 × 85, respectively. The TIOL reduced refractive astigmatism in the left eye; therefore, we believe that even after multiple RKs, the TIOL can be a suitable candidate to correct astigmatism if the corneal astigmatism is diurnally stable and symmetric.

1. Introduction

Radial keratotomy (RK) is a type of refractive surgery performed to correct myopia through radial incisions in the anterior corneal layers. To date, it has been performed in hundreds of thousands of patients in the United States alone; however, this method has since been supplanted by newer methods [1]. In 1939, Sato first performed incisional keratotomy, a surgical treatment for myopia, on the anterior and posterior surfaces of the cornea [2]. However, this treatment can cause complications such as bullous keratopathy [3]. To prevent this, Fyodorov restricted incisions to the anterior surface [4].

RK is associated with many complications, including refractive errors, such as overcorrection, undercorrection, astigmatism, and long-term instability of refraction [5]. Postoperatively, diurnal fluctuations in refraction and keratometry have been reported to affect visual acuity. In case of undercorrection, surgical management includes placing additional incisions between the incision lines and reopening the existing incisions; however, repeated operations can induce further irregular astigmatism. Diurnal fluctuation, which refers to specific changes in both refraction and keratometry unless otherwise specified, has been attributed to postoperative weakening of the structural integrity of the cornea, making the corneal shape susceptible to internal and external forces. These and other complications are challenging for existing intraocular lens (IOL) power calculations. To date, many attempts have been made to adapt the existing formulas for post-RK eyes; however, consistent results have yet to be obtained [6].

Toric intraocular lenses (TIOL) have been successfully used in patients after corneal refractive surgeries [7]. There have been

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reports of IOL implantation in post-RK eyes, including toric and multifocal lenses [8–12]. However, to the best of our knowledge, and based on the extent of our study, TIOL implantation after multiple RKs has yet to be reported. Herein, we present the case of a patient who underwent TIOL implantation after multiple RKs.

2. Case report

A 71-year-old Japanese male was referred to our hospital for bilateral cataract surgeries. He had undergone at least two bilateral RK procedures more than ten years ago. We were unable to obtain the preoperative data or details of the patient's prior surgeries. No ocular comorbidity was observed.

Upon examination, we observed a minimum of 30 radial corneal incisions in both the right eye (Fig. 1A) and the left eye (Fig. 1B). The average incision length in the right eye ranged from 2.65 mm to 4.72 mm, with a mean of 3.59 mm. In the left eye, it ranged from 3.17 mm to 5.15 mm, with a mean of 3.98 mm. This was calculated from slit-lamp photographs using ImageJ [13], based on corneal width measured using swept-source optical coherence tomography (CASIA2; Tomey, Aichi, Japan). However, we were unable to estimate the incision depth values during the examination. Similarly, there exists no previous data regarding the patient's optical zone; however, the minimal radius of the central clear zone was measured to be 3.07 mm in the right eye, and 2.69 mm in the left eye using ImageJ. In addition, the lenses in both eyes presented with grade 2 nuclear sclerosis, according to the Emery-Little cataract classification. Finally, the intraocular pressure (IOP) was 9 mmHg in each eye.

Visual acuity and other examinations were performed by experienced orthoptists. The uncorrected distance visual acuity (UDVA) was 0.04 decimal (1.40 logMAR) in the right eye and 0.07 decimal (1.15 logMAR) in the left eye. The best-corrected distance visual acuity (BCVA) was 0.7 decimal (0.15 logMAR) with a manifest refraction of -8.00 -3.00×80 in the right eye, and this was 0.9 decimal (0.05 logMAR) with a manifest refraction of -6.00 -3.50×80 in the left eye. In addition, endothelial cell counts were 2614 cells/mm^2 and 2565 cells/mm^2 in the right and left eyes, respectively. Axial length, as measured using an IOL Master 700 device (Carl Zeiss Meditec, Jena, Germany), was 27.96 mm in the right eye and 27.95 mm in the left eye. Moreover, the corneal thickness ranged from 455 μm to 468 μm in the right eye and from 451 μm to 474 μm in the left eye, as measured using CASIA2.

Diurnal variation was determined by measuring the total corneal cylindrical power ($\varphi = 3$ mm) on separate days before surgery, at 9 a.m. and 1 p.m., using CASIA2. From this point forward, the refractive values from the CASIA2 analysis are presented as real K values, which consider both the anterior and the posterior surfaces of the cornea. The total corneal astigmatism in the right eye shifted from -0.93 D @ 87° to -1.64 D @ 85° between 9 a.m. and 1 p.m., whereas the left eye presented a lesser shift from -3.60 D @ 79° to -3.81 D @ 79°. We also performed Fourier analyses of the axial powers (real K) to calculate regular astigmatism, asymmetric astigmatism, and higher-order aberration in each eye. Fourier analyses were conducted at 9 a.m. in the right eye (Fig. 2A) and the left eye (Fig. 2B), as well as at 1 p.m. in the right eye (Fig. 2C) and the left eye (Fig. 2D). In terms of corneal regular astigmatism (anterior and posterior) in the central optical zone (diameter 3 mm), the right eye shifted from 0.98 D @ 9° at 9 a.m. to 1.50 D @ 1° at 1 p.m., whereas the left eye shifted only slightly from 2.78 D @ 167° to 2.81 D @ 165°. Finally, using an OPD-Scan 3 device (Nidek, Aichi, Japan), the corneal total higher-order aberration (THOA) from the 3rd to 6th-order Zernike coefficients ($\varphi = 4$ mm) was measured as 0.559 μm and 0.458 μm in the right and left eyes, respectively.

Despite the patient's strong desire for TIOL implantation, it was determined that the right eye presented considerable diurnal fluctuation in addition to a greater degree of asymmetric astigmatism and higher-order aberration compared to the left eye, in which diurnal fluctuation was minimal. Therefore, a non-toric IOL was planned for the right eye, while a TIOL was prepared for the left eye.

The target refraction was set at -2.00 D. For lens power calculation, we considered four formulas: the Camellin-Calossi, Haigis-L, Barrett True K, and Barrett TK Universal II formulas. The lens powers were chosen based on the Camellin-Callossi formula, as the results were similar among all four formulas. Toricity was calculated using the Hoya Toric Calculator (Hoya, Tokyo, Japan). The lenses subsequently chosen for implantation were as follows: for the right eye, the XY1 lens (Hoya, Tokyo, Japan) with a lens power of +12.0

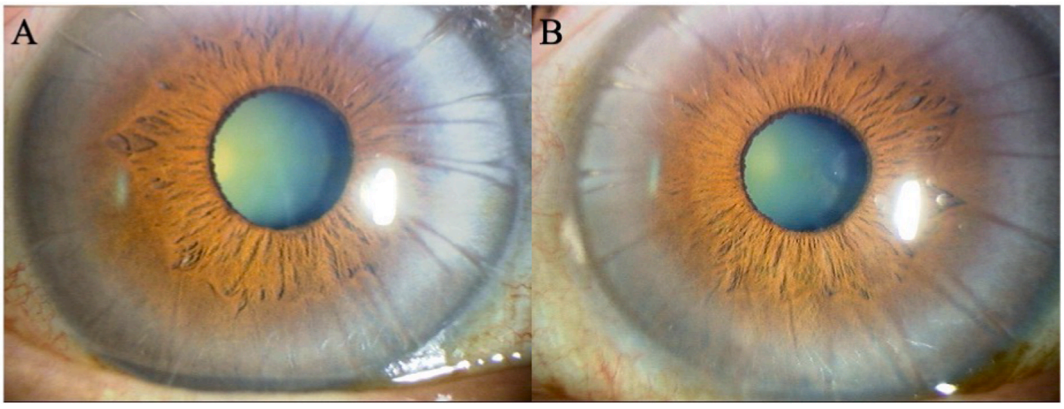

Fig. 1. Preoperative slit-lamp photographs. The right (1A) and left (1B) eyes show more than 30 radial corneal incision lines in each eye, and opacity in the crystalline lens suggests cataract.

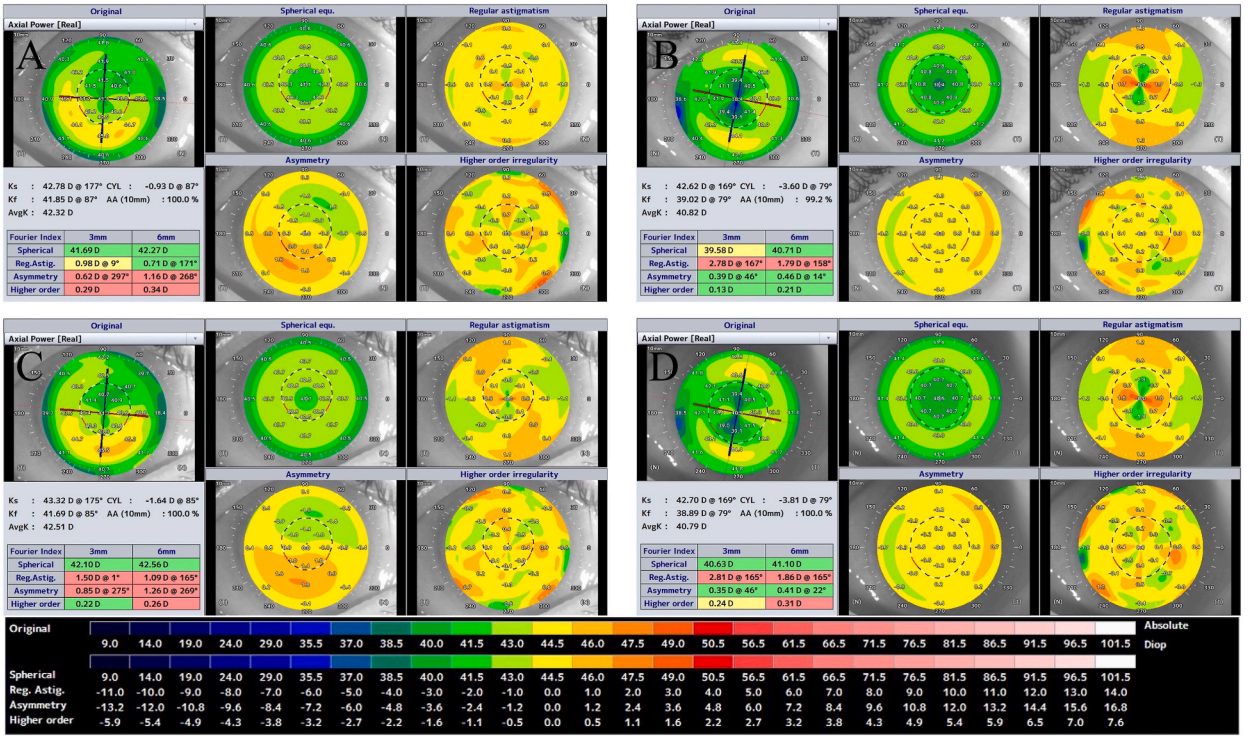

Fig. 2. Fourier analyses of real K. Regular astigmatism, asymmetry and higher order aberrations of the right (2A, 2C) and left (2B, 2D) eyes were examined at 9 a.m. and at 1 p.m.

D, and for the left eye, a toric XY1AT6 lens (Hoya, Tokyo, Japan) with a lens power of +14.5 D, cylindrical power of +3.75 D, and implantation axis of 172°. Emphasis was placed on preventing overcorrection of astigmatism in the patient. The postoperative estimates of the manifest refraction based on these formulas are presented in Table 1. The residual astigmatism in the left eye was estimated using the Hoya Toric Calculator as 1.56 × 82.

Phacoemulsification and aspiration, followed by IOL implantation, with a 2.2-mm transconjunctival single-plane sclerocorneal incision placed at the 11 o'clock position in each eye, were performed by an experienced surgeon (HT). Surgery was performed in the right eye, followed by four weeks in the left eye. The implantation axis was observed under the guidance of a Verion Image-Guided System (Alcon, Fort Worth, TX, USA).

Postoperative follow-up was continued for approximately six months. No perioperative complications were noted. One week after surgery, the UDVA was 0.7 decimal (0.15 logMAR) in the right eye and 1.0 decimal (0.00 logMAR) in the left eye. In addition, the BCVA was 0.8 decimal (0.10 logMAR) in the right eye and 1.2 decimal (−0.08 logMAR) in the left eye. Moreover, manifest refractions were +1.50 −2.25 × 80 and + 1.00 −2.25 × 75 in the right and left eyes, respectively. Furthermore, IOP was 11 mmHg in the right eye and

Table 1
Preoperative estimates of manifest refractions (spherical equivalent) obtained using four intraocular lens calculation formulas, and their arithmetic prediction errors by comparison to postoperative six-month measurements.

Formulas	Preoperative estimates (D)		Arithmetic prediction error[a] (D)	
	OD	OS	OD	OS
Camellin-Calossi	−2.34	−2.25	+0.84	+0.25
Haigis-L	−2.38	−2.00	+0.88	+0.00
Barrett True K	−1.52	−1.47	+0.02	−0.53
Barrett TK Universal II	−2.08	−1.91	+0.58	−0.09

IOL powers: (OD) +12.0 D, (OS) +14.5 D. A constant = 119.3, Keratometric index = 1.3375.
IOL master post-RK parameters.
(OD) K1 = 43.49 D, K2 = 42.67 D, Axial length = 27.96 mm, ACD = 3.24 mm.
(OS) K1 = 42.72 D, K2 = 40.42 D, Axial length = 27.95 mm, ACD = 3.25 mm.
Postoperative six-month manifest refraction (spherical equivalent): OD −1.50 D, OS −2.00 D.
ACD = anterior chamber depth; D = diopter; IOL = intraocular lens; OD = right eye; OS = left eye; RK = radial keratotomy.
[a] Arithmetic prediction error = Postoperative six-month manifest refraction (spherical equivalent) minus Preoperative estimates (the predicted postoperative refraction based on the IOL power actually implanted according to each formula).

9 mmHg in the left eye. One month after surgery, the TIOL misalignment in the left eye was 0°.

Corneal astigmatism was postoperatively analyzed using the CASIA2 at 9 a.m. The total corneal astigmatism (real K) was −1.38D @ 85° and −3.97 D @ 82° in the right and left eyes, respectively. The magnitude of corneal regular astigmatism (anterior and posterior) in the central optical zone (3 mm) was 1.08 D @ 6° and 2.50 D @ 168° in the right and left eyes, respectively. Postoperative keratometric readings of the steepest and flattest corneal meridians (Ks and Kf as real K) were 42.76 D and 41.38 D, respectively, for the right eye. For the left eye, these were 41.00 D and 37.03 D, respectively.

Six months after surgery, the UDVA in the right remained the same at 0.7 decimal (0.15 logMAR), whereas the left eye had shifted to 0.6 decimal (0.22 logMAR). Meanwhile, the BCVA was 1.2 decimal (−0.08 logMAR) in the right eye and 1.0 decimal (0.00 logMAR) in the left eye. Additionally, the manifest refractions were +0.00 −3.00 × 70 and −1.00 −2.00 × 85 in the right and left eyes, respectively. The patient was satisfied with the results and transferred to another hospital for long-term follow-up.

3. Discussion

The most intriguing aspect of this case was that the patient underwent multiple RKs, such that more than 30 radial corneal incision lines were present in each eye. It is intriguing to note that while a higher number of incisions corresponds to stronger corrections, it also entails potential drawbacks, such as increased endothelial damage, vision fluctuations, corneal weakening of the cornea, and higher probabilities of overcorrection [14]. Interestingly, the prospective evaluation of radial keratotomy (PERK) study used a standardized 8-incision procedure in all 793 eyes of 435 patients [15], and studies have indicated that four-incision radial keratotomy is sufficient in patients with low-to-moderate myopia [14].

Although the change in corneal shape following RK is not considered a direct complication, it poses a challenge when calculating the appropriate IOL power. Firstly, the central optical zone is reduced in the eyes after RK, resulting in an overestimation of corneal power by standard keratometry and corneal topography. Without corrective measures for the calculation, patients are found to be hyperopic after lens implantations [16]. Secondly, while the anterior and posterior corneal surfaces are flattened as a result of the anteriorly placed incisions, these deformations are not parallel, thus invalidating the underlying assumptions for most calculations [17]. This inconsistency in the anterior-to-posterior corneal curvature ratio is described as the keratometric index error [16].

In addition to repeated operations, additional incision lines also result in greater irregular astigmatism, which may render the eye unsuitable for IOL implantation. Our six-month postoperative refractive data showed a spherical equivalent of −1.50 D in the right eye and −2.00 D in the left eye, placing them within ±0.50 D of the target refraction (−2.00 D). In hindsight, these values represent a hyperopic shift of +0.84 D in the right eye and +0.25 D in the left eye from our Camellin-Calossi estimates. In comparison, the Barrett True K formula provided a corresponding estimate of −1.52 D in the right eye, while the Haigis-L formula provided an estimate of −2.00 D in the left eye (Table 1). As no formula provided consistent estimates for both eyes, no conclusion could be drawn regarding the superiority of any formula in this case.

The subjective refractive astigmatism in the right eye remained at −3.00 D six months after surgery. By contrast, the left eye exhibited a moderate improvement from −3.50 D to −2.00 D, which is within ±0.50 D of the estimated residual astigmatism of −1.56 D. For TIOL power, we selected the HOYA XY1AT6 which could be inserted through the smallest (<2.2 mm) incision that can be used in Japan because of the post-RK (over 30 incisions) in the patient. XY1AT6 has a weak astigmatism correction power in the current case; however, since this patient also had post-RK irregular astigmatism, we selected an IOL with weaker astigmatism correction power.

In addition, the magnitude of total corneal astigmatism (real K) changed from 0.93 D or 1.64 D, preoperatively, to 1.38 D, postoperatively in the right eye, whereas this changed from 3.60 D or 3.81 D, preoperatively, to 4.00 D, postoperatively in the left eye. These changes are comparable to perioperative changes of corneal astigmatism previously reported [18]. Examining the central 3-mm zone, the corneal regular astigmatism (real K) showed minimal perioperative changes, with values shifting slightly from 0.98 D to 1.08 D in the right eye and from 2.78 D to 2.50 D in the left eye. While the right eye exhibited a larger preoperative diurnal fluctuation, the corneal regular astigmatism (real K) in the 3-mm zone was consistent with the overall corneal astigmatism.

A case series of TIOL implantation in 40 post-RK eyes by Canedo et al. included an eye with as many as 24 incisions; however, most eyes had eight incisions or fewer [12]. They also reported a mean preoperative keratometric corneal astigmatism of 2.10 D (±0.98 D) and postoperative refractive (manifest) astigmatism of 0.46 D (±0.44 D). In their case series, biometry was conducted using Lenstar (Haag-Streit AG, Koeniz, Switzerland), which measured dual zones of 1.65 mm and 2.30 mm of the anterior surface [19]. Due to the scarcity of similar studies [8,10–12], the optimal zone for keratometric analysis in post-RK eyes requires further investigation.

It is important to acknowledge that our patient did not report any visual difficulties following the surgery. However, in cases where there is a fluctuating residual refractive error, alternate options such as the implantation of sulcus-fixated supplementary pinhole lenses [20] and the use of IOLs incorporating the pinhole technology have been reported with positive outcomes [11]. IC-8 is a small-aperture IOL that limits the peripheral defocused light that may arise from corneal deformation and has been recommended for cases of corneal irregularities. By contrast, light-adjustable lenses allow postoperative fine-tuning of refraction [21], which can be useful in extreme cases, such as ours.

One of the more important factors when considering TIOL implantation after RK is diurnal fluctuation. An 11-year follow-up of the PERK study reported morning-to-evening changes, particularly in eyes with manifest refraction or cylindrical powers greater than 0.50 D [22]. In this study, we believe that selecting a candidate eye with minimal fluctuations contributed to the satisfactory postoperative results. The surgery itself is difficult because, in an eye with as many as 30 RK incisions, determining a suitable incision point while limiting the induced astigmatism is challenging. In our case, we identified a sufficient space at the 11 o'clock position to make a 2.2-mm transconjunctival single-plane sclerocorneal incision.

This case report has several limitations. Firstly, limited data were obtained regarding the patient's prior RK procedures. This

includes the lack of information on preoperative refractive values, topographic data, as well as specific details about the procedures themselves, such as the equipment used for the incisions and the characteristics of the incisions. To account for this, we attempted to estimate the incision lengths and depths based on slit-lamp photographs and corneal data obtained using CASIA2. Secondly, it is important to note that the method used for calculating lens power in this case may not be generalizable to other cases. While online calculators recommended by the American Society of Cataract and Refractive Surgery (ASCRS) are widely used for lens power calculations, in this particular case, we utilized the Hoya Toric Calculator. At the time of treatment in 2019, AI-driven calculators, such as the PEARL-DGS and EVO, were not very popular for post-RK patients. However, they are now becoming mainstream for patients, such as those undergoing post-RK surgery [23].

Thirdly, as this was an individual case report, it is difficult to extract meaningful data that can generally be applied and to draw meaningful conclusions. However, even in a specialized medical institute such as ours, which receives many referrals of difficult or rare cases in a large population center, the case reported here is extremely rare, and presumably, toric IOL implantation in eyes with more than 30 RK incisions has not been reported. Therefore, we believe that this case report is useful for presenting a possibility of a treatment option for such difficult cases. Finally, a significant limitation of our case report is that the postoperative follow-up period was limited to six months. The cornea may take many months or years to stabilize postoperatively, which is especially important for the long-term observation of hyperopic shifts and diurnal fluctuations in post-RK eyes.

4. Conclusion

Despite the limitations of this case study, we have presented an example in which refractive astigmatism can be reduced with IOL implantation in a diurnally stable eye with an unusually large number of corneal incisions from multiple RKs. Further investigation is necessary to definitely conclude the effectiveness of this treatment option, although extreme cases like this are rare.

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Data availability statement

Data will be made available on request.

Statement of informed consent

Informed consent for publication of this case has been acquired from the patient. In addition, consent has been acquired for the publication of all images, clinical data, and related data in this case report.

Additional information

Drs. Chen and Torii contributed equally to this work and requested double first authorship.

This case report was also published as a paper presentation at the 2020 ASCRS (American Society of Cataract and Refractive Surgery) Annual Meeting and at the joint meeting of the 59th Annual Meeting of the Japanese Society for Cataract Research and the 46th Annual Meeting of the Japanese Society for Crystalline Lens Research in 2020.

CRediT authorship contribution statement

Steve S.W. Chen: Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Hidemasa Torii:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Erisa Yotsukura:** Writing – review & editing, Validation, Investigation. **Yasuyo Nishi:** Writing – review & editing, Validation, Data curation. **Kazuno Negishi:** Writing – review & editing, Validation, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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