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SYSTEMATIC REVIEW

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Efficacy of single-step transepithelial photorefractive keratectomy in myopia, hyperopia and astigmatism-a systematic review

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Abstract

Background This systematic review assesses the efficacy of single-step transepithelial photorefractive keratectomy (tPRK) in terms of postoperative pain, epithelial healing, postoperative haze and visual acuity. It also compares single tPRK to two-step tPRK where data is available.

Methods This systematic review adhered to the PRISMA reporting guidelines (Preferred Reporting Items for Systematic Reviews and Meta-analyses). An electronic literature search was conducted on PUBMED, Scopus, and Google Scholar. The quality of the studies included in this systematic review was evaluated using the Newcastle Ottawa Scale (NOS). The protocol of this systematic review was registered on PROSPERO with ID CRD42024494717.

Results A total of 11 studies published between 2013 and 2023 were included in this systematic review. Studies revealed a significant improvement in visual acuity with both single-step tPRK and two-step tPRK. Two studies showed that single-step tPRK not only offers a better UDVA but also a significant improvement in the manifest sphere, cylinder, and spherical equivalent at various follow-up periods compared to two-step tPRK. One study demonstrated the broad effectiveness of single-step tPRK for myopia correction across low-, moderate-, and high-severity groups. Rapid epithelial healing was a consistent finding. Complete epithelial healing within 72 h was noted in 100% of eyes treated with single-step tPRK in one of the studies. The incidence of corneal haze following tPRK was generally low across the studies. Post-tPRK pain scores were initially lower in the single-step tPRK group. One study reported that the maximum pain level within the first four days after surgery was significantly lower in the single-step tPRK group than in the two-step tPRK group.

Conclusion Both two-step and single-step tPRK are safe refractive procedures. Single-step tPRK, because of less haze formation, lower pain scores, faster healing, and greater effectiveness in improving visual acuity, is superior to the two-step technique.

Trial registration The protocol of this systematic review was registered on PROSPERO with ID CRD42024494717.

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Keywords Astigmatism, Refractive error, Refractive surgery, Transepithelial photorefractive keratectomy, Stream light, Single step transepithelial photorefractive keratectomy, Two step transepithelial photorefractive keratectomy

Background

Refractive errors are the world's most prevalent vision problem, affecting individuals of all ages [1]. These encompass conditions such as myopia (near-sightedness), hyperopia (farsightedness), and astigmatism (distorted vision at any distance) that significantly impact quality of life and can contribute to visual impairment [1–3]. A recent report indicated that refractive errors are the primary cause of moderate to severe vision impairment worldwide, affecting 157 million people [4]. Moreover, uncorrected refractive errors are the second leading cause of blindness, impacting 3.7 million individuals worldwide [4].

Fortunately, various corrective options exist for refractive errors. These include eyeglasses, contact lenses, and refractive surgeries such as Laser-assisted in situ keratomileusis (LASIK), Photorefractive keratectomy (PRK), small incision lenticule extraction (SMILE), Phakic intraocular lenses, and Refractive lens exchange (RLE) [4–10].

LASIK and SMILE are popular laser vision correction procedures that offer fast recovery and good results [11]. LASIK creates a corneal flap before reshaping the cornea and carries flap-related risks [11, 12]. SMILE has no flap-related complications, but it has limitations in terms of the types of refractive error that can be corrected and the higher cost compared to LASIK and PRK [11, 12]. In RLE, the natural lens is replaced with an implant, which is ideal for treating presbyopia but is more invasive and expensive [7]. Conventional PRK has served as a time-tested procedure for correcting refractive errors, particularly for hyperopia, patients with thinner corneas, and those who are in combat sports but have a slower healing time, prolonged visual recovery, limbal cell toxicity (with alcohol use) and an increased risk of haze formation [4–6]. In response to these limitations, transepithelial photorefractive keratectomy (tPRK) has emerged as a cutting-edge and promising technique for correcting refractive errors with minimal side effects. tPRK can be carried out as two-step or one-step approach [13, 14].

In contrast to the conventional PRK technique, tPRK technique removes the corneal epithelium using a laser [14, 15]. This approach aims to achieve faster visual recovery, reduce pain, improve epithelial healing, and lower haze formation. However, the two-step approach carries the risk of unintended hyperopic shifts, requiring adjustments to the ablation profile to prevent under- or overcorrection [14, 15]. Whereas, the one-step tPRK represents a groundbreaking innovation. It combines epithelial removal and stromal ablation into a single, laser-driven step. This potentially offers numerous advantages over both conventional and two-step tPRK procedures [14, 16]. One-step tPRK is effective and predictable for the correction of myopia, hypermetropia and myopic astigmatism, with minimal impact on corneal biomechanics compared to other refractive surgeries [14, 16–19].

This systematic review aimed to comprehensively assess the use of single-step tPRK for correcting refractive errors. We will analyse evidence from studies employing this method exclusively and compare it with evidence from studies utilizing the two-step tPRK approach. This evaluation will provide valuable insights to guide both surgeons and patients in making informed decisions about the most suitable refractive procedure, with the goal of improving visual health and quality of life for individuals with these common yet impactful conditions.

Methods

Protocol and registration

This systematic review adhered to the PRISMA reporting guidelines (Preferred Reporting Items for Systematic Reviews and Meta-analyses) [20]. The protocol of this systematic review was registered on PROSPERO with ID CRD42024494717.

Search strategy

An electronic literature search was conducted on PUBMED, Scopus, and Google Scholar. The literature search was limited to articles published between 2013 and 2023 and to the English language. Two reviewers, X and Y independently searched the articles using Boolean operators. The search strategy included medical subject headings (MESHs) and keywords such as Streamlight Trans-PRK, single-step transepithelial photorefractive keratectomy, two-step photorefractive keratectomy, refractive errors, myopia, hypermetropia, astigmatism, postoperative pain, UCVA, CDVA, BCVA, epithelial healing, and haze. Disagreements between the reviewers were resolved by consulting a third reviewer, Z.

Inclusion and exclusion criteria

Inclusion

The eligibility criteria were based on the PICO question, i.e., Population: Patients aged > 18 years and of any sex who were diagnosed with refractive myopia, hyperopia or astigmatism; Intervention: Single-step transepithelial photorefractive keratectomy; Control: Two-step photorefractive keratectomy; Outcomes: Primary outcome: visual acuity; and Secondary outcomes: Postoperative pain, epithelial healing, and haze. The types of studies included were nonrandomized control trials (cohort or case−control studies), randomized control trials, and case series.

Exclusion

Publications such as review articles or meta-analyses, editorials, conference papers, gray literature, books, case reports, guidelines, and qualitative studies were excluded.

Quality assessment of studies

The evaluation of study quality in this systematic review was conducted using the Newcastle Ottawa Scale (NOS) [21, 22], which assesses three main criteria: selection (encompassing four elements), comparability (one element), and outcome or exposure (three elements). Each study received a star for each NOS criterion it met. An additional star was awarded for studies that controlled for extra factors in the Comparability category, allowing a maximum of two stars in this dimension. The aggregate of these stars determined the study's overall quality: 7 to 9 stars denoted high quality, 4 to 6 stars indicated moderate quality, and fewer than 4 stars suggested poor quality. Reviewer Z initially appraised the studies, with Reviewer X validating these assessments. Disagreements between the reviewers were resolved by consulting a third reviewer, Y.

Study selection and data extraction

The search results on PubMed, Scopus and Google Scholar were imported into Endnote software (version 11). Initially, 79 articles were identified through searches in databases such as Google Scholar, PubMed, and Scopus. After removing duplicates and screening titles and abstracts, a more focused group of articles underwent full-text review for eligibility based on predefined criteria. Thus, only 11 articles that met the inclusion criteria were included (Fig. 1).

Data was extracted from the included articles by the Z reviewer. The extracted data included the name of the author, year of publication, country, study design, treatment type, sample size, age, sex, follow-up time, UDVA, manifest sphere, manifest cylinder, MRSE, and outcomes with p values (if available). The data was collected on an MS Excel spreadsheet.

Results

A total of 11 studies published between 2013 and 2023 were included in this systematic review. The included studies were case series, interventional studies, randomized controlled trials, and observational studies from countries such as Romania, Egypt, France, Germany, Turkey, China, and Iran. Seven studies were prospective, and four studies were retrospective. The sample sizes range from 25 to 250 patients to larger cohorts, such as the one in Lin et al. [23] with 2093 eyes. Other details of the included studies are given in Table 1.

Table 2 shows the outcomes of patients who underwent single-step tPRK and two-step tPRK for myopia and astigmatism correction. Studies revealed a significant improvement in visual acuity with both single-step tPRK and two-step tPRK. Specifically, in the studies by Abdel-Radi et al. [13] and Giral et al. [24] demonstrated that single-step tPRK not only offers a better UDVA but also a significant improvement in the manifest sphere, cylinder, and spherical equivalent at various follow-up periods compared to two-step tPRK. Gaeckle et al. observed similar positive outcomes in both single-step and two-step tPRK groups, with patients in both achieving an uncorrected UDVA of 1.0 or better [25]. Moreover, Xi et al. demonstrated **the** broad effectiveness of single-step tPRK for myopia correction across low-, moderate-, and high-severity groups. They reported significant improvements in the sphere, cylinder, and both UDVA and CDVA over a six-month follow-up period after single-step tPRK [26].

Table 3 highlights the safety profile of tPRK, which has minimal complications such as haze, low postoperative pain levels, and efficient epithelial healing. The incidence of corneal haze following tPRK was generally low across the studies. Sima et al. observed grade 0.5 haze in only two patients, which resolved with topical corticosteroids by the 3-month visit [27]. Abdel-Radi et al. noted grade 0 haze at 6 months in most eyes across different treatment groups [13]. Giral et al. and Abdelwahab et al. both reported reductions in haze over time, with no haze observed at 6 months in the former and minor, non-visually significant haze in the latter that resolved by the end of one year [24, 28]. Beser et al. reported that most eyes showed no corneal haze one year post operation, with a small percentage displaying clinically insignificant haze [29]. Post-tPRK pain scores were initially lower in the single-step tPRK group but plateaued by the 7th day according to Abdel-Radi [13]. Gaeckle et al. reported that the maximum pain level within the first four days after surgery was significantly lower in the single-step tPRK group than in the two-step tPRK group [25]. Adib-Moghaddam et al. reported mild intraoperative pain in a few patients, with a mean postoperative pain score of 1.2 [30]. Rapid epithelial healing was a consistent finding, with Abdel-Radi et al. and Abdelwahab et al. highlighting significantly faster healing times in the single-step tPRK groups [13, 28]. Complete epithelial healing within 72 h was noted in 100% of eyes treated with single-step tPRK in the study by Adib-Moghaddam et al. [30].

Table 4 shows the quality assessment of the included studies. A score of 9 stars indicates the highest quality according to the NOS criteria, reflecting robust study design, high comparability between groups, and

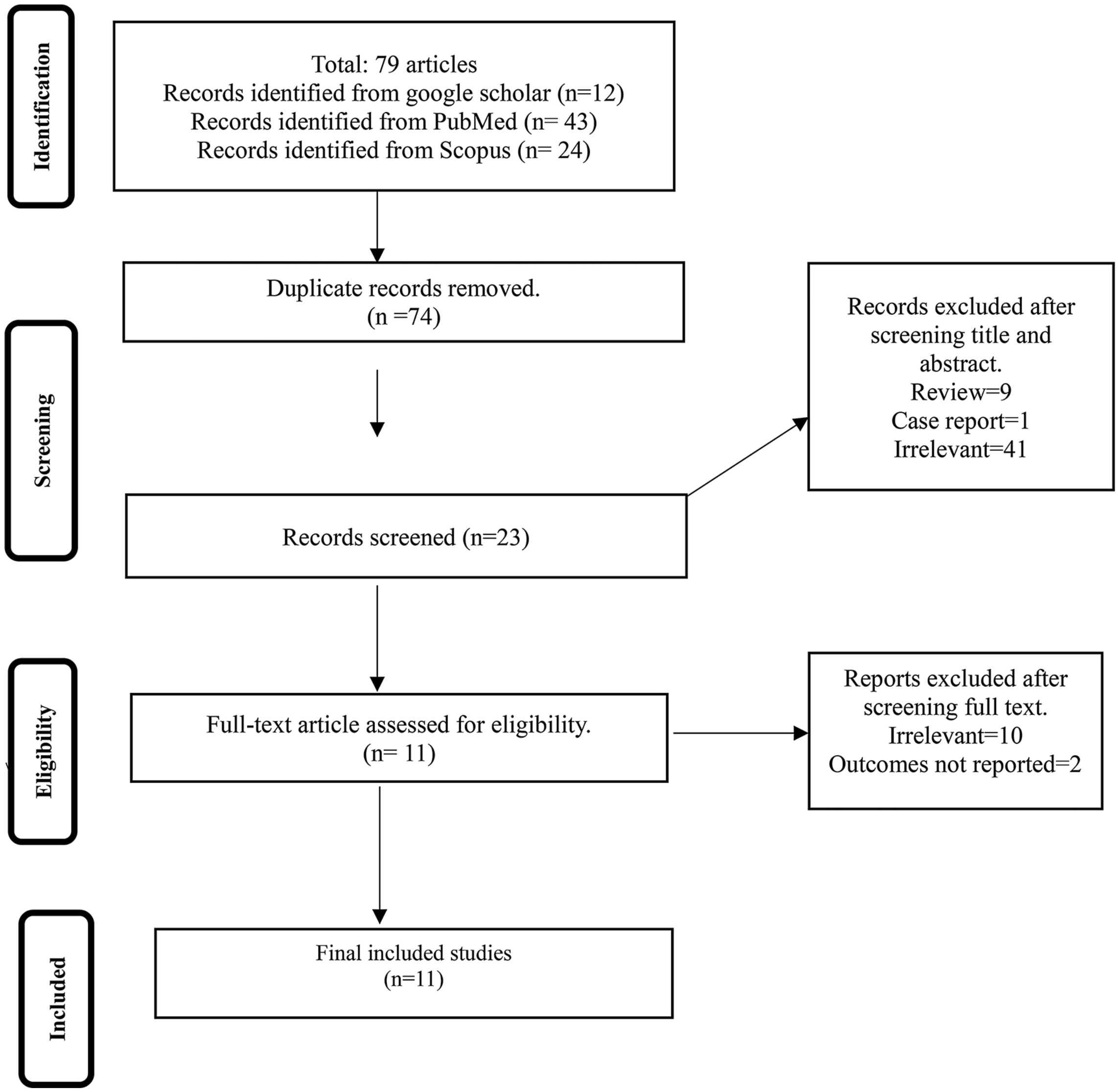

Fig. 1 PRISMA flowchart for article selection

comprehensive outcome assessment. Articles with lower scores primarily lost points in the Comparability category (N/A = not applicable), suggesting a lack of or insufficient comparison groups within the study design.

Studies by Sima et al. [27] and Abdel-Radi et al. [13] scored the highest, with a perfect 9/9. This indicates that these studies comprehensively met the criteria across selection, comparability, and outcome categories, demonstrating robust methodology, thorough outcome assessment, and effective comparability between groups. Gaeckle et al. [25] One study scored 8 out of 9, nearly reaching the highest score, with minor deductions again likely due to comparability issues. AbdelRadi et al. [31] One study scored 7 out of 9, reflecting a good methodological approach but with room for improvement in the Comparability category. The studies by Giral et al. [24], Abdelwahab et al. [28], Beser et al. [29], Lin et al. [23], Xi et al. [32], Xi et al. [26] and Adib-Moghaddam et al. [30] scored lower, each achieving a score of 6 out of 9. The primary reason for the lower scores was the lack of comparability due to the absence of a comparison group.

Discussion

PRK is a well-established laser refractive surgery for the correction of myopia, hypermetropia and astigmatism [33, 34]. The advent of tPRK has introduced a variation of the conventional technique, which promises a more comfortable postoperative experience and faster visual recovery [26, 28, 30, 31, 35–38]. It has demonstrated high efficacy and safety for correcting myopia and astigmatism, and improving refraction and hence quality of vision [30]. Another key advantage of single-step tPRK is faster healing of the corneal epithelium (outer layer). This layer is crucial for protecting the eye and maintaining

Table 1 Baseline characteristics of the included studies ($n = 11$)

Study ID	Author	Year	Country	Study design	Treatment	Laser Platform	Postoperative Treatment	Sample size	Average age or range	Gender (Female%)
1	Sima et al.[27]	2023	Romania	Randomized study	Single step tPRK	EX500 Excimer Laser	NSAIDs, lubricants, anti-inflammatory (dexamethasone), antibiotics (ofloxacin), oral ascorbic acid	30	30.2 ± 5.76	56.6
					Single step tPRK + Mitomycin C (0.02%)			30	28.23 ± 5.96	40
2	Abdel-Radi et al.[13]	2022	Egypt	Prospective comparative randomized interventional study	Two-step tPRK + Mitomycin C (0.02%)	EX500 Excimer Laser	Chloramphenicol, preservative-free artificial tears, fluorometholone, oral NSAIDs	25 patients (50 eyes)	25.1 ± 1.4	64
					Single step tPRK + Mitomycin C (0.02%)			25 patients (50 eyes)	25.4 ± 1.9	68
3	AbdelRadi et al.[31]	2023	Egypt	Prospective interventional study	Single step tPRK + Mitomycin C (0.02%)	EX500 Excimer Laser	Antibiotics (moxifloxacin), preservative-free lubricant, steroids (fluorometholone), oral NSAIDs	30 hyperopic patients, 48 eyes	38 ± 1.24	43.3
4	Giral et al.[24]	2021	France	Retrospective case-series	Single step tPRK	Schwind Amaris 500E	Antibiotics (azithromycin), Vitamin A drops, lubricants, oral painkillers, topical analgesic (oxybuprocaine) in case of severe pain	38 patients (69 eyes)	32 ± 4 (25–43)	34%
5	Gaeckle et al.[25]	2021	Germany	Prospective clinical observational study	Two-step tPRK	EX500 Excimer Laser	Preservative-free ofloxacin, preservative-free artificial tears, preservative-free corticosteroids, oral NSAIDs	50 patients (100 eyes)	27.2 ± 3.3	32
					Single step tPRK			50 patients (100 eyes)	27.7 ± 3.4	40
6	Abdel-wahab et al.[28]	2021	Egypt	Prospective cohort study	Single step tPRK	EX500 Excimer Laser	NSAID (Ketorolac tromethamine 0.45%), antibiotic eye drops (Moxifloxacin hydrochloride 0.5%), steroid (dexamethasone 0.1%), lubricants, Vitamin C 1000 mg	250 patients (500 eyes)	27.3 ± 6.1	44
7	Beser et al.[29]	2020	Turkey	Retrospective study	Single step tPRK	Schwind Amaris 1050 Hz	Moxifloxacin 0.5%, preservative-free artificial tears, dexamethasone sodium phosphate	46 patients (90 eyes)	27.15 ± 5.69	47.8
8	Lin et al.[23]	2019	Germany	Retrospective case series	Single step tPRK + Mitomycin C (0.02%)	Schwind Amaris with SmartPulse Tech	Lubricants, antibiotics (unspecified), corticosteroids	2093 eyes	34.9 ± 9.53	
9	Xi et al.[32]	2018	China	Retrospective study	Single step tPRK	Schwind Amaris 500 Excimer Laser	Levofloxacin 0.5%, fluorometholone 0.1%, preservative-free artificial tears	36 patients (47 eyes)	30.69 ± 4.85	72.2
10	Xi et al.[26]	2018	China	Prospective interventional study	Single step tPRK	Schwind Amaris 500 Hz Excimer Laser	Levofloxacin 0.5%, fluorometholone 0.1%, preservative-free artificial tears	96 eyes	19–39	70
11	Adib-Moghaddam et al.[30]	2016	Iran	Prospective interventional case series	Single step tPRK + Mitomycin C (0.02%)	Schwind Amaris 500 Hz Excimer Laser	Chloramphenicol, Chloramphenicol, oral ibuprofen, oral alprazolam, lotepred eye drops after 3 days	74 patients (146 eyes)	28.43 ± 5.49	72.6

Table 2 Visual acuity and refractive outcomes following single-step and two-step tPRK ($n = 11$)

Study ID	Author	Treatment	Total follow-up time	UDVA logMAR	CDVA logMAR	Manifest sphere (D)	Manifest Cylinder (D)	MRSE (D)
1	Sima et al.[27]	Single step tPRK Single step tPRK + Mitomycin C (0.02%)	3 months	Not reported	Pre op = 0.97 ± 0.56 vs. 0.92 ± 0.77, $p = 0.072$	Preop=-3.08 ± 0.52 vs. -3.4 ± 0.7, $p = 0.054$	Not reported	Not reported
2	Abdel-Radi et al.[13]	Two-step tPRK + Mitomycin C (0.02%) Single step tPRK + Mitomycin C (0.02%)	6 months	Preop = 1.04 ± 0.19 vs. 1.03 ± 0.23, $p = 0.948$, at 3 months = 0.10 ± 0.01 vs. 0.03 ± 0.009, $p = 0.001$, at 6 months = 0.08 ± 0.01 vs. 0.03 ± 0.008, $p = 0.001$	Preop = 0.02 ± 0.006 vs. 0.02 ± 0.006, $p = 0.697$, at 3 months = 0.02 ± 0.006 vs. 0.02 ± 0.006, $p = 0.77$, at 6 months = 0.03 ± 0.006 vs. 0.02 ± 0.006, $p = 0.645$	Preop=-2.42 ± 0.18 vs. -2.37 ± 0.25, $p = 0.548$, at 3 months=-0.25 ± 0.04 vs. 0.10 ± 0.03, $p = 0.001$, at 6 months=-0.23 ± 0.03 vs. 0.04 ± 0.2, $p = 0.001$	Preop=-1.50 ± 0.16 vs. -1.26 ± 0.14, $p = 0.337$, at 3 months=-0.59 ± 0.04 vs. -0.17 ± 0.03, $p = 0.001$, at 6 months=-0.43 ± 0.02 vs. -0.17 ± 0.03, $p = 0.001$	Preop=-3.17 ± 1.14 vs. -2.99 ± 1.61, $p = 0.269$, At 3 months=-0.53 ± 0.04 vs. 0.01 ± 0.04, at 6 months=-0.44 ± 0.03 vs. -0.04 ± 0.03, $p = 0.001$
3	Abdel-Radi et al.[31]	Single step tPRK + Mitomycin C (0.02%)	12 months	Preop = 0.53 ± 0.02, at 6 months = 0.07 ± 0.01, at 12 months = 0.08 ± 0.01	Preop = 0.02 ± 0.01, at 6 months = 0.010 ± 0.007, at 12 months = 0.010 ± 0.007	Not reported	Not reported	Not reported
4	Giral et al.[24]	Single step tPRK	6 months	Preop = 1.28 ± 0.07, at 3 months = 0.05 ± 0.23, at 6 months = 0.00 ± 0.09	Preop = 0.03 ± 0.03, at 3 months = 0.02 ± 0.21, at 6 months=-0.02 ± 0.05	At 3 months=-0.03 **±** 0.43, at 6 months=-0.02 ± 0.37	At 3 months=-0.07 **±** 0.26, at 6 months=-0.05 ± 0.17	Not reported
5	Gaeckle et al.[25]	Two-step tPRK Single step tPRK	6 weeks	Preop = 0.21 ± 0.09 vs. 0.22 ± 0.08, at 6 weeks = 1.1 ± 0.07 vs. 1.1 ± 0.07	Preop = 1.17 ± 0.18 vs. 1.11 ± 0.15, at 6 weeks = 1.21 ± 0.16 vs. 1.18 ± 0.15	Preop=-3.24 ± 1.20 vs. -2.77 ± 1.00, at 6 weeks = 0.32 ± 0.27 vs. 0.21 ± 0.30	Preop=-0.71 ± 0.65 vs. -0.64 ± 0.58, at 6 weeks=-0.23 ± 0.14 vs. −0.21 ± 0.21	Not reported
6	Abdel-wahab et al.[28]	Single step tPRK	12 months	Not reported	Not reported	Preop = −1.84 + 0.86	Preop = −0.55 + 0.53	Preop = −2.12 + 0.83
7	Beser et al.[29]	Single step tPRK	1 year	Preop = 1.02 ± 0.33, at 12 months = −0.005 ± 0.02	Preop = −0.001 ± 0.02, at 12 months = −0.02 ± 0.03	Not reported	Not reported	Preop = −2.55 ± 0.93, at 12 months = −0.10 ± 0.23
8	Lin et al.[23]	Single step tPRK + Mitomycin C (0.02%)	6 months	Not reported	Not reported	Preop = −4.65 ± 2.53, at 6 months = 0.35 ± 0.46, $p = 0.001$	Not reported	Not reported
9	Xi et al.[32]	Single step tPRK	6 months	Preop = 0.93 ± 0.28, at 6 months = −0.10 ± 0.07, $p = 0.001$	Preop = −0.10 ± 0.07, at 6 months = −0.14 ± 0.07, $p = 0.001$	Preop = −3.87 ± 1.15 vs. 0.35 ± 0.46, $p = 0.001$	Preop = −1.11 ± 0.40 vs. −0.33 ± 0.25, $p = 0.001$	Preop = −4.30 ± 1.27, at 6 months = 0.18 ± 0.46, $p = 0.001$

Table 2 (continued)

Study ID	Author	Treatment	Total follow-up time	UDVA logMAR	CDVA logMAR	Manifest sphere (D)	Manifest Cylinder (D)	MRSE (D)
10	Xi et al.[26]	Single step tPRK	6 months	Low myopia: Preop = 0.77 ± 0.21, at 6 months = -0.106 ± 0.05, Moderate myopia: Preop = 0.97 ± 0.19, at 6 months = -0.09 ± 0.05, High myopia = Preop = 1.18 ± 0.20, at 6 months = -0.047 ± 0.076	Low myopia: Preop = -0.128 ± 0.063, at 6 months = -0.159 ± 0.056, Moderate myopia: Preop=-0.075 ± 0.072, at 6 months = -0.138 ± 0.066, High myopia: Preop = -0.103 ± 0.07, at 6 months = -0.106 ± 0.072	Low myopia: Preop=-2.43 ± 0.57, at 6 months=-0.32 ± 0.23 Moderate myopia: Preop=-4.16 ± 0.72, at 6 months = 0.19 ± 0.54, High myopia: Preop=-6.39 ± 0.50, at 6 months = 0.28 ± 0.51	Low myopia: Preop = -0.70 ± 0.46, at 6 months = -0.32 ± 0.23, Moderate myopia: Preop = -0.56 ± 0.54, at 6 months = -0.34 ± 0.23, High myopia: Preop = -0.88 ± 0.58, at 6 months = -0.43 ± 0.27	Low myopia: Preop = -2.78 ± 0.65, at 6 months = 0.30 ± 0.33, Moderate myopia: Preop = -4.43 ± 0.85, at 6 months = 0.02 ± 0.51, High myopia: Preop = -6.85 ± 0.61, at 6 months = 0.07 ± 0.52
11	Adib-Moghaddam et al.[30]	Single step tPRK + Mitomycin C (0.02%)	18 months	Not reported	Not reported	Preop = − 3.85 ± 1.90, at 18 months = 0.41 ± 0.81, p = 0.001	Preop = − 0.75 ± 0.70, at 18 months = − 0.29 ± 0.21, p = 0.001	Not reported

clear vision. It therefore also has less postoperative pain than conventional tPRK [19, 25, 29, 39, 40].

In this systematic review, both single-step and two-step tPRK demonstrated significant improvements in visual acuity for myopia and astigmatism correction. However, studies by Abdel-Radi et al. and Giral et al. suggest that single-step tPRK might offer a slight edge, achieving better UDVA and showing a sphere, cylinder, and spherical equivalent compared to the two-step approach at various follow-up periods [13, 24]. Furthermore, studies have consistently reported faster epithelial healing in the single-step group than in the two-step group [13, 16, 24, 25, 28, 30]. This quicker healing translates to a shorter period of vulnerability to infection and discomfort after surgery [25, 41]. We also found that single-step tPRK appears to be safe and well tolerated. The incidence of corneal haze following tPRK was generally low across the studies [13, 24, 25, 27, 28, 30, 31]. Additionally, postoperative pain scores were lower with single-step tPRK, especially in the initial days after surgery [13, 25, 28, 30].

Evidence focusing specifically on tPRK and PRK for hyperopia and hyperopic astigmatism remains limited. Available data suggest that high hyperopic corrections are associated with a higher risk of adverse outcomes. While Adib-Moghaddam et al. reported no eye lost two or more lines of preoperative CDVA loss in their cohort of hyperopic patients [42]. O'Brart et al. found that 8% of eyes lost two lines of Snellen BCVA, attributed primarily to cataract formation rather than PRK in hyperopic patients. [43] Abdel-Radi et al. observed no significant haze in most eyes after single-step tPRK for hyperopia, demonstrating the effectiveness of mitomycin C in reducing haze formation [31]. In contrast, O'Brart et al. found residual peripheral corneal haze in 25% of eyes at 7.5 years postoperatively, particularly at higher corrections [43]. These findings suggest that with optimized postoperative protocols, including the use of mitomycin C, the safety profile of tPRK for hyperopia may be comparable to its application in myopia and astigmatism. However, the predictability and refractive stability of hyperopic PRK remain challenging at higher correction levels.

Previous reviews have documented the efficacy and safety of conventional PRK and two-step tPRK, providing a foundation for understanding the evolution of refractive surgery techniques [9, 35, 39]. Our findings align with these earlier reports in terms of efficacy and safety but further suggest that the single-step approach might offer additional benefits in terms of reduced postoperative pain, faster visual recovery, and potentially lower haze rates, echoing advancements in laser technology and procedural efficiency.

This systematic review rigorously assessed the quality of the included studies using established criteria for evaluating the methodological soundness and risk of

Table 3 Epithelial healing, corneal hazing, and pain following single-step and two-step TPRK ($n = 11$)

Study ID	Author	Epithelial healing	Haze	Pain
1	Sima et al.[27]	43 eyes (89.5%) showed complete epithelial healing on the 3rd postoperative day, and all eyes (100%) were completely healed by the 4th postoperative day in the group treated with MMC.	Two patients (6.66%) from the group without MMC (Group I) were presented at the 1-month postop visit with grade 0.5 haze. No significant difference in the development of haze was observed between the group treated with MMC and the group without MMC after three months.	Not reported
2	Abdel-Radi et al.[13]	The single step tPRK group experienced faster epithelial healing, with a mean complete epithelial healing duration significantly shorter than the two steps tPRK group (3.24 ± 0.43 days vs. 5.48 ± 0.76 days).	There was no significant difference in haze grades between the two groups at the 3-month follow-up. Specifically, 62% of eyes in the single step tPRK group and 60% of eyes in the two steps tPRK group had zero haze.	The single step tPRK group reported significantly lower pain scores at 8 h, 1 day, and 3 days postoperation. However, by the 7th day, pain scores were similar between the two groups, suggesting a faster initial recovery in the single step tPRK.
3	AbdelRadi et al.[31]	Epithelial healing was achieved effectively, with 89.5% of eyes showing complete healing on the third postoperative day and 100% by the fourth postoperative day.	No haze was observed in 62.5% of eyes at 6 months and in 85.4% of eyes at 12 months postoperatively.	Not reported
4	Giral et al.[24]	There were no delays in epithelial healing observed during the 1-week follow-up visit.	During the first postoperative week, 23% and 7% of eyes were presented with grade 1 and grade 2 haze, respectively. By the first month, only three eyes (4%) had corneal haze, all of which were grade 1. At the 6-month follow-up, the haze rate was zero.	Not reported
5	Gaeckle et al.[25]	Complete epithelial wound closure was achieved significantly faster in the tPRK group ($p < 0.0001$).	No patient developed a postoperative corneal haze during the observation period	Maximum pain level within the first 4 days after surgery was significantly lower in the tPRK group compared to the PRK group ($p < 0.0001$).
6	Abdel-wahab et al.[28]	Epithelial healing was rapid; 90.6% of eyes achieved complete epithelial healing by day three, and all eyes were completely healed by day six.	No haze was observed at 12th month	The average pain duration postsurgery was 1.5 days, with a mean pain intensity score of 3.74. After epithelial healing, no patients reported any eye pain during subsequent follow-up visits.
7	Beser et al.[29]	Not reported	At the first-year postoperative clinical examination, 74% of eyes had no haze, while 26% had clinically insignificant haze. None of the patients had a corneal haze of + 2 or more according to Fantes' classification.	Not reported
8	Lin et al.[23]	Not reported	Not reported	Not reported
9	Xi et al.[32]	Not reported	Not reported	Not reported
10	Xi et al.[26]	Not reported	Not reported	Not reported
11	Adib-Moghaddam et al.[30]	Complete corneal re-epithelialization was observed in 91.10% of eyes 48 h after surgery and in 100% of eyes by 72 h.	No eye developed a haze grade of 2 C degrees or higher throughout the follow-up period of 18 months.	Mild intraoperative pain was reported in a few cases. The mean pain score reported two days after surgery was 1.2 ± 1.0.

Table 4 Quality assessment of the included studies ($n = 11$)

Study ID	Author	Selection	Comparability	Outcome	Total Score
1	Sima et al.[27]	★★★★	★★	★★★	9
2	Abdel-Radi et al.[13]	★★★★	★★	★★★	9
3	Abdel-Radi et al.[31]	★★★	★	★★★	7
4	Giral et al.[24]	★★★	N/A	★★★	6
5	Gaeckle et al.[25]	★★★★	★	★★★	8
6	Abdelwahab et al.[28]	★★★	N/A	★★★	6
7	Beser et al.[29]	★★★	N/A	★★★	6
8	Lin et al.[23]	★★★	N/A	★★★	6
9	Xi et al.[32]	★★★	N/A	★★★	6
10	Xi et al.[26]	★★★	N/A	★★★	6
11	Adib-Moghaddam et al.[30]	★★★	N/A	★★★	6

bias. Quality assessment tools such as the NOS for observational studies and RCTs are employed to systematically appraise the internal validity and overall reliability of the evidence [21, 22, 44]. By critically appraising the study design, sample size, patient selection criteria, outcome measures, and follow-up durations, the review ensures that only high-quality studies with robust methodologies are included in the synthesis. This approach enhances the credibility and validity of the review findings, enabling clinicians and researchers to make well-informed decisions based on the available evidence. This review has several strengths. This study adhered to the PRISMA guidelines, ensuring a systematic and comprehensive search strategy. The analysis included a variety of study designs, providing a broader perspective on the current evidence. Additionally, we compared single-step tPRK with the two-step approach, offering valuable insights for surgeons and patients considering refractive surgery options. However, limitations are also present. The review included a moderate number of studies, with some lacking comparison groups, potentially impacting the generalizability of the findings. Furthermore, the evidence for tPRK in hyperopia and hyperopic astigmatism is limited, with a higher incidence of haze and refractive regression compared to myopia. Long-term data on safety and efficacy beyond one year are also scarce. Future research with larger sample sizes, longer follow-up periods, and robust study designs is warranted to further solidify the evidence base for single-step tPRK. Hence, this review can inform ophthalmologists and patients by providing valuable insights into the potential benefits of single-step tPRK. By understanding the current evidence on its efficacy and safety profile, patients can make more informed decisions regarding refractive surgery options, while ophthalmologists can stay updated on the latest advancements in laser vision correction techniques.

Conclusion

Both two-step and single-step tPRK are safe refractive procedures. Single step tPRK, because of less haze formation, lower pain scores, faster healing, and greater effectiveness in improving visual acuity, is superior to the two-step technique.

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Author contributions

Conceptualization: SA, KA. Data curation: KA, SA, WM. Formal analysis: KA. Methodology: KA. Project administration: SA, KA. Supervision: SA, KA. Validation: WM. Visualization: WM. Writing -original draft: KA. Writing-review & editing: SA, KA, WM. All authors reviewed the manuscript.

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Data availability

Data used in the analyses can be found in the published article, which were listed in the references of this manuscript.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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Competing interests
The authors declare no competing interests.

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