Observational Study

Medicine

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Surface ablation laser surgery

Bibliometric and visualized analysis from 2004 to 2023

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Abstract

Surface ablation laser surgery has resurged in popularity recently because of its safety in correcting myopia and favorable postoperative corneal biomechanical properties. This study aimed to investigate the current focal points and future trends in surface ablation laser surgery over the last 2 decades. The Web of Science Core Collection was used as the primary data source to retrieve literature related to surface ablation laser surgery. All records, including full records and reference details, were exported in plain text format. VOSvivewer, CiteSpace, and Pajek were used to perform the bibliometric and visual analyses of the countries/regions, institutions, authors, journals, and keywords of relevant publications. A total of 3415 articles on surface ablation laser surgery were published in 253 journals. These articles were authored by 9681 individuals from 2751 institutions across 79 countries. The United States leads in terms of productivity and influence in this field. The Tehran University of Medical Sciences and Kymion GD were the most productive institutions and authors, whereas the University of Crete and Randleman JB were the most influential. The Journal of Cataract and Refractive Surgery was the most productive and influential in this area, and citation analysis revealed that the top 10 most-cited references focused primarily on postoperative wound healing and wavefront aberration. The keywords were grouped into the following 5 clusters: clinical effects and complications, special indications, iatrogenic corneal ectasia, haze, and pain management. High-frequency keywords in recent years included transepithelial photorefractive keratectomy, retreatment, transepithelial phototherapeutic keratectomy, and biomechanical properties. This bibliometric analysis examined the development trends, global cooperation, research hotspots, and future directions of surface ablation over the past 20 years.

Abbreviations: DALK = deep anterior lamellar keratoplasty, LASEK = laser epithelial keratomileusis, MMC = mitomycin C, PIOL = phakic intraocular lens, PRK = photorefractive keratectomy, PTK = phototherapeutic keratectomy, WoSCC = Web of Science Core Collection.

Keywords: bibliometric analysis, CiteSpace, photorefractive keratectomy, refractive surgery, transepithelial photorefractive keratectomy, VOSviewer

1. Introduction

Refractive error is a predominant reversible visual impairment worldwide and is treated through refractive surgery.[1] Refractive surgery improves patient quality of life, work capability, and daily performance, beyond the independence from spectacles.[2] Corneal refractive surgery using excimer or femtosecond lasers reshapes the corneal tissue to correct refractive errors, such as myopia, hyperopia, and astigmatism. Surface ablation laser surgery, the earliest form of corneal refractive surgery, is safe and has favorable biomechanical properties, particularly for patients with high myopia or thin corneas.[3,4] However, this procedure involves removing the corneal epithelium and anterior stroma, leading to postoperative pain, discomfort, corneal turbidity, and scarring during healing.[5,6] Surface ablation laser surgery includes various methods of epithelial removal, including mechanical photorefractive keratectomy (PRK), which uses a blunt blade; laser epithelial keratomileusis (LASEK), which employs 20% alcohol to loosen the corneal epithelium; epipolis-laser in situ keratomileusis, which uses mechanical debridement to preserve the epithelium as a flap; and transepithelial PRK, which involves direct excimer laser ablation of the epithelium.[1]

Bibliometric and visual analyses are crucial for examining medical documents. Bibliometrics involves using statistical data to study the relationships among publications and quantitatively analyzing published information, including those in books, journals, and their metadata, such as abstracts,

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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keywords, and citations.[7,8] A visual map can provide insights into the relative contributions of different countries, institutions, authors, and journals to specific research fields[9] and the internal correlation between cited and co-cited papers.[9] Using these methods, researchers can determine hotspots and track developmental trends in specific fields. Over the past 2 decades, surface ablation laser surgery has been researched extensively via laboratory and clinical studies. However, studies summarizing the key areas of focus and emerging trends remain lacking. To address this gap, we used a bibliometric method to comprehensively evaluate the current research status and potential developments in surface ablation laser surgery.

2. Methods

2.1. Data sources and search strategies

The Web of Science Core Collection (WoSCC) was used as the primary data source for retrieving related literature on surface ablation laser surgery, with the most recent retrieval conducted on April 1, 2024. The Core Collection is one of the most comprehensive and influential citation databases across disciplines and is widely used in bibliometric research.[10] The search strategy included the topic keywords "Photorefractive keratectomy" OR "Laser epithelial keratomileusis" OR "Transepithelial photorefractive keratectomy" OR "Transepithelial PRK" OR "epithelial LASIK," a publication year range of 2004 to 2023, and the document type article. No language restrictions were imposed. This search retrieved 3415 publications (Fig. 1). The records were exported as plain-text files, including full records and cited references. Raw data from WoSCC were initially downloaded and verified by 2 authors (N.J. and Z.L.) independently. The following basic info for each article was collected: author, title, abstract, institution, country, keywords, and references. The data in this research comes from public databases, so it does not involve ethical approval.

2.2. Data visualization

We used VOSviewer (version 1.6.20), CiteSpace (version 6.3. R1), and Pajek (version 5.18) for the visual analysis of countries/regions, institutions, authors, journals, and keywords in relevant publications. VOSviewer, developed in 2010 by Nees Jan van Eck and Ludo Waltman of Leiden University, is a document visualization software that generates and explores maps based on network data.[11] VOSviewer was used for the co-authorship analysis of countries/regions, institutions, and authors; co-citation analysis of journals; and co-occurrence analysis of keywords. Pajek was used to assist VOSviewer in layout adjustments when analyzing countries/regions and keywords. CiteSpace, developed by Chaomei Chen et al of Drexel University, facilitates the analysis of emerging trends in a certain of knowledge.[12,13] CiteSpace was used to perform burst detection on keywords and dual-map overlays of journals in current research. The country-wise distribution of publications was visualized using the online tool available at www.mapchart.net. To analyze the annual distribution of the number of publications, the data were entered into Microsoft Excel 2020 and a bar chart was created to visually represent the distribution over the years.

3. Results

3.1. Annual publication distribution analysis

From 2004 to 2023, 3415 articles were retrieved related to surface ablation laser surgery from WoSCC. The annual publication

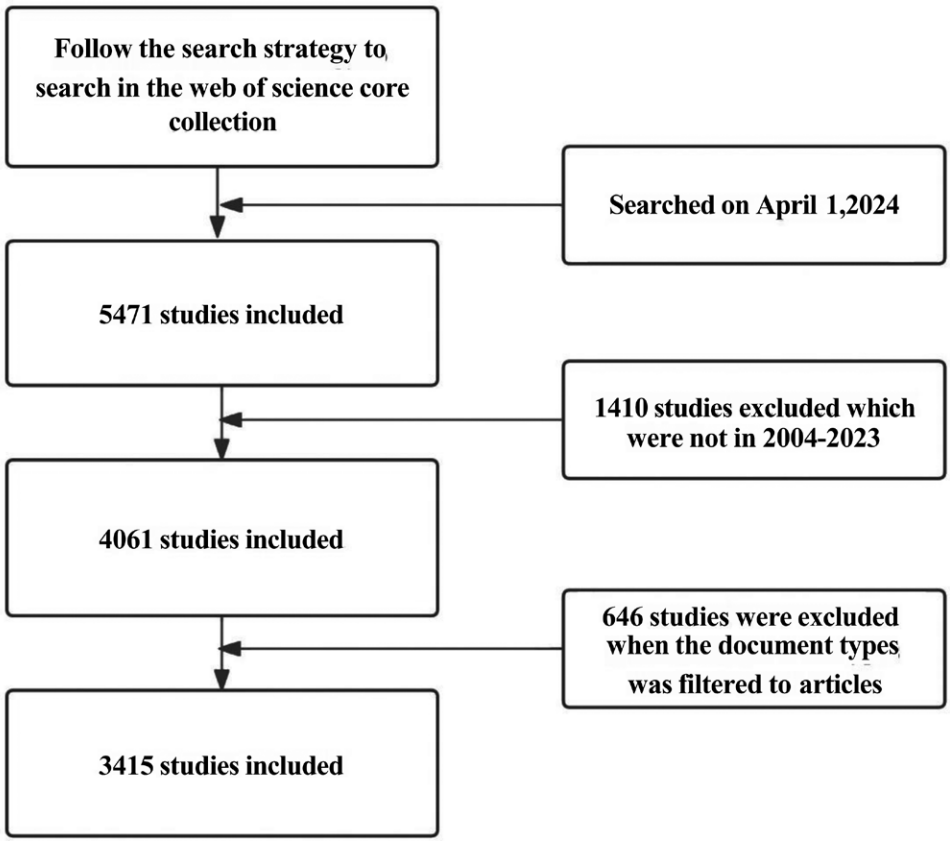

Figure 1. Data sources and search strategies.

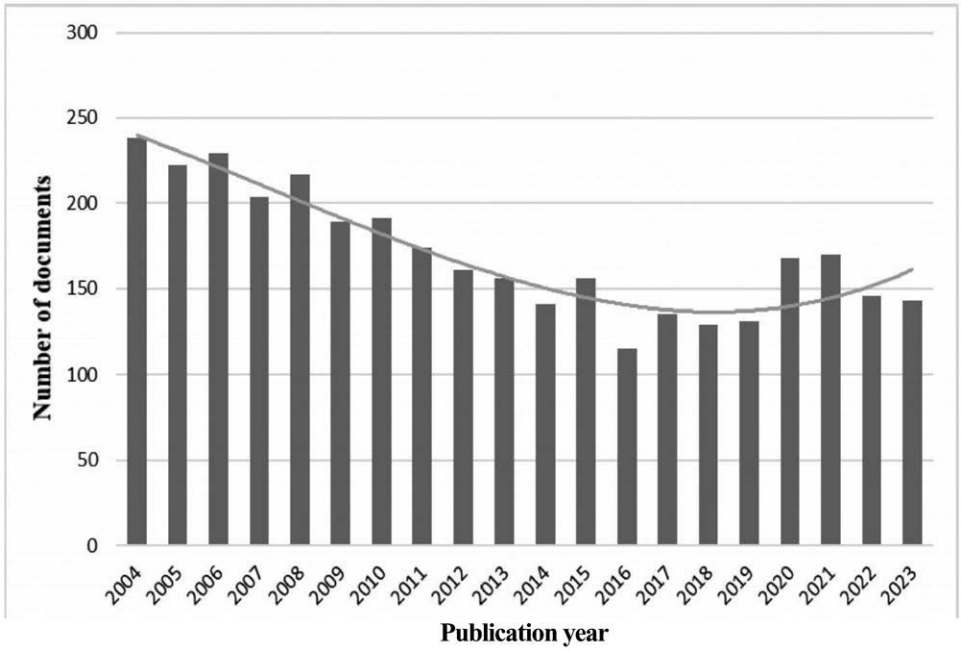

Figure 2. Annual number of publications in surface ablation laser surgery research between 2004 and 2023.

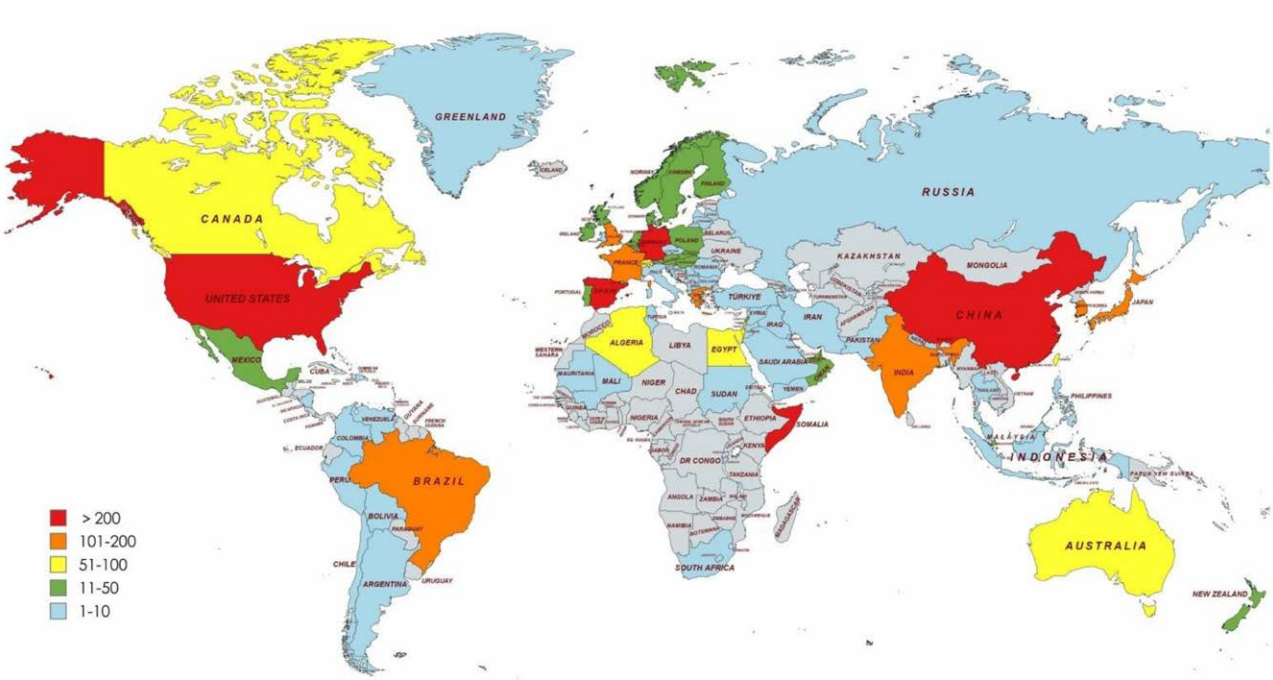

Figure 3. Distribution of main research countries/regions in surface ablation laser surgery research.

distribution for surface ablation laser surgery is presented in Figure 2. Excimer laser surface ablation publications exhibited a decreasing trend over the past decade, which has fluctuated to an upward trend in recent years, suggesting a return of research attention on surface ablation laser surgery.

3.2. Distribution and co-authorship of countries/regions

The distribution of publications related to surface ablation laser surgery by country/region over the past 20 years is depicted in Figure 3, with 3415 publications across 79 countries. The 3 most productive countries/regions were the USA (1068 publications, 31.3%), China (333 publications, 9.8%), and Germany (275 publications, 8.1%). The countries with the highest number of cited publications were the USA (30,455 citations, 32.2%), England (5785 citations, 6.1%), and Spain (5474 citations, 5.8%) (Table 1). Figure 4 illustrates co-authorship across different countries/regions, revealing that the USA had the most extensive international cooperation (link = 49) and strongest collaboration was with China (link strength = 62).

3.3. Distribution and co-authorship of organizations

The topic search yielded 3415 publications from 2751 different institutions. Table 2 presents the top ten institutions in terms of productivity and influence within the field of surface ablation laser surgery. Tehran University of Medical Sciences had 76 publications, followed by Yonsei University and the University of Crete with 66 and 59 publications, respectively. The top 3 most-cited institutions were the University of Crete, Cleveland Clinic, and Yonsei University with 1663, 1374, and 1369 citations, respectively. Figure 5 illustrates the collaborative network among institutions that published more than 10 articles on surface ablation laser surgery. In this network, node size, node connection, and same node color indicates the number of publications by an institution, level of collaboration, and stronger collaboration between institutions, respectively.

3.4. Distribution and co-authorship of authors

Over the last 2 decades, 9681 authors have contributed to the research on surface ablation laser surgery. Table 3 highlights the top 10 authors based on their productivity and influence in this field. The authors with the highest number of publications were Kymion GD, followed by Arba-Mosquera and Wilson SE, with 50, 48, and 43 publications, respectively. In contrast, the most influential authors were Randleman JB, Kymionis GD, and Wilson SE, with their articles cited 1792, 1595, and 1560 times. Figure 6 shows the collaborative network of authors who have published more than 5 articles in this area. In this network, node size, node connections, and same node color indicates the number of publications by an author, level of collaboration, and stronger collaboration between the authors, respectively. For example, Arba-Mosquera S had the largest node in its group, with 34 collaborators in the global collaboration network (with >5 published related articles).

Table 1

Top 10 productive/influential countries/regions in surface ablation laser surgery research (2004–2023).

Rank	Countries	Documents	Rank	Countries	Citations
1	USA	1068 (31.3%)	1	USA	30,455 (32.2%)
2	China	333 (9.8%)	2	England	5785 (6.1%)
3	Germany	275 (8.1%)	3	Spain	5474 (5.8%)
4	Spain	266 (7.8%)	4	Germany	4894 (5.2%)
5	Italy	240 (7%)	5	Italy	4716 (5%)
6	England	188 (5.5%)	6	China	4156 (4.4%)
7	South Korea	164 (4.8%)	7	Japan	3497 (3.7%)
8	Iran	160 (4.7%)	8	Greece	3239 (3.4%)
9	Brazil	149 (4.4%)	9	France	3151 (3.3%)
10	Japan	133 (3.9%)	10	South Korea	2511 (2.7%)

3.5. Analysis of journals

A total of 3415 articles from 253 journals were retrieved using WoSCC. Table 4 displays the top 10 journals with the highest number of publications. Leading the field of surface ablation laser surgery was the Journal of Cataract & Refractive Surgery (629 publications, impact factor 2.8), followed by the Journal of Refractive Surgery (598, 2.4), and Cornea (247, 2.8).

3.6. Reference analysis

A total of 34,255 references were cited from 3415 publications. Table 5 displays the top 10 most-cited references, with 9 concentrating on postoperative wound healing and wavefront aberration. Wound healing after excimer laser keratomileusis (photorefractive keratectomy) in monkeys' by Professor Savoldelli in 1990 held the top position, with 244 citations.

3.7. Co-occurrence analysis and citation bursts of keywords

A keyword co-occurrence analysis was used to identify research hotspots in surface ablation laser surgery (Fig. 7). Among the 2824

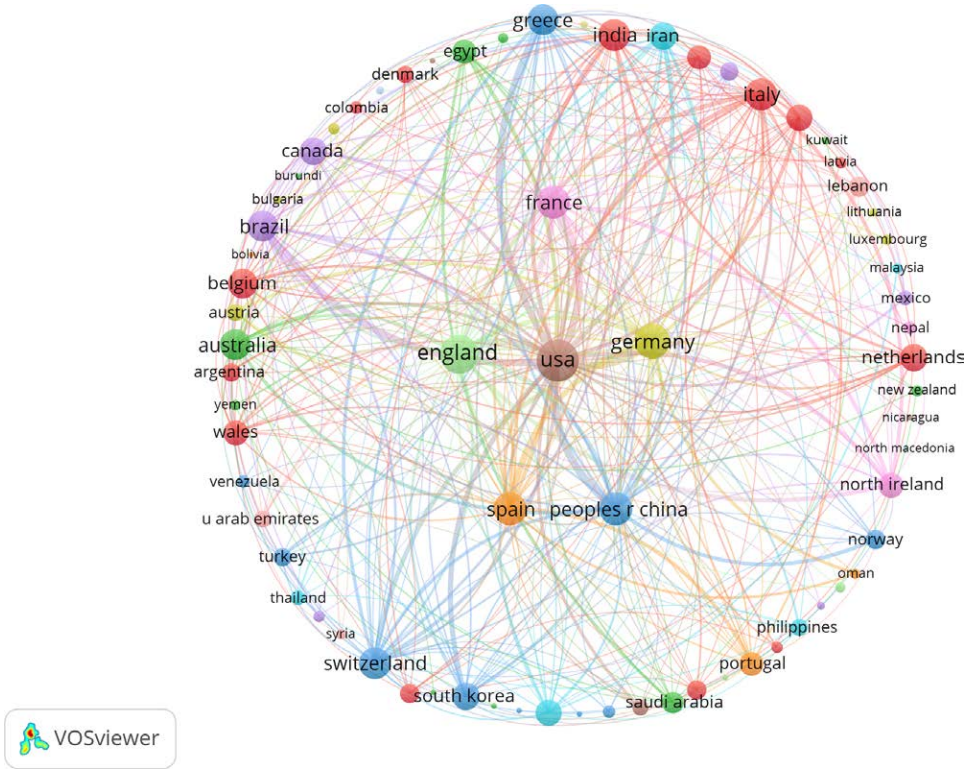

Figure 4. Co-authorship network of countries/regions in surface ablation laser surgery research.

Table 2

Top 10 productive/influential organizations in surface ablation laser surgery research (2004–2023).

Rank	Organization (country)	Documents	Rank	Organization (country)	Citations
1	Tehran University of Medical Sciences (Iran)	76	1	University of Crete (Greece)	1663
2	Yonsei University (South Korea)	66	2	Cleveland Clinic (USA)	1374
3	University of Crete (Greece)	59	3	Yonsei University (South Korea)	1369
4	Schwind eye tech solutions (Germany)	58	4	Visa Medicals (England)	1335
5	University of Sao Paulo (Brazil)	56	5	University of Sao Paulo (Brazil)	1321
6	Cleveland Clinic (USA)	52	6	University of Miami (USA)	1308
7	University of Valladolid (Spain)	51	7	Columbia University (England)	994
8	Tel Aviv University (Israel)	51	8	Schwind eye tech solutions (Germany)	969
9	The University of Utah (USA)	46	9	University of Valladolid (Spain)	916
10	Wenzhou Medical University (China)	45	10	Tehran University of Medical Sciences (Iran)	762

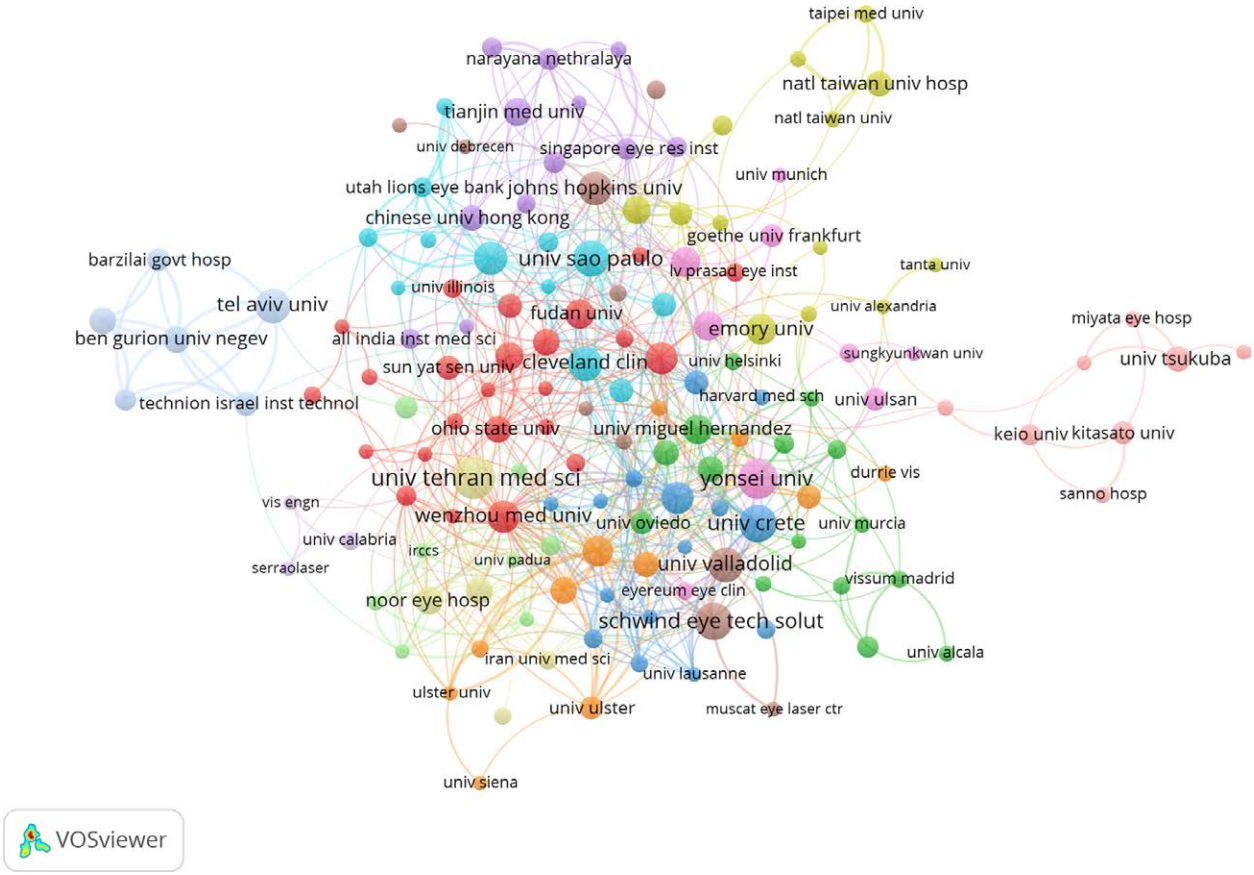

Figure 5. Co-authorship network of institutions in surface ablation laser surgery research.

Table 3

Top 10 productive/influential authors in surface ablation laser surgery research (2004–2023).

Rank	Author (countries)	Documents	Rank	Author (countries)	Citations
1	Kymionis GD (Greece)	50	1	Randleman JB (USA)	1792
2	Arba-Mosquera S (Germany)	48	2	Kymionis GD (Greece)	1595
3	Wilson SE (USA)	43	3	Wilson SE (USA)	1560
4	Alio JL (Spain)	41	4	Reinstein DZ (England)	1557
5	Reinstein DZ (England)	41	5	Archer TJ (England)	1526
6	Archer TJ (England)	40	6	Stulting RD (USA)	1140
7	Mimouni M (Israel)	38	7	Alio JL (Spain)	1099
8	Moshirfar M (USA)	36	8	Gobbe M (England)	974
9	Kim EK (South Korea)	35	9	Mohan RR (USA)	891
10	Kaiserman I (Israel)	33	10	Kanellopoulos AJ (Greece)	784

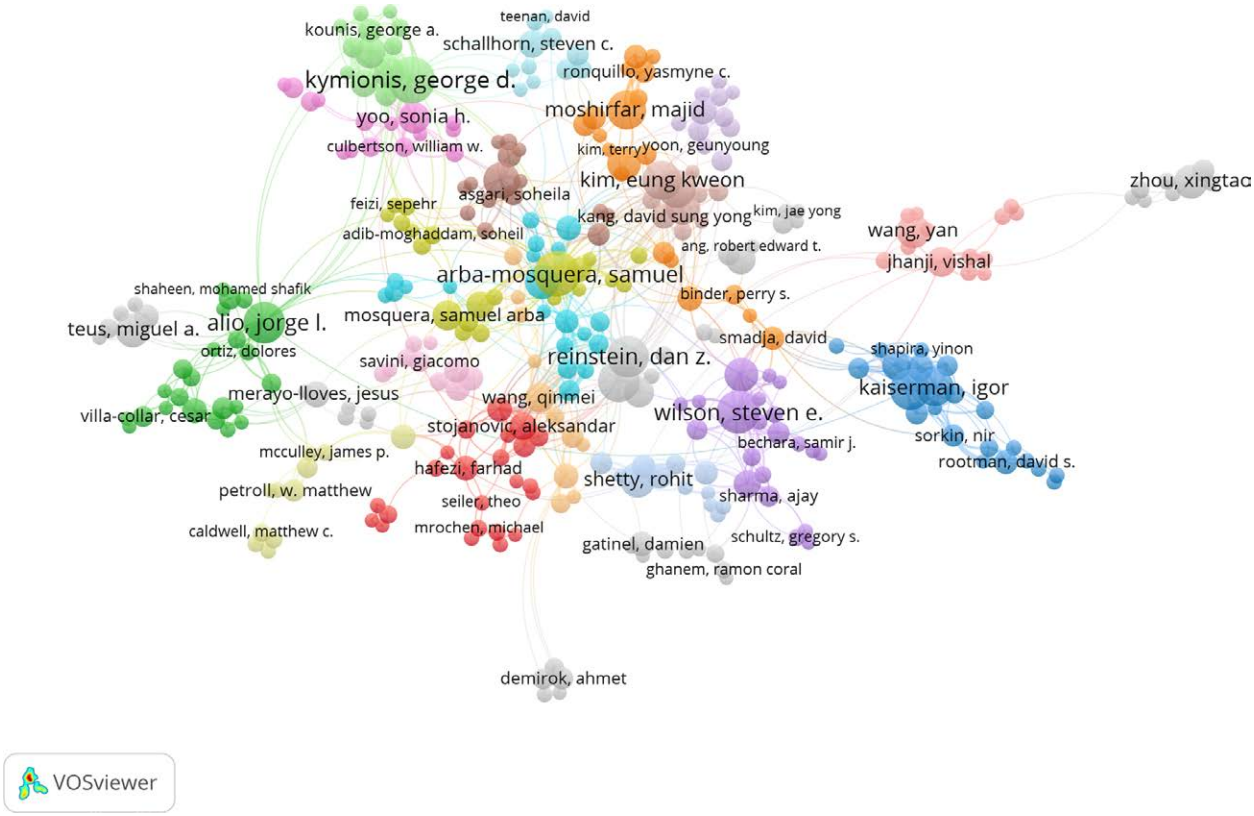

Figure 6. Co-authorship network of authors in surface ablation laser surgery research.

Table 4

Top 10 productive journals in surface ablation laser surgery research (2004–2023).

Rank	Journal	Documents	Impact factor
1	Journal of Cataract & Refractive Surgery	629	2.8
2	Journal of Refractive Surgery	598	2.4
3	Cornea	247	2.8
4	Investigative Ophthalmology & Visual Science	124	4.4
5	Ophthalmology	117	13.7
6	American Journal of Ophthalmology	116	4.2
7	European Journal of Ophthalmology	71	1.7
8	International Ophthalmology	57	1.6
9	Eye & Contact Lens	48	2.2
10	Graefe Archive for Clinical and Experimental Ophthalmology	48	2.7

author keywords, 72 met the minimum threshold of 10 occurrences. The node size, connection, and color in the visualization corresponds to the frequency of keyword occurrence; strength of the link between the keywords; and distinct clusters, including red, green, blue, yellow, and purple, each highlighting a different research topic, respectively. By examining keyword citation bursts, we explored research hotspots and predicted the future trends in surface ablation laser surgery (Fig. 8). Recent burst keywords, such as transepithelial photorefractive keratectomy, retreatment, transepithelial phototherapeutic keratectomy (PTK), and biomechanical properties, signify cutting-edge research areas in this field.

4. Discussion

4.1. Global trends in research on surface ablation laser surgery

This study examined 3415 original articles published over a 20-year period from 2004 to 2023. The analysis revealed a gradual decline in the literature focusing on surface ablation during the first decade, which was likely influenced by advancements in lamellar and intraocular refractive surgery. However, recent years have witnessed a noticeable increase in publications, possibly owing to the growing interest in corneal biomechanics and popularity of TransPRK procedures. Our analysis of countries/regions demonstrated that 79 countries were involved in research on surface ablation laser surgery. This suggests that the topic has a global reach, fostering extensive exchange and collaboration across borders. Notably, the USA stands out as the leader in terms of publication quantity, citations, and total link strength. This underscores its position as a key hub for international research on surface ablation laser surgery, facilitating significant academic interactions and partnerships. By examining the distribution of institutions and authors, we identified the most productive and influential entities in the field. The Tehran University of Medical Sciences had the highest publication count, whereas the University of Crete had the broadest impact. An analysis of the coauthors revealed that Wenzhou Medical University had the most extensive network of collaborations, suggesting a diverse range of partnerships. Kymion, Arba Mosquera, and Wilson were among the most productive and influential researchers in this field. By analyzing the coauthor network map, we can offer valuable insights to researchers looking for potential collaborators (Fig. 6). Thirteen distinct research groups were identified within this network. The professors Kymion, Arba-Mosquera, and Wilson served as the focal point for the green, yellow, and cyan group, respectively. Our analysis of journal distribution identified the Journal of Cataract and Refractive Surgery as the core publication in the realm of surface ablation laser surgery, exhibiting the highest productivity and impact. The top ten cited studies primarily focused on wound healing and wavefront aberrations, following surface ablation. The mechanisms underlying postoperative healing of corneal injury and alterations in visual quality have consistently been significant topics of interest.

Table 5

Top 10 cited references in surface ablation laser surgery research (2004–2023).

Rank	Title	Citations	Year	Author
1	Wound healing after excimer laser keratomileusis (photorefractive keratectomy) in monkeys. (PMID: 2334323)	224	1990	Fantes FE
2	Photorefractive keratectomy: a technique for laser refractive surgery. (PMID: 3339547)	184	1988	Munnerlyn CR
3	Comparison of corneal wavefront aberrations after photorefractive keratectomy and laser in situ keratomileusis. (PMID: 9932992)	175	1999	Oshika T
4	Ocular aberrations before and after myopic corneal refractive surgery: LASIK-induced changes measured with laser ray tracing. (PMID: 11328757)	146	2001	Moreno-barriuso E
5	Evaluation of the prophylactic use of mitomycin-C to inhibit haze formation after photorefractive keratectomy. (PMID: 12498842)	143	2002	Carones F
6	Apoptosis, necrosis, proliferation, and myofibroblast generation in the stroma following LASIK and PRK. (PMID: 12589777)	136	2003	Mohan RR
7	Riboflavin/ultraviolet-a-induced collagen crosslinking for the treatment of keratoconus. (PMID: 12719068)	131	2003	Wollensak G
8	Stromal wound healing explains refractive instability and haze development after photorefractive keratectomy: a 1-year confocal microscopic study. (PMID: 10889092)	129	2000	Moller-pedersen T
9	Wound healing in the cornea: a review of refractive surgery complications and new prospects for therapy. (PMID: 15968154)	123	2005	Netto MV
10	Ocular optical aberrations after photorefractive keratectomy for myopia and myopic astigmatism. (PMID: 10636408)	119	2000	Seiler T

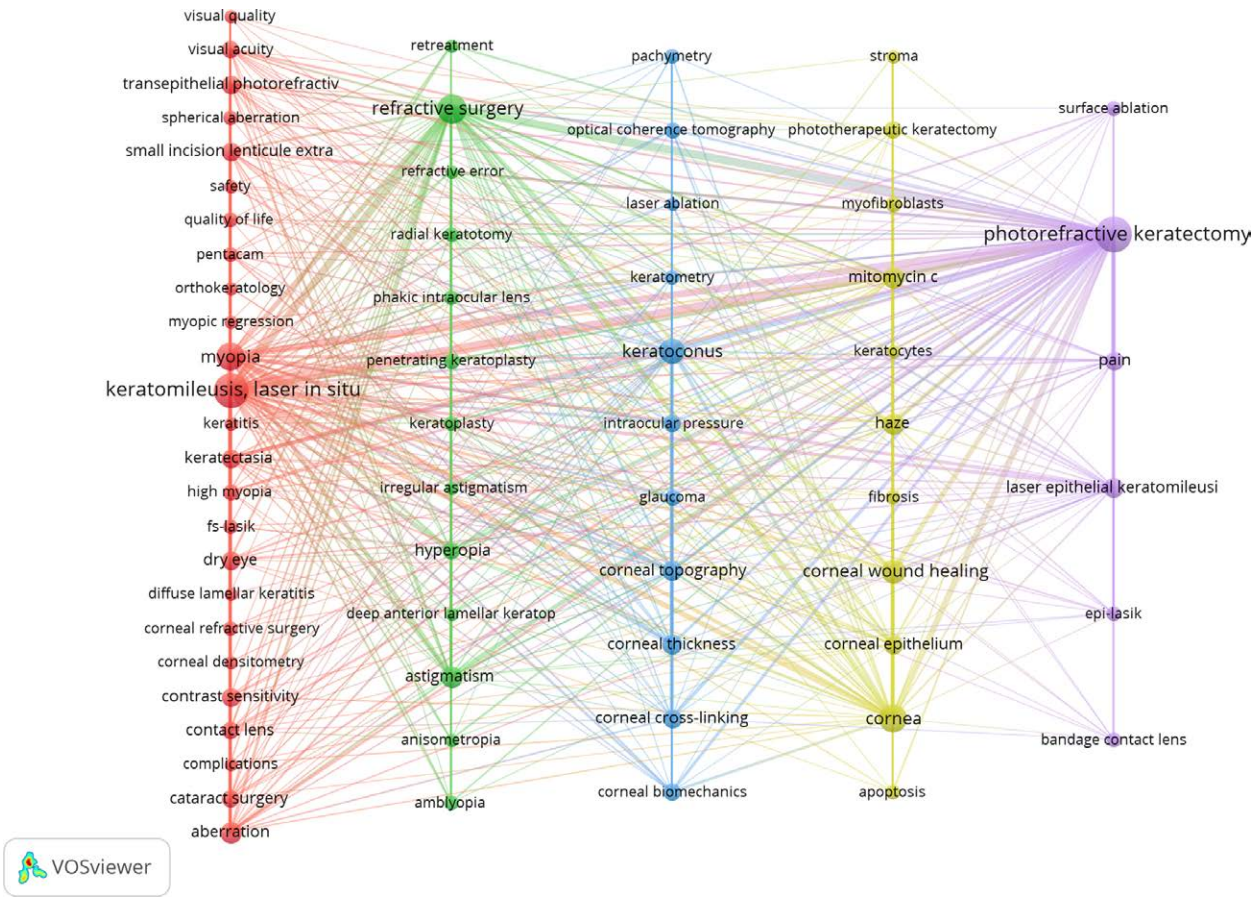

Figure 7. Co-occurrence network of keywords in surface ablation laser surgery research.

4.2. Research frontiers and hotspots

A citation burst of keywords can help identify the research frontiers in a particular field. In recent years, keywords, such as transepithelial photorefractive keratectomy, retreatment, transepithelial PTK, and biomechanical properties, have been indicated for future research. Co-occurrence analysis of keywords revealed the internal structure and research hotspots within the field. Figure 7 illustrates the division of the research topics related to surface ablation laser surgery into 5 clusters, each with distinct similarities. These clusters focus on key areas, such as clinical effects and complications, special indications, iatrogenic corneal ectasia, haze, and pain management.

Cluster#1 (red) included common keywords related to the clinical effects and complications of surface ablation. High-frequency keywords included keratomileusis, laser in situ, myopia, aberration, keratectasia, dry eye, small-incision lenticule extraction, transepithelial photorefractive keratectomy, contrast sensitivity, cataract surgery, contact lens, visual acuity, high myopia, Pentacam, corneal refractive surgery, fs-LASIK, quality of life, spherical aberration, complications, orthokeratology, corneal densitometry, keratitis, myopic regression, safety, and visual quality. A meta-analysis of 18 trials involving 1423 eyes found that PRK, TransPRK, LASEK, and Epi-LASIK demonstrated good effectiveness, predictability, and safety within 6 months after surgery, with no significant differences between the procedures.[14] A comparative study of the treatment of myopia

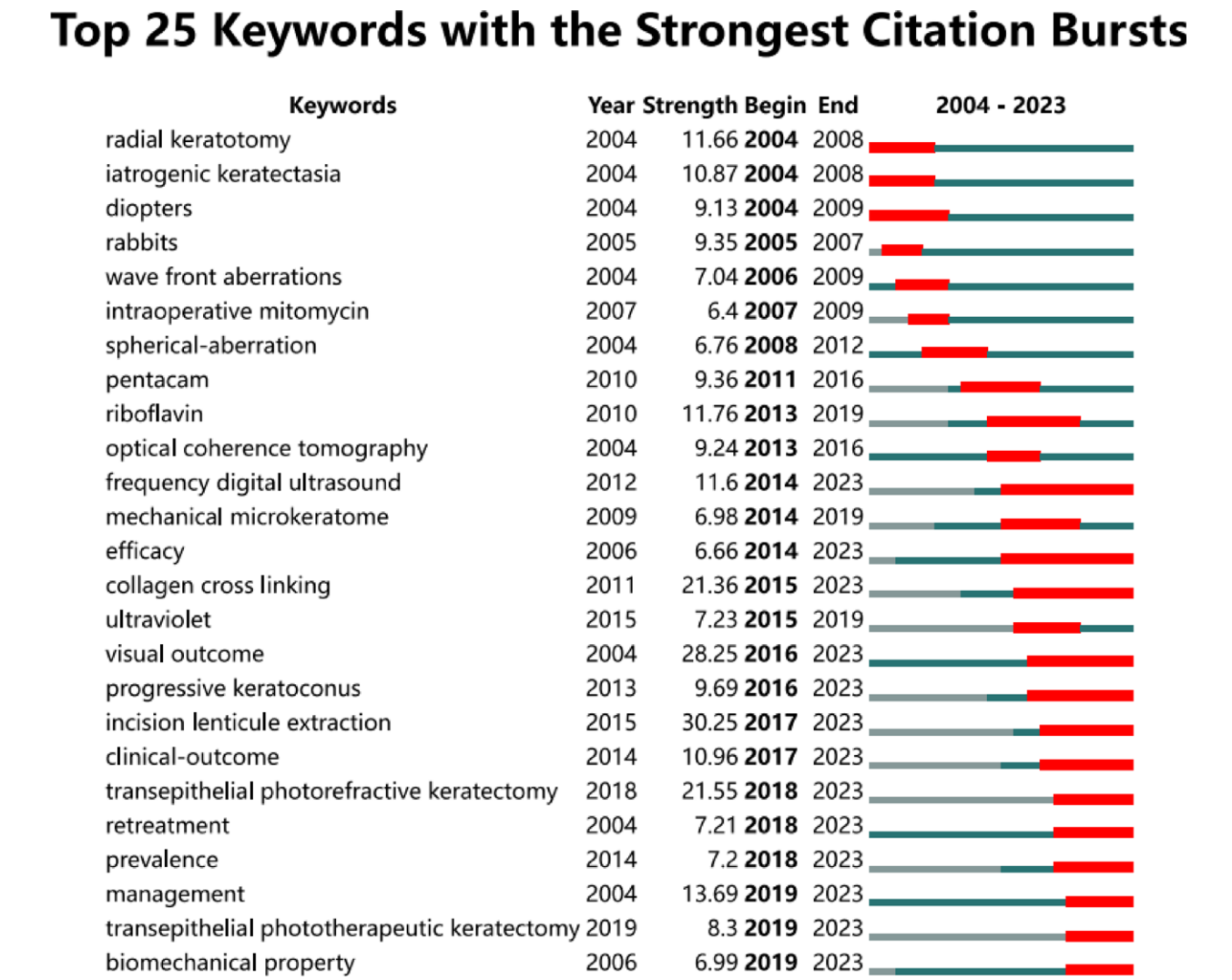

Figure 8. Top 25 keywords with the strongest citation bursts in surface ablation laser surgery research.

and astigmatism involving various techniques, such as LASIK, FS-LASIK, SMILE, PRK, LASEK, Epi-LASIK, and TransPRK, found no statistically significant differences in effectiveness (uncorrected visual acuity) between any pair of treatments.[15] Individuals who have undergone refractive surgery may experience visual quality issues even if their visual acuity has been corrected to 20/20.[16] Current research indicates that postsurgical surface ablation can lead to higher-order, spherical, and coma aberrations, possibly affecting the quality of retinal imaging.[17–19] Our previous studies have shown that TransPRK can increase higher-order aberrations and irregular astigmatism of the cornea postoperatively.[20] Wavefront-guided surface ablation may induce fewer corneal aberrations than wavefront-optimized ablation, particularly in patients with significant preoperative corneal aberrations.[21–25] However, no significant difference was observed in postoperative visual acuity and diopters between the 2 approaches.

Although surface resection is safe and clinically effective, postoperative complications can occur. One of the most common complications of corneal refractive surgery is dry eye, which significantly affects an individual's quality of life. The main causes of postoperative dry eye include damage to the corneal nerves, reduced tear secretion, and tear film instability due to the inflammatory response during corneal healing.[26] Depending on the severity of postoperative signs and symptoms, a step-by-step approach can be adopted, involving the use of lubricants, anti-inflammatory drugs, mucin secretion agents, and autologous serum. The preexisting identification and treatment of dry eye are crucial for enhancing postoperative visual outcomes and increasing patient satisfaction.[27,28] Iatrogenic Keratectasia is a rare and serious complication of resurfacing surgery and will be discussed in detail in Cluster #3. Infectious keratitis is a rare complication that affects vision after superficial resection, with an overall incidence rate of 0.013% to 0.2%.[29–31] Common pathogens associated with postoperative infections include staphylococci, fungi, herpes simplex virus, Acanthamoeba, Nocardia, atypical mycobacteria, and other cocci and bacilli.[32] Factors, such as postoperative corneal epithelial barrier damage, prolonged use of bandaged contact lenses, and application of topical corticosteroids, were the main contributors to infectious keratitis.[29] Postoperative myopic regression affects the predictability, effectiveness, and stability of refractive surgery and is a reason for patient dissatisfaction. Myopia regression after refractive surgery may be attributed to changes in the posterior corneal surface resulting from epithelial compensation, stromal thickening, wound-healing cascade, and biomechanics.[33] Higher refractive correction (>-5.00 D), smaller optical zone (<6.00 mm), and unstable fixation were the risk factors for myopic regression following PRK.[34] Furthermore, corneal irregularity within a 5-mm zone and simulated keratometry astigmatism are also associated with regression of refractive error.[35] Other complications of surface resection include pain,

delayed epithelial healing, over- or under-correction, cutting eccentricity, and turbidity.[36]

Cluster#2 (green) encompassed keywords pertaining to specific indications for surface ablation laser surgery. The key terms that frequently appeared in this cluster included refractive surgery, astigmatism, hyperopia, penetrating keratoplasty, amblyopia, keratoplasty, phakic intraocular lens (PIOL), radial keratotomy, anisometropia, refractive error, retreatment, deep anterior lamellar keratoplasty (DALK), and irregular astigmatism. Surface ablation laser surgery has demonstrated positive correction effects for myopia and astigmatism.[14,37] Recently, interest has been growing in the expansion of indications for surface ablation procedures, including treatment for corneal irregularities, retreatment of primary refractive surgeries, and anisometropic amblyopia. Residual astigmatism after keratoplasty presents a significant challenge for corneal surgeons and frequently impedes visual rehabilitation.[38] Wavefront- or topography-guided PRK is commonly used to treat residual astigmatism and refractive errors following penetrating keratoplasty and DALK.[39] This procedure has shown significant improvements in uncorrected distance visual acuity, refractive outcomes, and corneal curvature, with favorable long-term efficacy and safety results.[40–44] Compared with laser vision correction, PIOL offers a broader spectrum of refractive error correction.[45] PIOL is a safe and effective option for correcting myopia and regular astigmatism after DALK.[46,47] Refractive regression resulting from alterations in corneal biomechanics and tissue remodeling following laser vision correction, along with inadequate correction during the initial surgery or remaining astigmatism, may necessitate a secondary enhancement procedure. Surface ablation reduces the risk of ectasia by preserving as much corneal stroma as possible while avoiding the complications associated with creating or lifting a flap.[48] Surface ablation enhancement is effective and safe in addressing residual refractive errors or regression following primary corneal refractive surgery.[49–53] Topography-guided PRK or TransPRK can effectively correct irregular astigmatism and hyperopia secondary to radial keratotomy, provide good refractive outcomes, and enhance the vision-related quality of life.[54–56] Mitomycin C (MMC) may be used during surgery to minimize haze development. The primary cause of amblyopia is often an uncorrected refractive error, and the conventional treatment approach involves correcting the refractive error and using an eye patch. Nonetheless, some children diagnosed with anisometropic amblyopia may have difficulty tolerating glasses or contact lenses, which restricts the effectiveness of traditional treatment methods.[57] Superficial ablation is an effective surgical alternative for children with anisometropic amblyopia who cannot tolerate traditional treatments; it can reduce anisometropia and improve visual acuity and stereopsis.[58–60]

Cluster#3 (blue) comprised common keywords related to postoperative iatrogenic keratectasia after surface ablation. The key topics included corneal biomechanics, corneal crosslinking, corneal thickness, corneal topography, glaucoma, intraocular pressure, keratoconus, keratometry, laser ablation, optical coherence tomography, and pachymetry. Iatrogenic corneal ectasia is a severe complication of refractive corneal surgery and is characterized by progressive corneal steepening and stromal thinning in the postoperative period, resulting in a decrease in both uncorrected and corrected visual acuities.[61] The worldwide incidence of corneal ectasia after PRK was 25 cases per 100,000 individuals. In cases where no identifiable risk factors were identified before surgery, the incidence decreased to 20 per 100,000.[62] Risk factors for corneal ectasia after keratorefractive surgery can be categorized into absolute and relative factors. Absolute risk factors include keratoconus and frustrated keratoconus, whereas relative risk factors include thin remaining stromal bed thickness (more prevalent in cases of high myopia and thin corneas), abnormal corneal topography, and a high ablation ratio (calculated as ablation depth + epithelial thickness divided by central corneal thickness).[63,64] Additionally, factors, such as younger age, high postoperative intraocular pressure, and family history of keratoconus, also contribute to this risk.[65] Therefore, preoperative screening for keratoconus is essential. Corneal topography can detect corneal ectasia before any deterioration in best-corrected vision or the appearance of typical slit-lamp findings.[66] Corneal tomography, such as Pentacam (Oculus, Wetzlar, Germany), can precisely measure the height variations of the front and back of the cornea, making it more sensitive for diagnosing early keratoconus.[67] Corneal visualization using Scheimpflug technology (Corvis ST, Oculus, Wetzlar, Germany) allows the assessment of corneal degeneration parameters through the dynamic examination of corneal reactions. Deformation and deflection amplitudes demonstrated high sensitivity and specificity in differentiating between normal, suspected, and keratoconic eyes.[68] The combined index of Pentacam and Corvis ST, known as the tomographic and biomechanical index, demonstrated higher sensitivity and specificity than other parameters.[69] In recent years, several studies have used machine learning techniques to screen for keratoconus, demonstrating promising diagnostic accuracy and significant potential.[70] Corneal epithelial mapping using optical coherence tomography is a crucial tool for screening subclinical keratoconus. In keratoconus, the compensatory mechanism of the epithelium can result in an irregular distribution and thinning at the apex of the cone, forming a distinctive epithelial ring pattern.[71] Researchers have been actively developing screening indices and algorithms that focus on epithelial thickness distribution in relation to keratoconus.[72–75] Recently, a novel procedure has emerged that combines CXL with primary corneal refractive surgery to increase postoperative biomechanical stability and reduce the occurrence of future corneal ectasia.[76] This surgery is recommended for candidates with risk factors for postoperative corneal ectasia, including younger age, high myopia, thin cornea, and suspected keratoconus.[77] In long-term studies published to date, myopic patients with risk factors for corneal ectasia have not developed corneal ectasia following PRK Xtra.[78–81]

Cluster#4 (yellow) focused on keywords related to corneal wound healing and haze after surface ablation surgery. Key terms included cornea, corneal wound healing, MMC, haze, corneal epithelium, PTK, myofibroblasts, fibrosis, apoptosis, keratocytes, and stroma. Following surface resection, the cornea undergoes a series of intricate wound-healing processes to repair damage and restore normal tissue function. The diversity of the healing response plays a significant role in determining postoperative outcomes following refractive surgery, potentially leading to overcorrection, under-correction, regression, or haze.[82] Haze is a form of subepithelial fibrosis that occurs during pathological healing of the cornea following laser corneal refractive surgery and can lead to varying degrees of reduced corneal transparency. The complete structure of the basement membrane is crucial for blocking inflammation and preventing growth factors from reaching the superficial corneal stroma. Inflammatory mediators, such as IL-1, Fas ligand, and TNFα, which are generated following superficial laser damage to the epithelium and basement membrane, lead to corneal cell apoptosis.[83] Apoptotic and necrotic cell fragments trigger the release of cytokines and growth factors. Transforming growth factors β and platelet-derived growth factor transform keratocytes into myofibroblasts.[33] Myofibroblasts secrete glycosaminoglycans and disordered ibrillary collagen, forming fibrotic tissue that decreases corneal transparency.[83] Risk factors for haze include hyperopia, high myopia, high astigmatism, previous corneal refractive surgery, young age, ultraviolet exposure, dry eye disease, and vitamin D deficiency.[84–87] MMC is an antimetabolite that inhibits the proliferation and differentiation of myofibroblasts, thereby preventing subepithelial haze formation.[88] A systematic review and meta-analysis of 12 randomized

controlled trials demonstrated that the use of MMC can effectively decrease haze formation following PRK without statistically significant adverse effects, such as endothelial cell loss.[89] Topical corticosteroids are effective in preventing corneal haze 3 months after surgery, although they are not as effective in preventing delayed haze, except in cases of high myopia.[85] Persistent severe haze that is resistant to medical therapy may necessitate surgical intervention, which can involve techniques, such as manual debridement, or using PTK and MMC.

Cluster#5 (purple) encompassed the common keywords associated with postoperative pain management during surface ablation. The high-frequency keywords in this cluster included photorefractive keratectomy, LASEK, pain, epi-lasik, bandage contact lens, and surface ablation. Pain resulting from the unique healing response following surface resection poses a significant challenge for healthcare providers and patients. Pain is caused by increased spontaneous activity of exposed nerve fibers after removal of the epithelial-stromal layer and stimulation of nociceptor endings by inflammatory mediators released from the damaged tissue.[90,91] Following surface ablation surgery, postoperative pain escalates quickly, peaks at 24 hours, and then diminishes gradually over the next 72 to 96 hours.[91,92] No consistent trends were observed in the postoperative pain outcomes across different epithelial removal techniques. Mohammadpour and Eliaçik et al discovered that LASEK resulted in less pain and discomfort during the early postoperative period than PRK.[93,94] However, previous RCT trials have indicated that early postoperative pain levels were similar between the 2 procedures.[95] The comparison of postoperative pain levels between Epi-LASIK and PRK remains a topic of debate. Crestana et al observed that in contrast to PRK, patients who underwent Epi-LASIK experienced more discomfort in the early postoperative phase.[96] Magone et al reported that the average daily pain score of Epi-LASIK was only 0.33 lower than that of PRK on a 6-point pain scale, with no clinically significant difference between the two.[97] Similarly, Torres et al found no significant difference in pain levels on the first day after surgery between Epi-LASIK and PRK.[98] While TransPRK initially appeared to result in less postoperative pain than traditional PRK,[99] subsequent studies suggested that patients undergoing mechanical PRK experienced less pain 1 day after the procedure.[100–102] Bandage contact lenses can reduce pain due to eyelid irritation of the corneal mechanoreceptors, aid epithelial healing, and are the standard of care for patients undergoing surface ablation.[103] The U.S. Food and Drug Administration has approved the following 3 types of silicone hydrogel soft-bandage contact lenses: balafilcon A (Purevision), lotrafilcon A (Air Optix nights and day aqua), and senofilcon A (Acuvue Oasys).[104] Li and Duru conducted a comparative study of postoperative pain relief and discomfort using various bandage contact lenses and showed that Senofilcon A caused less pain than balafilcon A and lotrafilcon B.[105,106] This can potentially be attributed to the smaller elastic modulus and sharper and thinner design of senofilcon A lenses, which may contribute to a softer lens with minimal movement, ultimately leading to improved comfort. Mohammadpour et al found that Lotrafilcon B significantly reduced post-PRK pain and discomfort compared with balafilcon A.[107] Various classes of topical ophthalmic medications, including topical anesthetics, nonsteroidal anti-inflammatory drugs, and topical opioids, are used to manage pain after surface ablation.[6] Local hypothermia control is also used as a post-PRK pain management method. Zeng et al demonstrated that 24-hour periorbital cold patching is more effective in reducing postoperative pain than irrigation with a low-temperature-balanced salt solution.[108] Furthermore, a combination of pain management strategies may offer superior outcomes. Shetty et al showed that the use of bandaged contact lenses stored at 2 to 8 °C significantly decreased postoperative pain perception.[109] Additionally, ketorolac- or diclofenac-soaked contact lenses were more effective than unsoaked lenses in alleviating pain after surface ablation.[110–112]

4.3. Limitations

This study had certain limitations. Our database included only the WoS core database, which may not have comprehensively covered all publications on surface ablation laser surgery. Future research will aim to incorporate multiple commonly used databases to enhance the accuracy of data analysis. Publications published over the past 20 years were extracted from the WoS core database, potentially limiting the representation of all research topics in surface ablation laser surgery. While the bibliometric analysis was conducted objectively using a software, the interpretation of the results may have been influenced by the subjective tendencies of the researcher.

5. Conclusion

This study is the first bibliometric analysis of the research trends in surface ablation laser surgery over the past 20 years. A knowledge map was created to visualize the annual publication volume; distribution of countries/regions; and collaborations among institutions, authors, source journals, and keywords in this field. These findings offer valuable insights for researchers seeking appropriate journals for publication, fostering collaboration between institutions and authors, and identifying research hotspots and trends to guide future research agendas.

Author contributions

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