Review Article

Choroidal melanoma treatment: a shift towards vision preservation

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ABSTRACT

Background: Choroidal melanoma is the most common primary intraocular malignancy in adults, and is known for its aggressive nature and potential for metastasis. Historically, enucleation was the primary treatment, which resulted in significant morbidity and psychological distress. Recent advances have led to a paradigm shift towards vision-preserving therapies. This review aimed to explore advances in choroidal melanoma treatment and their impact on patient care and quality of life.

Methods: For this narrative review, we conducted a literature search of major databases, including PubMed/MEDLINE, Embase, and Scopus, from January 1, 1998, to December 30, 2024. The search strategy employed the following keywords: "choroidal melanoma," "vision preservation," "plaque brachytherapy," "proton beam therapy," "stereotactic radiosurgery," "enucleation," "ocular oncology," "retinal health," "visual acuity," "quality of life," "computational intelligence," and "AI (artificial intelligence)." We included English-language studies of any design focusing on choroidal melanoma treatment, particularly treatment involving vision-preserving strategies.

Results: Advances in vision-preserving therapies, such as plaque brachytherapy, proton-beam irradiation, and stereotactic radiosurgery, have revolutionized the management of choroidal melanoma. These modalities offer improved patient outcomes by reducing the need for enucleation and preserving visual acuity. Plaque brachytherapy achieves high tumor-control rates with minimal side effects, while proton-beam irradiation provides precise tumor targeting, which is particularly beneficial for large tumors. Stereotactic radiosurgery is effective for smaller tumors, but may result in decreased visual acuity over time. Emerging therapies, such as Bel-Sar (AU-011), show promise in controlling tumor growth while preserving vision. The ability of Bel-Sar to control tumors while preserving vision could provide patients with a more favorable prognosis and improved quality of life. Immunotherapy holds significant promise, particularly with the potential for use of immune checkpoint inhibitors and vaccine therapies. Additionally, artificial intelligence (AI) is becoming increasingly important in the management of choroidal melanoma.

Conclusions: The shift from enucleation to vision-preserving therapies has significantly improved outcomes and quality of life for patients with choroidal melanoma. Future research should focus on optimizing current therapies for better visual acuity preservation and on exploring new targeted therapies to enhance tumor control while minimizing side effects. Moreover, studies on AI applications for managing this sight- and life-threatening eye condition could significantly transform treatment outcomes.

KEYWORDS

choroidal melanoma, enucleation surgery, vision, radioisotope brachytherapy, radioisotope plaque therapy, proton beam radiation therapy, targeted molecular therapy, computational intelligence, AI (artificial intelligence)

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INTRODUCTION

Choroidal melanoma is the most common primary intraocular malignancy in adults, and represents a significant portion of all melanomas diagnosed [1]. Choroidal melanoma is also the most common type of uveal melanoma [2]. This rare but aggressive cancer affects the choroid and has a high likelihood of metastasis, particularly to the liver [2]. The incidence of choroidal melanoma varies with higher rates observed in populations of Northern European descent, particularly among those with lighter skin and blue eyes [3]. In the United States (US), the incidence is approximately six cases per million annually, while in Scandinavian countries, it reaches up to 7.5 cases per million annually [1].

The psychological and functional impact of vision loss due to choroidal melanoma cannot be overstated. Preserving vision is crucial for maintaining quality of life, as the ability to see affects not only one's physical ability to perform daily tasks, but also has a profound psychological impact [4-7]. Historically, enucleation was the primary treatment approach for choroidal melanoma, which, while effective for preventing metastasis, resulted in significant morbidity and was associated with worse vision-specific quality of life [4, 5]. However, advances in medical technology and treatment modalities have led to a paradigm shift in the management of this disease in recent years [8], with a growing emphasis on vision-preserving therapies [8]. These include plaque radiation therapy, proton-beam therapy (PBT), and other forms of external beam radiation. These innovations have markedly improved patient outcomes by reducing the need for enucleation and by preserving visual acuity [1, 5, 9, 10].

This narrative review explored advances in choroidal melanoma treatment, highlighting the shift from enucleation to vision-preserving therapies and their impact on patient care and quality of life. This narrative synthesis integrated the findings of diverse studies to provide a comprehensive overview of current information and to highlight the knowledge gaps in the field of choroidal melanoma treatment.

METHODS

For this narrative review, a literature search spanning multiple decades was conducted in major electronic databases: PubMed/MEDLINE, Embase, and Scopus. The search strategy employed the following keywords: "choroidal melanoma," "vision preservation," "plaque brachytherapy," "proton beam therapy," "stereotactic radiosurgery," "enucleation," "ocular oncology," "retinal health," "visual acuity," "quality of life," "computational intelligence," and "AI (artificial intelligence)." The search was limited to articles published from January 1, 1998, to December 30, 2024.

The inclusion criteria for this review were studies of any design focusing on choroidal melanoma treatment, particularly those emphasizing vision preservation strategies, pathological findings, diagnostic methodologies, and therapeutic interventions. Only English-language studies were considered. Exclusion criteria included non-English studies and articles not specifically addressing choroidal melanoma or vision-preserving treatment for this condition. The selected articles were assessed based on their relevance to advances in choroidal melanoma treatment, focusing on vision-preserving strategies, pathological findings, diagnostic methodologies, and therapeutic interventions. Furthermore, the reference lists of the included papers were searched manual to select further relevant studies.

RESULTS and DISSCUSSION

Historical context of choroidal melanoma treatment

Choroidal melanoma has a complex history of treatment that has evolved significantly over the years [1]. Traditional treatments have included enucleation and external beam radiation therapy (EBRT), each of which has its own benefits and drawbacks [11, 12].

Historically, the primary treatment for choroidal melanoma was enucleation, i.e., surgical removal of the affected eye. This method was the gold standard for centuries, due to its ability to provide a histological diagnosis and potentially reduce the risk of local recurrence [12, 13]. However, despite its widespread use, enucleation had significant drawbacks, including the loss of vision and the potential psychological impact on patients. Moreover, concerns existed that enucleation might facilitate metastasis by altering the immune system, allowing existing micrometastases to grow unchecked [13]. One study indicated that, while enucleation after definitive radiotherapy did not negatively impact survival if the tumor was non-viable, it was associated with high death rates if it was performed due to tumor regrowth. This suggests that enucleation may not prevent systemic recurrence in cases of active tumor [14, 15].

EBRT was introduced as an alternative to enucleation, offering a way to preserve the eye. Early forms of EBRT included techniques, such as PBT and stereotactic Gamma Knife radiosurgery [16, 17]. While EBRT can be effective, it often requires specialized equipment and may not be as widely available as other treatments. Additionally, EBRT can cause significant side effects, including vision loss, cataracts, retinal detachment, and neovascular glaucoma. Notably, some patients might still require enucleation due to complications, such as tumor regrowth [13, 18].

Cosmetic issues associated with enucleation can be significant, as it involves the removal of the eye, and possibly replacement with a prosthetic eye [19, 20]. One study using a novel prosthesis for orbital reconstruction after enucleation reported excellent cosmetic results, with minimal complications, and highlighted the importance of post-surgical care in maintaining patients' quality of life [19]. Notably, patients facing enucleation or significant vision loss often experience

anxiety, depression, and a reduced quality of life. The loss of an eye can affect self-esteem and social interactions [5]. This emphasizes the need for more effective and safer treatments that can preserve vision and improve quality of life [5, 6].

Current vision-preserving treatments

Plaque brachytherapy

Plaque brachytherapy is a highly effective vision-preserving treatment for choroidal melanoma that offers localized radiation delivery using radioactive plaques [21, 22]. This method involved attaching a small carrier containing radioactive "seeds" to a plaque, which is then placed on the outside of the eyeball over the tumor site. The plaque is designed to shield nearby tissues from radiation, ensuring that most of the radiation is focused on the tumor [22].

Mechanisms and benefits: Plaque brachytherapy involves delivery of a precise dose of radiation directly to the tumor, minimizing exposure to surrounding healthy tissues. This localized approach helps to reduce the risk of complications, such as radiation retinopathy and optic neuropathy, which are common with more generalized radiation therapies [16, 23]. The choice of radioisotope, such as iodine-125 or ruthenium-106, depends on the tumor characteristics and desired treatment duration [24]. The benefits of plaque brachytherapy include high tumor-control rates and relatively minimal side effects as compared to that of other treatments, such as enucleation. Plaque brachytherapy has been shown to achieve comparable survival rates to enucleation for medium-sized tumors, making it a preferred option for preserving vision as well as the eye [24]. Additionally, advances in plaque design and customization allow for more precise radiation delivery, further reducing potential complications [22].

Outcomes: A retrospective case series involving 400 patients treated with palladium-103 brachytherapy showed superior local tumor control and visual acuity outcomes as compared to those of other radiation therapies. The mean apical radiation dose was 73.3 gray (Gy) over 5–7 days [25]. A case report demonstrated successful treatment of an extra-large choroidal melanoma using a customized eye plaque, in which the tumor height was reduced from 13.7 mm to 4.8 mm, and vision improved to 20/60 by 1 year post-treatment [22]. Another study described the histological appearance of enucleated eyes treated with plaque brachytherapy, highlighting the effectiveness of this method in controlling tumors. However, it also noted complications, such as radiation retinopathy and optic neuropathy [23]. The Collaborative Ocular Melanoma Study compared iodine-125 brachytherapy with enucleation for choroidal melanoma. It found no significant difference in mortality rates between the two treatments, with 5-year survival rates of 81% for brachytherapy and 82% for enucleation [26]. Another study analyzed the regression patterns of choroidal melanomas after brachytherapy using radioactive isotopes of ruthenium and iodine. The results showed that the cross-sectional area of tumors decreased faster than did their thickness during the first year post-treatment. The study highlighted the heterogeneity in regression patterns, emphasizing the importance of considering tumor shape and regression patterns when evaluating treatment outcomes [27]. Finally, a study comparing eye plaque interstitial brachytherapy (EPIBT) with PBT for uveal melanoma found that EPIBT had higher 2-year (97% vs. 93%) and 5-year (77% vs. 51%) overall survival rates [28]. Overall, plaque brachytherapy offers a promising approach for managing choroidal melanoma while maintaining quality of life [29].

Proton-beam irradiation

Proton-beam irradiation (PBI) is a highly effective treatment for choroidal melanoma, offering precise delivery of proton radiation directly to the tumor while minimizing damage to surrounding healthy tissue [30, 31]. This precision is due to the unique physical properties of protons, which allow for a sharp dose fall-off outside the target area, thereby protecting critical structures, such as the retina and optic nerve [30, 31].

Mechanisms and benefits: PBI involves the use of protons, i.e., charged subatomic particles, to deliver powerful doses of radiation to the tumor. This method is particularly beneficial for tumors located near sensitive areas, such as the optic nerve or fovea, where traditional radiation therapies might cause significant collateral damage [30, 31]. PBI offers several advantages over other forms of radiation therapy, including reduced damage to surrounding tissue and improved vision preservation. PBI is particularly advantageous for large tumors or those in close proximity to critical ocular structures, as it provides effective tumor control while minimizing visual toxicities associated with other treatments, such as brachytherapy [30, 32]. Additionally, PBI is considered the gold standard for ocular melanomas, due to its ability to maintain eye function and structure [32].

Outcomes: A study examining the outcomes of 336 patients with large choroidal melanomas who underwent PBI found significant long-term results. Ten years post-treatment, the eye was preserved in 70%, and tumor control was achieved in 88% of the patients. However, visual acuity retention was less favorable, with only 9% maintaining a visual acuity of at least 20/200 and 22% able to count fingers at the same threshold [31]. A Korean study involving 24 patients with choroidal melanoma who were treated with PBT showed a gradual regression in tumor volume over time, as observed by magnetic resonance imaging. The local control rate and complication profile were comparable to those of previous studies [33]. A comprehensive review highlighted that proton therapy achieved consistently high local control rates, often exceeding 95% for uveal melanomas. This high efficacy was attributed to the precise delivery of protons, which minimized damage to surrounding tissues [32]. A study analyzing visual acuity outcomes in patients with small choroidal melanomas who were treated with PBI found that over half

of the patients had a visual acuity equivalent to 20/80 or worse at 5-years post-treatment, particularly for tumors near the optic disc or fovea [34]. PBT offers significant benefits for treating large uveal melanomas by delivering high doses of radiation while safeguarding critical eye structures, such as the optic nerve and retina. This precision allows for enhanced tumor control and minimizes visual complications as compared to other forms of radiation therapy [30]. In summary, PBI is a vision-preserving treatment for choroidal melanoma that offers precise tumor targeting, reduced tissue damage, and high local control rates, making it a preferred option for managing ocular melanomas [30-35].

Stereotactic radiosurgery

Mechanisms and benefits: Stereotactic radiosurgery (SRS) involves the delivery of high-dose radiation in a single session, which is particularly advantageous for its precision and non-invasive nature. This technique allows for steep dose-gradients outside the target volume, minimizing exposure to surrounding tissues and reducing potential side effects [36, 37]. Systems such as CyberKnife and Gamma Knife are commonly used in SRS, providing accurate irradiation of the tumor, while sparing critical structures, such as the optic nerve and macula [37, 38]. SRS has been shown to be effective for smaller choroidal melanomas, achieving high local control rates and allowing for rapid recovery times. Studies have reported tumor-control rates ranging from 84% to 100%, with eye preservation in 78–97.4% of cases [3, 37]. However, visual acuity may decrease over time due to complications, such as radiation retinopathy and maculopathy [39].

Outcomes: A case series using CyberKnife SRS for choroidal melanoma, conducted in Central America, achieved a 100% tumor-control rate without systemic metastases over a median follow-up of 27.5 months. However, most patients experienced a decline in visual acuity, with notable complications, including radiation maculopathy and retinopathy [39]. A study comparing SRS and PBT for posterior uveal melanoma found that both treatments were effective, with PBT offering better post-operative visual outcomes [40]. SRS is advantageous given that it is performed in a single session under local anesthesia, but visual loss after SRS was more common than after PBT [40]. The rate of visual decline with SRS is significantly influenced by the radiation dose and its proximity to critical visual structures, emphasizing the importance of precise dosing to minimize ocular complications [41]. Another study focusing on the early results of SRS in uveal melanoma found it to be an effective treatment modality for eye conservation. However, it also identified risk factors for radiation retinopathy, emphasizing the importance of careful patient selection and follow-up [42]. A study evaluating single-dose stereotactic radiotherapy for uveal melanoma reported high eye-preservation rates, similar to those achieved with fractionated stereotactic radiotherapy (78.6–97.4%). This approach is particularly useful for tumors not suitable for ruthenium brachytherapy due to their size or location [3].

In summary, while SRS is effective for smaller tumors, it can also be used in combination with other treatments for larger choroidal melanomas. For instance, PBT is often preferred for larger tumors due to its ability to deliver precise and uniform doses while sparing surrounding healthy tissues [40]. SRS can complement PBT by offering an alternative treatment for tumors that are not suitable to brachytherapy, or in cases where combined treatments are necessary [3]. This versatility makes SRS a valuable option in the management of choroidal melanoma, particularly when used alongside other modalities to optimize outcomes [3, 40].

Emerging therapies and technologies

Bel-Sar

Bel-Sar, also known as AU-011, is an innovative targeted therapy under investigation for treating early-stage choroidal melanoma [43-45]. It functions as a papillomavirus-like particle drug conjugate, specifically targeting modified heparin sulfate proteoglycans that are overexpressed in tumor cells. This targeted approach enables Bel-Sar to exert direct cytotoxic effects on tumor cells and to stimulate long-term antitumor immunity. Recent Phase 2 trial results [46], presented at the Retina Society Annual Meeting in Lisbon, Portugal, showcased promising outcomes for Bel-Sar. Among patients eligible for Phase 3 trials [47], an 80% tumor-control rate was achieved, with complete cessation of tumor growth following treatment. The average tumor growth rate decreased dramatically from 0.351 mm/year pre-treatment to 0.011 mm/year post-treatment, highlighting the efficacy of Bel-Sar ($P < 0.0001$). Notably, visual acuity was preserved in 90% of patients, constituting a significant achievement, considering that 80% of these patients were at high risk of vision loss due to the proximity of the tumor to critical visual structures. The safety profile of Bel-Sar was highly favorable, with no severe adverse effects and only mild ocular side effects reported. Bel-Sar has the potential to revolutionize the treatment paradigm for early-stage choroidal melanoma by offering a vision-preserving option [46, 47]. Current standard treatments, such as radiotherapy, often result in significant vision loss, with up to 87% of patients experiencing visual acuity below 20/200 (the threshold for legal blindness) after treatment [37, 48]. The ability of Bel-Sar to control tumors while preserving vision could provide patients with a more favorable prognosis and improved quality of life [46, 47]. Aura Biosciences is currently enrolling patients in a global Phase 3 trial to evaluate the efficacy and safety of Bel-Sar further [47].

Targeted therapies

Tebentafusp-tebn, marketed as Kimmtrak, is the first FDA-approved treatment specifically targeting metastatic uveal melanoma [49, 50]. It is a bispecific fusion protein that has transformed the treatment landscape for this aggressive form of

eye cancer [49, 50]. Tebentafusp works by targeting the gp100 protein on melanoma cells, fused to an anti-CD3 single-chain antibody fragment, thereby facilitating an immune attack on cancer cells. This mechanism allows for a more targeted approach, and enhancing the effectiveness of the immune response against melanoma cells [50, 51]. The introduction of tebentafusp has marked a significant advance in improving survival outcomes for patients with metastatic uveal melanoma [52], particularly those with a human leukocyte antigen (HLA)-A*02:01 genetic profile [49, 50]. In a pivotal trial, tebentafusp was shown to enhance overall survival substantially in HLA-A*02:01-positive patients with previously untreated metastatic uveal melanoma. Specifically, the median overall survival in the tebentafusp group was 21.6 months, as compared to 16.9 months in the control group, with a hazard ratio of 0.68 (95% confidence interval, 0.54–0.87). Over a follow-up period of at least 36 months, the estimated survival rate was notably higher in the tebentafusp group, with 27% of patients surviving as compared to 18% in the control group [53]. A Phase 2 study involving patients with previously treated metastatic uveal melanoma revealed that tebentafusp achieved a low objective response rate of only 5%. However, it demonstrated a significant 1-year overall survival rate of 62% and a median overall survival of 16.8 months. These findings suggest that tebentafusp provides clinical benefits that extend beyond the conventional measures of radiographic response [54]. A real-world study in Canada reported that, among 36 patients treated with tebentafusp, 14% achieved tumor reduction and 64% achieved disease control. The 1-year overall survival rate was 68% [55].

Immunotherapy

Immunotherapy works by stimulating the immune system to attack cancer cells, thus harnessing the body's natural defenses to target and eradicate malignant cells. This approach has revolutionized the treatment of various cancers, including melanoma [56, 57]. In melanoma, immunotherapy can be particularly effective because melanoma cells often express antigens that can be recognized by the immune system [57]. In choroidal melanoma, immunotherapy holds significant promise, particularly with the potential for use of immune checkpoint inhibitors and vaccine therapies. Immune checkpoint inhibitors, such as anti- programmed death receptor 1 or anti-PD-1 antibodies, have shown remarkable success in treating advanced melanoma by reversing suppression of T cell activation, thereby stimulating an antitumor immune response [57, 58]. Additionally, cancer vaccines, including exosome vaccines, are emerging as innovative strategies. These vaccines can deliver tumor-specific antigens directly to immune cells, enhancing the activity of dendritic cells and $CD8^+$ T cells to create an effective antitumor environment [56, 58]. While these therapies have primarily been explored in cutaneous melanoma, their application in choroidal melanoma could offer new avenues for treatment, potentially improving outcomes for patients with this challenging disease [57, 58].

Some clinical trials have indicated that immunotherapy can be effective in treating uveal melanoma. For instance, a Phase 1 clinical trial [59] involving SD-101, a Toll-like receptor 9 agonist, has demonstrated the potential of this approach for treating metastatic uveal melanoma. SD-101 was administered via hepatic arterial infusion, which helped to overcome barriers to liver treatment by effectively delivering the drug to the tumor site. The trial has shown enhanced immune activity, with increased $CD4^+$ and $CD8^+$ T cell responses and a reduction in myeloid-derived suppressor cells within the tumors. Notably, the combination of SD-101 with nivolumab resulted in the highest progression-free survival rate of 11.7 months [59]. A Phase II study [60] has also examined the efficacy of combining nivolumab and ipilimumab in treating metastatic uveal melanoma. The study reported an overall response rate of approximately 17%, which was slightly lower than that of some other reports, but was still indicative of therapeutic activity. The median progression-free survival was about 6 months, and the median overall survival was 19.1 months [60].

Role of artificial intelligence in choroidal melanoma management

Diagnostic models

Recent studies have shown that machine learning (ML) models can effectively distinguish between a choroidal nevus and choroidal melanoma with high accuracy [61]. For instance, a model developed by researchers at the Cleveland Clinic achieved an accuracy of 86% in differentiating between these conditions by using non-invasive diagnostic data, such as tumor size, location, orange pigmentation, and presence of drusen. This model has significant implications for reducing overtreatment by accurately identifying benign nevi versus malignant melanomas [61]. While not specifically highlighted for choroidal melanoma, convolutional neural networks are widely used in ocular oncology for image analysis. They can be integrated into diagnostic workflows to enhance the accuracy of tumor detection and classification [62]. Another significant application of ML is prediction of the malignant transformation of choroidal nevi [63]. A recent study showcased the effectiveness of an ML algorithm in identifying risk factors for the malignant transformation of melanocytic choroidal tumors [63]. The algorithm utilized ultra-widefield fundus imaging and B-scan ultrasonography to analyze key features, such as lesion thickness, presence of subretinal fluid, orange pigment, proximity to the optic nerve, ultrasound hollowness, and drusen. The model demonstrated exceptional accuracy, achieving areas under the curve of 0.982 for predicting lesion thickness and 0.964 for detecting subretinal fluid [63].

Prognostic applications

One study employed a multilayer perceptron artificial neural network to predict all-cause mortality in patients with choroidal melanoma across a nationwide US cohort [64], marking a first in this area. The model achieved impressive accuracy of 85.8%

and 87.1% in the training and testing sets, respectively, for predicting 10-year survival [64]. It also demonstrated a mean area under the receiver operating characteristic curve of 92.1%. For 5-year survival predictions, the model showed an accuracy of 77.5% and 75.6% in the training and testing sets, respectively, with a mean area under the curve of 85.1% [64]. The study highlighted the significant potential of artificial intelligence (AI) in accurately forecasting survival outcomes for choroidal melanoma patients, underscoring its value in clinical decision-making and patient care [64]. Although not specifically focused on choroidal melanoma, AI has been used to predict gene expression profiling from digital cytopathology images in uveal melanoma. This application aids in prognosis by identifying genetic markers associated with tumor behavior and patient outcomes. Extension of such techniques to choroidal melanoma could enhance prognostication [65].

Future perspectives

Future directions in the application of AI for choroidal melanoma management include several key areas. Firstly, integrating AI into clinical workflows can enhance both diagnosis and prognosis by providing healthcare professionals with more accurate and timely information, potentially streamlining decision-making processes and improving patient care [63, 66]. Secondly, AI-assisted personalized medicine holds significant promise in ocular oncology. By analyzing individual patient data, AI can help to tailor treatment plans based on genetic profiles, tumor characteristics, and other factors, potentially leading to more effective treatment outcomes [66, 67]. Lastly, addressing data scarcity remains a critical challenge. Future studies may be able to leverage advanced techniques, such as generative adversarial networks and few-shot learning to improve model performance and overcome these limitations [63, 66]. As AI continues to evolve, its integration into clinical practice could revolutionize the management of choroidal melanoma by enhancing diagnostic accuracy, predicting survival outcomes, and facilitating personalized treatment strategies.

This narrative review has summarized findings from studies over the past two decades to provide a comprehensive overview of the latest information and knowledge gaps in terms of the treatment of choroidal melanoma. It emphasizes the shift towards preserving vision and how this focus has impacted patient outcomes. However, the review was limited by the absence of systematic literature searches and meta-analysis strategies, which makes it difficult to determine which vision-preserving treatment modalities are the most effective for managing choroidal melanoma. Future systematic reviews and meta-analyses may help to guide clinicians toward selecting the best treatment options for preserving vision in patients with choroidal melanoma.

CONCLUSIONS

This review underscores significant advances in choroidal melanoma treatment, transitioning from enucleation to vision-preserving modalities, such as plaque brachytherapy and PBI. These therapies have improved patient outcomes by reducing the need for enucleation and preserving visual acuity. Emerging treatments, such as Bel-Sar, offer promising results in early-stage disease management by controlling tumor growth while maintaining vision. Immunotherapy holds significant promise, particularly with the potential for use of immune checkpoint inhibitors and vaccine therapies. Future research directions include optimizing current therapies for better visual acuity preservation and exploring new targeted therapies to enhance tumor control while minimizing side effects, thereby ultimately enhancing patient care and quality of life. Additionally, the use of AI in managing this sight-threatening and life-threatening eye condition could transform its treatment outcomes.

ETHICAL DECLARATIONS

Ethical approval: This study was a narrative review, and no ethical approval was required.

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