Review Article

Curcumin in ocular diseases: therapeutic potential, mechanisms of action, and innovative delivery systems

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ABSTRACT

Background: Curcumin, a natural polyphenol derived from Curcuma longa L., has gained considerable attention in ophthalmology because of its potent anti-inflammatory, antioxidant, and immunomodulatory properties. This review evaluates the therapeutic potential of curcumin in ocular diseases and explores innovative strategies to enhance its bioavailability.

Methods: A comprehensive search was conducted in four major electronic databases—PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar—using keywords related to curcumin, ophthalmology, and drug delivery systems. Studies published in English up to March 10, 2025, were included. Relevant articles were selected based on their focus on the therapeutic effects of curcumin and the application of advanced delivery methods.

Results: Curcumin shows promising therapeutic potential in various ocular conditions due to its anti-inflammatory, antioxidant, and anti-angiogenic properties. Studies highlight its beneficial effects in corneal neovascularization, promoting corneal wound healing, and dry eye disease. It also demonstrates efficacy against allergic and bacterial conjunctivitis, pterygium recurrence, anterior uveitis, and cataracts. Moreover, curcumin may be beneficial in glaucoma, age-related macular degeneration (AMD), and diabetic retinopathy, offering a multi-targeted approach to preserving vision and ocular health. However, its poor bioavailability remains a major limitation. Strategies to overcome this challenge include the development of structural analogs, bioavailability enhancers, and advanced drug delivery systems such as nanoparticles, liposomal systems, micelles, hydrogel-based systems, and nanoemulsions, all of which may enhance the stability, bioavailability, and controlled release of curcumin.

Conclusions: Curcumin has garnered attention in ophthalmology because of its multifaceted therapeutic properties, including anti-inflammatory, antioxidant, apoptosis regulating, antibacterial, and immunomodulatory actions. These properties have demonstrated promising results, highlighting the potential of curcumin in treating various ophthalmic conditions. Despite the promising potential of curcumin in ophthalmic therapies, addressing its poor bioavailability by using innovative drug delivery systems is crucial for maximizing its clinical efficacy. To address these challenges, substantial research has focused on enhancing the bioavailability of curcumin through the development of structural analogs, bioavailability enhancers, and advanced drug delivery systems. Innovative formulations, including nanoparticles, liposomal systems, micellar solutions, hydrogel-based systems, nanoemulsions, microspheres, and transferosomes, are promising approaches to improve the stability, bioavailability, and controlled release of curcumin, offering a hopeful avenue for its future application in ocular therapies.

KEYWORDS

curcumin phytosome, turmeric yellow, ocular surgery, eye disease, bioavailability, drug delivery system, therapeutic use

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INTRODUCTION

Curcumin, a natural polyphenol derived from Curcuma longa L., exhibits a diverse range of pharmacological properties, including antioxidant, anti-inflammatory, antimicrobial, antimutagenic, and anticancer effects [1]. Consequently, curcumin has been investigated for its potential role in preventing and treating various diseases, including diabetes, cancer, rheumatoid arthritis, atherosclerosis, pulmonary infections, chronic intestinal inflammation, allergic conditions, asthma, autoimmune disorders, psoriasis, and neurodegenerative disorders such as Alzheimer's disease [2].

Clinical studies have demonstrated the favorable safety profile, tolerability, and therapeutic efficacy of curcumin, supporting its use for medical purposes [3]. Despite its promising pharmacological profile, the clinical application of curcumin remains a challenge because of its poor aqueous solubility, low bioavailability, rapid metabolism, and systemic elimination. These pharmacokinetic limitations hinder its therapeutic efficacy and complicate dose optimization [4, 5]. Furthermore, the susceptibility of curcumin to photodegradation and autofluorescence complicates pharmacological assessments and limits its therapeutic reliability [4, 5].

Recently, curcumin has gained increasing interest in ophthalmology because of emerging evidence from both in vitro and *in vivo* studies suggesting its potential benefits for a range of ocular diseases [6]. Curcumin exhibits significant antimicrobial and immunomodulatory properties that influence the intricate interactions between infection, inflammatory responses, and oxidative damage, which are fundamental factors in the progression of numerous ocular disorders [1]. Curcumin may exert therapeutic effects in conditions such as corneal wound healing, dry eye disease, conjunctivitis, anterior uveitis, glaucoma, cataracts, age-related macular degeneration (AMD), and diabetic retinopathy [6].

These findings highlight the potential of curcumin as an adjunctive or alternative therapy for ocular diseases. Thus, this review explores the pharmacological properties of curcumin in ocular diseases, highlights the challenges in ocular drug delivery, and discusses recent advances in curcumin formulations for improved ocular delivery.

METHODS

A targeted literature search was conducted to examine the therapeutic potential of curcumin in ocular diseases, with a focus on its mechanisms of action and innovative delivery systems. Four electronic databases were searched—PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar—on March 10, 2025, for studies published in English. Search terms included "curcumin," "ophthalmology," "eye," "therapy," "inflammation," "vascularization," "antioxidant," "immunomodulatory," and various drug delivery systems such as "nanoparticles," "liposomal," "micellar," "hydrogel," "nanoemulsions," "microspheres," and "transferosomes." Studies were included if they addressed the therapeutic effects of curcumin or innovative delivery methods in ophthalmic diseases. Additional relevant studies were identified through manual review of reference lists of selected articles.

RESULTS and DISSCUSSION

Pharmacological Properties of Curcumin in Ophthalmology

Curcumin demonstrates a broad spectrum of pharmacological effects, including antioxidant, anti-inflammatory, antimutagenic, antimicrobial, and anticancer properties [7]. Table 1 summarizes the mechanisms by which curcumin exerts its therapeutic effects in ocular health. These activities render it a promising and adaptable therapeutic agent, particularly when combined with advanced drug delivery systems [1].

Table 1. Mechanisms by which curcumin exerts therapeutic effects in ocular health

Effects	Mechanism of Action	Therapeutic Relevance
Anti-inflammatory [8-12]	Blocks pro-inflammatory signals (e.g., NF-κB, NLRP3), reduces cytokine activity (TNF-α, IL-1β, IL-6).	Regulates inflammation, ensuring benefits for tissue repair while preventing chronic inflammation.
Antioxidant [13-19]	Activates NRF2 to enhance antioxidant enzymes (SOD, catalase, GPX), neutralizing ROS.	Protects ocular cells from oxidative stress, maintaining mitochondrial function and preventing damage.
VEGF Inhibition [13, 16, 17, 20-25]	Suppresses VEGF, controlling angiogenesis in conditions such as DR and AMD.	Prevents pathological neovascularization, ensuring proper blood vessel formation in the eye.
Apoptosis Regulation [13, 16, 17, 20-25]	Modulates Bcl-2/Bax ratio, preventing uncontrolled cell death while allowing elimination of damaged cells.	Protects ocular cells and ensures selective removal of damaged cells, aiding in tissue health.
Antibacterial Effects [8, 9]	Neutralizes ROS, inhibits bacterial biofilm formation, and supports controlled inflammation.	Reduces bacterial load, minimizes excessive inflammation, and enhances defense against microbial infections.
Immunomodulation [10-12, 26]	Modulates immune response, stabilizes extracellular matrix, and regulates endoplasmic reticulum stress.	Promotes tissue repair and regeneration, especially in autoimmune and infectious eye diseases.

Abbreviations: NF-κB, Nuclear factor kappa-light-chain-enhancer of activated B cells; NLRP3, NLR family pyrin domain containing 3; TNF-α; tumor necrosis factor-alpha; IL-1β, Interleukin 1 beta; IL-6, interleukin 6; NRF2, nuclear factor erythroid 2-related factor 2; SOD, superoxide dismutase; GPX, glutathione peroxidase; ROS, reactive oxygen species; VEGF, vascular endothelial growth factor; DR, diabetic retinopathy; AMD, age-related macular degeneration; Bcl-2, B-cell lymphoma 2; Bax, Bcl-2-associated X protein.

Table 2. Therapeutic applications of curcumin in ocular conditions [6].

Anatomical structure	Ocular conditions
Anterior segment of the eye	❖ Corneal Neovascularization ❖ Corneal wound healing ❖ Dry eye disease ❖ Conjunctivitis (allergic / bacterial) ❖ Pterygium ❖ Anterior Uveitis ❖ Cataract ❖ Glaucoma
Posterior segment of the eye	❖ Age related macular degeneration ❖ Diabetic retinopathy

Curcumin may exert therapeutic effects on various anatomical structures of the eye through the mechanisms described above [6], as illustrated in Table 2.

Challenges in Ocular Drug Delivery of Curcumin

The therapeutic potential of curcumin is substantially hindered by its poor bioavailability, even when administered at high oral doses (12 g/d) [27]. Several factors contribute to this limitation, including retention of curcumin at the pre-enterocytic level by gastrointestinal mucus, which contains enzymes capable of modifying curcumin before absorption [27]. Additionally, curcumin interacts with enterocytic proteins that alter its structure, further impairing its absorption [27]. Once absorbed, curcumin undergoes extensive phase I (modification) and phase II (conjugation) metabolism, primarily in the liver, intestines, and gut microbiota, producing curcumin glucuronide and curcumin sulfate [28]. Double bonds are further reduced by cellular reductases, producing metabolites such as dihydrocurcumin, tetrahydrocurcumin, hexahydrocurcumin, and octahydrocurcumin. Some of these exhibit significant antioxidant activity, potentially contributing to the therapeutic effects of curcumin [29, 30]. However, limited solubility, rapid systemic metabolism, and degradation upon exposure to gastrointestinal fluids generally contribute to the poor oral bioavailability of curcumin [31]. Additionally, curcumin in solution is susceptible to photodegradation under UV exposure, complicating its physical handling [31].

Delivery of curcumin to the eye presents further challenges because of the pharmacokinetic and pharmacodynamic barriers of the ocular environment. Tear production, blinking, and clearance mechanisms limit drug retention and absorption, and the anatomical complexity of the anterior and posterior segments further reduces bioavailability [32]. Extensive research has focused on strategies to enhance curcumin bioavailability, including structural modifications, bioavailability enhancers, and advanced delivery systems [33]. Curcumin analogs, which are synthetic or modified derivatives, have been developed to improve pharmacokinetic properties. The curcumin molecule features a highly reactive β-diketone group—a key factor contributing to its low bioavailability; various analogs have been synthesized to address this issue [34]. Wang et al. designed the prodrug dephosphorylated curcumin, which demonstrated improved molecular stability in aqueous environments [35]. Similarly, Muangnoi et al. investigated the antioxidant properties of curcumin and its prodrug, curcumin diethyl disuccinate (CurDD), demonstrating that both protect against oxidative stress, with CurDD offering superior protection. This suggests that CurDD may be a promising therapeutic agent, particularly for AMD [36].

Another approach to improve the bioavailability of curcumin involves bioavailability enhancers such as piperine, a bioactive component of black pepper that inhibits intestinal glucuronidation of curcumin, significantly increasing its systemic availability [37-39]. These strategies aim to optimize the therapeutic potential of curcumin by overcoming its pharmacokinetic limitations.

Advances in Curcumin Formulations for Ocular Delivery

Nanoparticles: Nanoparticle-based delivery systems have emerged as a promising strategy to enhance the stability, bioavailability, and controlled release of curcumin in ocular therapies [1]. A Pluronic-F127-stabilized curcumin nanoparticle system (<20 nm) demonstrated high solubility (4.3 mg/mL) and neuroprotective effects, significantly reducing retinal ganglion cell loss in glaucoma models [40]. Similarly, curcumin-loaded nanoparticles (170.2 nm) developed for dry eye disease exhibited high drug entrapment (90%) and sustained release, with *ex vivo* and *in vivo* studies confirming their safety and therapeutic potential [41]. In corneal neovascularization, methoxy poly ethylene glycol-poly [ε-caprolactone] nanoparticles improved curcumin retention, reduced angiogenic sprouting, and downregulated vascular endothelial growth factor (VEGF), inflammatory cytokines, and matrix metalloproteinases [42]. Additionally, they inhibited nuclear factor kappa B activation in lipopolysaccharide induced corneal cells without adverse structural effects [42]. These findings support curcumin nanoparticles as a promising therapy for various ocular diseases, including glaucoma, dry eye disease, and corneal neovascularization [40-42].

Liposomal Systems: Liposomal carriers enhance the bioavailability and stability of curcumin by encapsulating the drug within lipid bilayers, protecting it from degradation and improving ocular tissue penetration [43]. A variety of polyethylene glycol and d-alpha-tocopheryl polyethylene glycol 1000 succinate-based nanocarriers have been developed for ocular drug

delivery, including nanoparticles [44, 45], micelles [46], and solid lipid nanoparticles [47]. These formulations improve drug retention, prolong release, and enhance therapeutic efficacy in ocular diseases.

Micelles and Micellar Solutions: Nanomicellar systems have emerged as a promising enhancement of the solubility, stability, and ocular delivery of curcumin by forming colloidal structures that improve drug dispersion and absorption in ocular tissues [48]. In vitro and in vivo studies demonstrated that compared to free curcumin solutions, curcumin-loaded nanomicelles significantly enhance cellular uptake and corneal permeation, exhibiting excellent ocular tolerance with no signs of irritation in rabbit models [49]. Additionally, the synthesized micellar curcumin formulations demonstrated negligible toxicity and good cytocompatibility, rendering them as promising nanocarriers for ocular drug delivery for conditions including hypertensive eye diseases [50]. Moreover, Guo et al. demonstrated that intranasal nanomicellar curcumin promotes corneal epithelial and nerve wound healing in a diabetic mouse model with corneal abrasion [51].

Hydrogel-Based Systems: Hydrogel-based systems have emerged as effective curcumin delivery platforms in ocular therapies, offering controlled and sustained drug release to maintain therapeutic levels and improve patient compliance [1]. Curcumin nanoparticles with β-cyclodextrin in a hyaluronic acid hydrogel significantly reduced dosing frequency compared to conventional treatments, enhancing tissue healing in ulcerative keratitis [52]. Additionally, an alginate-incorporated curcumin hydrogel demonstrated potential as a surgical graft in retinal tissue engineering [53].

Nanoemulsions: Nanoemulsions have emerged as an effective strategy for ocular curcumin delivery by enhancing solubility, improving bioavailability, and enabling targeted drug delivery with minimal systemic side effects [54]. A curcumin-based nanoemulsion eye drop demonstrated promising therapeutic potential for dry eye syndrome in mice [55].

Microspheres and Transferosomes: Transferosomes have emerged as a promising ocular delivery platform for hydrophobic drugs, demonstrating good corneal biocompatibility and significantly enhanced corneal and conjunctival penetration [56]. These vesicular carriers enable deeper drug delivery, improving the therapeutic potential of curcumin for ophthalmic applications [56]. Additionally, curcumin microspheres have been explored as a floating drug delivery system for sustained oral administration, highlighting their potential for extended drug release [57].

This review highlights the promising therapeutic potential of curcumin in the management of ocular diseases, emphasizing its well-documented anti-inflammatory, antioxidant, and immunomodulatory effects. A major strength of this review is its focused synthesis of recent innovations in drug delivery systems for curcumin aimed at overcoming its limited bioavailability—one of the primary barriers to its clinical application. However, the review is limited by the heterogeneity of study designs and the predominance of preclinical data, which limits conclusiveness regarding clinical efficacy. Furthermore, variations in formulation strategies and outcome measures complicate direct comparisons across studies. Further research should prioritize well-designed clinical trials to validate the therapeutic benefits of curcumin in ocular diseases. In parallel, the continued development and standardization of advanced delivery systems are essential to ensure consistent bioavailability, targeted delivery, and sustained therapeutic action in ocular tissues.

CONCLUSIONS

Curcumin has garnered attention in ophthalmology because of its multifaceted therapeutic properties, including anti-inflammatory, antioxidant, VEGF inhibitory, apoptosis regulating, antibacterial, and immunomodulatory actions. These properties have demonstrated promising results in both in vivo and in vitro studies, highlighting the potential of curcumin in treating various ophthalmic conditions, such as corneal neovascularization, corneal wound healing, dry eye disease, conjunctivitis, pterygium, anterior uveitis, glaucoma, cataracts, AMD, and diabetic retinopathy. However, its therapeutic potential is significantly limited by its poor bioavailability. To address these challenges, substantial research has focused on enhancing the bioavailability of curcumin through the development of structural analogs, bioavailability enhancers, and advanced drug delivery systems. Innovative formulations, including nanoparticles, liposomal systems, micellar solutions, hydrogel-based systems, nanoemulsions, microspheres, and transferosomes, are promising approaches to improve the stability, bioavailability, and controlled release of curcumin, offering a hopeful avenue for its future application in ocular therapies.

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REFERENCES

1. Ribeiro A, Oliveira D, Cabral-Marques H. Curcumin in Ophthalmology: Mechanisms, Challenges, and Emerging Opportunities. Molecules. 2025 Jan 21;30(3):457. doi: 10.3390/molecules30030457. PMID: 39942561; PMCID: PMC11820683.
2. Hewlings SJ, Kalman DS. Curcumin: A Review of Its Effects on Human Health. Foods. 2017 Oct 22;6(10):92. doi: 10.3390/foods6100092. PMID: 29065496; PMCID: PMC5664031.
3. Panknin TM, Howe CL, Hauer M, Bucchireddigari B, Rossi AM, Funk JL. Curcumin Supplementation and Human Disease: A Scoping Review of Clinical Trials. Int J Mol Sci. 2023 Feb 24;24(5):4476. doi: 10.3390/ijms24054476. PMID: 36901908; PMCID: PMC10003109.
4. Baker M. Deceptive curcumin offers cautionary tale for chemists. Nature. 2017 Jan 11;541(7636):144-145. doi: 10.1038/541144a. PMID: 28079090.
5. Bisson J, McAlpine JB, Friesen JB, Chen SN, Graham J, Pauli GF. Can Invalid Bioactives Undermine Natural Product-Based Drug Discovery? J Med Chem. 2016 Mar 10;59(5):1671-90. doi: 10.1021/acs.jmedchem.5b01009. Epub 2015 Oct 27. PMID: 26505758; PMCID: PMC4791574.
6. Radomska-Leśniewska DM, Osiecka-Iwan A, Hyc A, Góźdź A, Dąbrowska AM, Skopiński P. Therapeutic potential of curcumin in eye diseases. Cent Eur J Immunol. 2019;44(2):181-189. doi: 10.5114/ceji.2019.87070. Epub 2019 Jul 30. PMID: 31530988; PMCID: PMC6745545.
7. Chandrasekaran PR, Madanagopalan VG. Role of Curcumin in Retinal Diseases-A review. Graefes Arch Clin Exp Ophthalmol. 2022 May;260(5):1457-1473. doi: 10.1007/s00417-021-05542-0. Epub 2022 Jan 11. PMID: 35015114; PMCID: PMC8748528.
8. Aggarwal BB, Gupta SC, Sung B. Curcumin: an orally bioavailable blocker of TNF and other pro-inflammatory biomarkers. Br J Pharmacol. 2013 Aug;169(8):1672-92. doi: 10.1111/bph.12131. PMID: 23425071; PMCID: PMC3753829.
9. Chen M, Hu DN, Pan Z, Lu CW, Xue CY, Aass I. Curcumin protects against hyperosmoticity-induced IL-1beta elevation in human corneal epithelial cell via MAPK pathways. Exp Eye Res. 2010 Mar;90(3):437-43. doi: 10.1016/j.exer.2009.12.004. Epub 2009 Dec 23. PMID: 20026325.
10. Karakuş MM, Çalışkan UK. Phytotherapeutic and Natural Compound Applications for Age-Related, Inflammatory and Serious Eye Ailments. Curr Mol Pharmacol. 2021;14(5):689-713. doi: 10.2174/1874467213666201221163210. PMID: 33349225.
11. Kumar B, Aggarwal R, Prakash U, Sahoo PK. Emerging therapeutic potential of curcumin in the management of dermatological diseases: an extensive review of drug and pharmacological activities. Future Journal of Pharmaceutical Sciences. 2023 May 22;9(1):42. doi: 10.1186/s43094-023-00493-1.
12. Heydari M, Khalili MR, Nowroozzadeh MH, Bamdad S, Sahebkar A, Shariati MA, Thiruvengadam M. Therapeutic implications of curcumin in the treatment of inflammatory eye diseases: A review. Current Pharmaceutical Biotechnology. 2023 Mar 1;24(4):553-61. doi.org/10.2174/1389201023666220609085614.
13. Allegrini D, Raimondi R, Borgia A, Sorrentino T, Montesano G, Tsoutsanis P, Cancian G, Verma Y, De Rosa FP, Romano MR. Curcumin in Retinal Diseases: A Comprehensive Review from Bench to Bedside. Int J Mol Sci. 2022 Mar 24;23(7):3557. doi: 10.3390/ijms23073557. PMID: 35408920; PMCID: PMC8998602.
14. Wang L, Li C, Guo H, Kern TS, Huang K, Zheng L. Curcumin inhibits neuronal and vascular degeneration in retina after ischemia and reperfusion injury. PLoS One. 2011;6(8):e23194. doi: 10.1371/journal.pone.0023194. Epub 2011 Aug 9. PMID: 21858029; PMCID: PMC3153496.
15. Ashrafizadeh M, Ahmadi Z, Mohammadinejad R, Farkhondeh T, Samarghandian S. Curcumin Activates the Nrf2 Pathway and Induces Cellular Protection Against Oxidative Injury. Curr Mol Med. 2020;20(2):116-133. doi: 10.2174/1566524019666191016150757. PMID: 31622191.
16. Lin TC, Lin YY, Hsu CC, Yang YP, Yang CH, Hwang DK, Wang CY, Liu YY, Lo WL, Chiou SH, Peng CH, Chen SJ, Chang YL. Nanomedicine-based Curcumin Approach Improved ROS Damage in Best Dystrophy-specific Induced Pluripotent Stem Cells. Cell Transplant. 2019 Nov;28(11):1345-1357. doi: 10.1177/0963689719860130. Epub 2019 Jul 17. PMID: 31313605; PMCID: PMC6802151.
17. Buccarello L, Dragotto J, Hassanzadeh K, Maccarone R, Corbo M, Feligioni M. Retinal ganglion cell loss in an ex vivo mouse model of optic nerve cut is prevented by curcumin treatment. Cell Death Discov. 2021 Dec 15;7(1):394. doi: 10.1038/s41420-021-00760-1. PMID: 34911931; PMCID: PMC8674341.
18. Guo SP, Chang HC, Lu LS, Liu DZ, Wang TJ. Activation of kelch-like ECH-associated protein 1/nuclear factor erythroid 2-related factor 2/antioxidant response element pathway by curcumin enhances the anti-oxidative capacity of corneal endothelial cells. Biomed Pharmacother. 2021 Sep;141:111834. doi: 10.1016/j.biopha.2021.111834. Epub 2021 Jun 18. PMID: 34153850.
19. Qiao Y, He J, Chen W, Yu Y, Li W, Du Z, Xie T, Ye Y, Hua SY, Zhong D, Yao K, Zhou M. Light-Activatable Synergistic Therapy of Drug-Resistant Bacteria-Infected Cutaneous Chronic Wounds and Nonhealing Keratitis by Cupriferous Hollow Nanoshells. ACS Nano. 2020 Mar 24;14(3):3299-3315. doi: 10.1021/acsnano.9b08930. Epub 2020 Feb 17. PMID: 32048825.
20. Mandal MN, Patlolla JM, Zheng L, Agbaga MP, Tran JT, Wicker L, Kasus-Jacobi A, Elliott MH, Rao CV, Anderson RE. Curcumin protects retinal cells from light-and oxidant stress-induced cell death. Free Radic Biol Med. 2009 Mar 1;46(5):672-9. doi: 10.1016/j.freeradbiomed.2008.12.006. Epub 2008 Dec 24. PMID: 19121385; PMCID: PMC2810836.
21. Hollborn M, Chen R, Wiedemann P, Reichenbach A, Bringmann A, Kohen L. Cytotoxic effects of curcumin in human retinal pigment epithelial cells. PLoS One. 2013;8(3):e59603. doi: 10.1371/journal.pone.0059603. Epub 2013 Mar 26. PMID: 23555722; PMCID: PMC3608655.

22. Li J, Wang P, Zhu Y, Chen Z, Shi T, Lei W, Yu S. Curcumin Inhibits Neuronal Loss in the Retina and Elevates Ca^{2+}/Calmodulin-Dependent Protein Kinase II Activity in Diabetic Rats. J Ocul Pharmacol Ther. 2015 Nov;31(9):555-62. doi: 10.1089/jop.2015.0006. Epub 2015 Jul 24. PMID: 26207889; PMCID: PMC4642824.
23. Carozza G, Tisi A, Capozzo A, Cinque B, Giovannelli A, Feligioni M, Flati V, Maccarone R. New Insights into Dose-Dependent Effects of Curcumin on ARPE-19 Cells. Int J Mol Sci. 2022 Nov 25;23(23):14771. doi: 10.3390/ijms232314771. PMID: 36499098; PMCID: PMC9738655.
24. Esfandiari A, Hashemi F. Protective effects of curcumin on ischemic reperfusion of rat retina. Comparative Clinical Pathology. 2019 Feb 5;28:89-95. doi: 10.1007/s00580-019-02894-2.
25. Zhao X, Gao M, Liang J, Chen Y, Wang Y, Wang Y, Xiao Y, Zhao Z, Wan X, Jiang M, Luo X, Wang F, Sun X. SLC7A11 Reduces Laser-Induced Choroidal Neovascularization by Inhibiting RPE Ferroptosis and VEGF Production. Front Cell Dev Biol. 2021 Feb 18;9:639851. doi: 10.3389/fcell.2021.639851. PMID: 33681224; PMCID: PMC7930391.
26. Haghshenas L, Banihashemi S, Malekzadegan Y, Catanzaro R, Moghadam Ahmadi A, Marotta F. Microbiome as an endocrine organ and its relationship with eye diseases: Effective factors and new targeted approaches. World J Gastrointest Pathophysiol. 2024 Sep 22;15(5):96446. doi: 10.4291/wjgp.v15.i5.96446. PMID: 39355345; PMCID: PMC11440246.
27. Anand P, Kunnumakkara AB, Newman RA, Aggarwal BB. Bioavailability of curcumin: problems and promises. Mol Pharm. 2007 Nov-Dec;4(6):807-18. doi: 10.1021/mp700113r. Epub 2007 Nov 14. PMID: 17999464.
28. Vareed SK, Kakarala M, Ruffin MT, Crowell JA, Normolle DP, Djuric Z, Brenner DE. Pharmacokinetics of curcumin conjugate metabolites in healthy human subjects. Cancer Epidemiol Biomarkers Prev. 2008 Jun;17(6):1411-7. doi: 10.1158/1055-9965.EPI-07-2693. PMID: 18559556; PMCID: PMC4138955.
29. Dei Cas M, Ghidoni R. Dietary Curcumin: Correlation between Bioavailability and Health Potential. Nutrients. 2019 Sep 8;11(9):2147. doi: 10.3390/nu11092147. PMID: 31500361; PMCID: PMC6770259.
30. Luca SV, Macovei I, Bujor A, Miron A, Skalicka-Woźniak K, Aprotosoaie AC, Trifan A. Bioactivity of dietary polyphenols: The role of metabolites. Crit Rev Food Sci Nutr. 2020;60(4):626-659. doi: 10.1080/10408398.2018.1546669. Epub 2019 Jan 7. PMID: 30614249.
31. Sasaki H, Sunagawa Y, Takahashi K, Imaizumi A, Fukuda H, Hashimoto T, Wada H, Katanasaka Y, Kakeya H, Fujita M, Hasegawa K, Morimoto T. Innovative preparation of curcumin for improved oral bioavailability. Biol Pharm Bull. 2011;34(5):660-5. doi: 10.1248/bpb.34.660. PMID: 21532153.
32. Maharjan P, Cho KH, Maharjan A, Shin MC, Moon C, Min KA. Pharmaceutical challenges and perspectives in developing ophthalmic drug formulations. Journal of Pharmaceutical Investigation. 2019 Mar 15;49:215-28. doi: 10.1007/s40005-018-0404-6.
33. Nebbioso M, Franzone F, Greco A, Gharbiya M, Bonfiglio V, Polimeni A. Recent Advances and Disputes About Curcumin in Retinal Diseases. Clin Ophthalmol. 2021 Jun 18;15:2553-2571. doi: 10.2147/OPTH.S306706. PMID: 34177257; PMCID: PMC8219301.
34. Noureddin SA, El-Shishtawy RM, Al-Footy KO. Curcumin analogues and their hybrid molecules as multifunctional drugs. Eur J Med Chem. 2019 Nov 15;182:111631. doi: 10.1016/j.ejmech.2019.111631. Epub 2019 Aug 19. PMID: 31479974.
35. Wang J, Xiong T, Zhou J, He H, Wu D, Du X, Li X, Xu B. Enzymatic formation of curcumin in vitro and in vivo. Nano Research. 2018 Jun;11:3453-61. doi: 10.1007/s12274-018-1994-z.
36. Muangnoi C, Sharif U, Ratnatilaka Na Bhuket P, Rojsitthisak P, Paraoan L. Protective Effects of Curcumin Ester Prodrug, Curcumin Diethyl Disuccinate against H2O2-Induced Oxidative Stress in Human Retinal Pigment Epithelial Cells: Potential Therapeutic Avenues for Age-Related Macular Degeneration. Int J Mol Sci. 2019 Jul 9;20(13):3367. doi: 10.3390/ijms20133367. PMID: 31323999; PMCID: PMC6651864.
37. Aggarwal BB, Harikumar KB. Potential therapeutic effects of curcumin, the anti-inflammatory agent, against neurodegenerative, cardiovascular, pulmonary, metabolic, autoimmune and neoplastic diseases. Int J Biochem Cell Biol. 2009 Jan;41(1):40-59. doi: 10.1016/j.biocel.2008.06.010. Epub 2008 Jul 9. PMID: 18662800; PMCID: PMC2637808.
38. Ohori H, Yamakoshi H, Tomizawa M, Shibuya M, Kakudo Y, Takahashi A, Takahashi S, Kato S, Suzuki T, Ishioka C, Iwabuchi Y, Shibata H. Synthesis and biological analysis of new curcumin analogues bearing an enhanced potential for the medicinal treatment of cancer. Mol Cancer Ther. 2006 Oct;5(10):2563-71. doi: 10.1158/1535-7163.MCT-06-0174. PMID: 17041101.
39. Shoba G, Joy D, Joseph T, Majeed M, Rajendran R, Srinivas PS. Influence of piperine on the pharmacokinetics of curcumin in animals and human volunteers. Planta Med. 1998 May;64(4):353-6. doi: 10.1055/s-2006-957450. PMID: 9619120.
40. Davis BM, Pahlitzsch M, Guo L, Balendra S, Shah P, Ravindran N, Malaguarnera G, Sisa C, Shamsher E, Hamze H, Noor A, Sornsute A, Somavarapu S, Cordeiro MF. Topical Curcumin Nanocarriers are Neuroprotective in Eye Disease. Sci Rep. 2018 Jul 23;8(1):11066. doi: 10.1038/s41598-018-29393-8. PMID: 30038334; PMCID: PMC6056418.
41. Laddha UD, Chikhale SS, Dashputre NL, Gaikwad SS, Moravkar KK, Kshirsagar SJ. Development and in vitro, ex vivo, in vivo investigation of curcumin loaded nanoparticles in management of dry eye disease. Journal of Drug Delivery Science and Technology. 2023 Sep 1;87:104802. doi: 10.1016/j.jddst.2023.104802.
42. Pradhan N, Guha R, Chowdhury S, Nandi S, Konar A, Hazra S. Curcumin nanoparticles inhibit corneal neovascularization. J Mol Med (Berl). 2015 Oct;93(10):1095-106. doi: 10.1007/s00109-015-1277-z. Epub 2015 Apr 17. PMID: 25877858.
43. Farooq MA, Trevaskis NL. TPGS Decorated Liposomes as Multifunctional Nano-Delivery Systems. Pharm Res. 2023 Jan;40(1):245-263. doi: 10.1007/s11095-022-03424-6. Epub 2022 Nov 14. PMID: 36376604; PMCID: PMC9663195.
44. Warsi MH. Development and optimization of vitamin E TPGS based PLGA nanoparticles for improved and safe ocular delivery of ketorolac. Journal of Drug Delivery Science and Technology. 2021 Feb 1;61:102121. doi: 10.1016/j.jddst.2020.102121.
45. Alkholief M, Albasit H, Alhowyan A, Alshehri S, Raish M, Abul Kalam M, Alshamsan A. Employing a PLGA-TPGS based nanoparticle to improve the ocular delivery of Acyclovir. Saudi Pharm J. 2019 Feb;27(2):293-302. doi: 10.1016/j.jsps.2018.11.011. Epub 2018 Nov 23. PMID: 30766442; PMCID: PMC6362158.

46. Grimaudo MA, Pescina S, Padula C, Santi P, Concheiro A, Alvarez-Lorenzo C, Nicoli S. Poloxamer 407/TPGS Mixed Micelles as Promising Carriers for Cyclosporine Ocular Delivery. Mol Pharm. 2018 Feb 5;15(2):571-584. doi: 10.1021/acs.molpharmaceut.7b00939. Epub 2018 Jan 24. PMID: 29313693.
47. Shahab MS, Rizwanullah M, Imam SS. Formulation, optimization and evaluation of vitamin E TPGS emulsified dorzolamide solid lipid nanoparticles. Journal of drug delivery science and technology. 2022 Feb 1;68:103062. doi: 10.1016/j.jddst.2021.103062.
48. Alshamrani M, Sikder S, Coulibaly F, Mandal A, Pal D, Mitra AK. Self-Assembling Topical Nanomicellar Formulation to Improve Curcumin Absorption Across Ocular Tissues. AAPS PharmSciTech. 2019 Jul 17;20(7):254. doi: 10.1208/s12249-019-1404-1. PMID: 31317354.
49. Li M, Xin M, Guo C, Lin G, Wu X. New nanomicelle curcumin formulation for ocular delivery: improved stability, solubility, and ocular anti-inflammatory treatment. Drug Dev Ind Pharm. 2017 Nov;43(11):1846-1857. doi: 10.1080/03639045.2017.1349787. Epub 2017 Jul 11. PMID: 28665151.
50. Duan Y, Cai X, Du H, Zhai G. Novel in situ gel systems based on P123/TPGS mixed micelles and gellan gum for ophthalmic delivery of curcumin. Colloids Surf B Biointerfaces. 2015 Apr 1;128:322-330. doi: 10.1016/j.colsurfb.2015.02.007. Epub 2015 Feb 11. PMID: 25707750.
51. Guo C, Li M, Qi X, Lin G, Cui F, Li F, Wu X. Intranasal delivery of nanomicelle curcumin promotes corneal epithelial wound healing in streptozotocin-induced diabetic mice. Sci Rep. 2016 Jul 11;6:29753. doi: 10.1038/srep29753. PMID: 27405815; PMCID: PMC5378915.
52. Sohani Z, Jamshidi S, Koohi MK, Malakootikhah J, Abarkar M, Golchin D, Roshani S, Naghdi H, Aghajanpour-Moghaddam-Gazafroudi N, Gazafroudi, Amjadi N, Izadi-Niaki R. Novel ophthalmic hyaluronic acid-hydrogel with curcumin nanoparticles for enhanced healing of ulcerative keratitis in rabbit model. Sci Rep. 2024 Oct 4;14(1):23046. doi: 10.1038/s41598-024-74195-w. PMID: 39367103; PMCID: PMC11452625.
53. Park JH, Shin EY, Shin ME, Choi MJ, Carlomagno C, Song JE, Khang G. Enhanced retinal pigment epithelium (RPE) regeneration using curcumin/alginate hydrogels: In vitro evaluation. Int J Biol Macromol. 2018 Oct 1;117:546-552. doi: 10.1016/j.ijbiomac.2018.05.127. Epub 2018 May 18. PMID: 29782973.
54. Rachmawati H, Budiputra DK, Mauludin R. Curcumin nanoemulsion for transdermal application: formulation and evaluation. Drug Dev Ind Pharm. 2015 Apr;41(4):560-6. doi: 10.3109/03639045.2014.884127. Epub 2014 Feb 7. PMID: 24502271.
55. Hadipour Jahromy M, Qomi M, Fazelipour S, Sami N, Faali F, Karimi M, Adhami Moghadam F. Evaluation of curcumin-based ophthalmic nano-emulsion on atropine-induced dry eye in mice. Heliyon. 2024 Apr 3;10(7):e29009. doi: 10.1016/j.heliyon.2024.e29009. PMID: 38601632; PMCID: PMC11004198.
56. Barbalho GN, Brugger S, Raab C, Lechner JS, Gratieri T, Keck CM, Rupenthal ID, Agarwal P. Development of transferosomes for topical ocular drug delivery of curcumin. Eur J Pharm Biopharm. 2024 Dec;205:114535. doi: 10.1016/j.ejpb.2024.114535. Epub 2024 Oct 18. PMID: 39427684.
57. Kumar K, Pant NC, Ahmad S, Fateh MV, Rai AK, Verma B, Chaurasia H. Development and evaluation of floating microspheres of curcumin in alloxan-induced diabetic rats. Tropical Journal of Pharmaceutical Research. 2016 Oct 5;15(9):1819-25. doi: 10.4314/tjpr.v15i9.1.