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The Role of Laser Therapy in the Treatment of Diabetic Macular Edema (DME): A Review of Contemporary Methods and Clinical Outcomes

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Abstract

Introduction: Diabetic macular edema (DME) is a leading cause of vision loss in patients with diabetic retinopathy. Laser therapy, used for many years in the treatment of DME, allows for the reduction of edema and protection of vision.

Aim of the Study: The aim of this paper is to review the role of laser therapy in the treatment of DME, covering traditional methods such as panretinal and focal photocoagulation, as well as newer approaches like micropulse laser therapy. The paper also analyzes a comparison of laser therapy with other treatment methods, such as VEGF inhibitor injections and steroid therapies, highlighting the advantages and limitations of each. Challenges related to treatment precision and therapy resistance, as well as new technologies and future directions in the development of laser therapy for DME, will also be discussed. The goal is to provide a comprehensive overview of the role of laser therapy in DME treatment and its place in modern ophthalmologic practice.

Materials and Methods: A literature review was conducted in databases such as PubMed, Scopus, Web of Science, and Google Scholar, using relevant keywords. The selection of studies was limited to those with full access to the content or available in open-access repositories.

Conclusions: Diabetic macular edema (DME) remains a leading cause of vision loss in patients with diabetes, and effective treatment, including laser therapy and pharmacological therapies, is crucial for reducing edema and improving vision. The future of DME treatment lies in the integration of modern

technologies, including artificial intelligence, VEGF therapy, and gene therapies, which could significantly improve treatment outcomes and reduce the number of required interventions.

Keywords: laser therapy, diabetic macular edema, focal laser, micropulse laser

Introduction

Introduction to the Issue: Diabetes is a chronic metabolic disease characterized by elevated blood glucose levels, resulting from disturbances in insulin production or function. It is one of the most common diseases worldwide, and its prevalence continues to rise, making it a significant health concern [1]. Diabetes can lead to numerous complications, both microangiopathic and macroangiopathic, which have a substantial impact on patients' quality of life. One of the more severe complications of diabetes is diabetic macular edema (DME), which is the leading cause of vision loss in individuals with diabetes [2]. DME is characterized by the accumulation of fluid in the macula, leading to impaired visual acuity and potentially causing permanent retinal damage [1]. Due to the increasing number of DME cases and its impact on patients' health, this issue has become a key focus in the treatment of retinal diseases.

Scope and Methodology: This paper presents a literature review on the treatment of diabetic macular edema (DME) through laser photocoagulation, analyzing randomized controlled trials from the past 10 years (2013-2023). Selected studies assessed the effectiveness of photocoagulation in improving visual acuity and reducing retinal thickness, and also compared it to pharmacological therapies, such as VEGF inhibitor injections [1,2]. Exclusion criteria included studies with insufficient clinical data or small sample sizes [3]. Only works published between 2013 and 2023 were included to account for the most recent advancements in DME treatment [4].

Theoretical Basis of DME and the Mechanism of Action of Laser Therapy

Definition and Pathophysiology: Diabetic macular edema (DME) is one of the leading causes of vision loss in patients with diabetic retinopathy (DR), characterized by the accumulation of fluid in the macula, the central part of the retina responsible for sharp vision. Chronic hyperglycemia damages the retinal microcirculation, especially the capillaries, increasing their permeability and leading to fluid leakage into the surrounding tissues [1,2]. Hypoxia exacerbates this process by stimulating the release of vascular endothelial growth factor (VEGF), which leads to abnormal vessel growth and increased permeability, further deepening the edema in the macula [2,3]. As a result, visual acuity worsens, potentially leading to permanent vision loss if treatment is not initiated in a timely manner [5,1]. DME

is also associated with a higher risk of other diabetic complications, such as proliferative retinopathy [3].

Principles of Laser Therapy: Laser therapy is a commonly used treatment for DME, based on the use of laser light, which acts on retinal tissues depending on the wavelength and energy applied during the procedure. Traditional retinal photocoagulation, using an argon laser, causes tissue coagulation, particularly of damaged capillaries, which reduces fluid leakage and decreases macular edema [1,6]. Micropulse laser therapy, based on low-energy pulses, allows for selective coagulation of affected vessels, reducing damage to surrounding tissues and minimizing the risk of side effects [1,7]. Newer technologies, such as pattern scan, offer more precise coverage of the retinal area and better control over the distribution of light energy, which improves treatment accuracy [8].

Thanks to modern imaging technologies, such as OCT, it is possible to monitor treatment effects in real-time, allowing for precise assessment of edema and therapy efficacy [2]. Contemporary approaches also consider integration with other treatment methods, such as VEGF inhibitor injections, which may improve long-term therapeutic outcomes [6,1]. Despite technological advancements, challenges still remain regarding the individualization of therapy and the precise selection of patients [5].

History and Evolution of Laser Therapy in the Treatment of DME

The Beginnings of Laser Use in Ophthalmology: Laser therapy in ophthalmology began in the 1960s when the argon laser was first used to treat retinal diseases, including diabetic retinopathy. Initially, laser photocoagulation became the standard treatment for DME, helping to halt the progression of the disease and improve vision [6,3].

Evolution of Techniques: Over the years, more precise techniques were developed, such as micropulse laser therapy, which reduces the risk of damage to surrounding tissues and improves treatment outcomes [7]. New laser scanning systems, such as pattern scan, enabled precise coverage of affected areas of the retina, enhancing the effectiveness of the procedures [8].

Changes in Treatment Protocols: Initial protocols required large, invasive procedures, but over time, more conservative approaches were developed, with fewer sessions, which reduced the risk of complications [2]. Contemporary guidelines also include combining laser therapy with other methods, such as VEGF inhibitor injections, which increases the effectiveness of treatment [6].

Types of Laser Therapy Used in DME

Laser Photocoagulation (Panretinal and Focal): Laser photocoagulation, including focal photocoagulation, was the standard method for treating DME, effectively reducing retinal edema through the coagulation of damaged vessels. This technique is still widely used, although it is associated with the risk of complications, such as scarring and tissue damage [6,1].

Micropulse Laser Therapy (MPDL): Micropulse laser therapy is a newer approach that uses low-energy pulses for selective coagulation of affected vessels, minimizing damage to surrounding tissues. It is a method with a better safety profile, offering greater patient comfort and improved outcomes compared to traditional photocoagulation [7,9].

Modern Technologies and Innovations: Modern laser systems, such as variable energy lasers and pattern scanning, offer more precise treatment, reducing procedure time and the risk of complications. Additionally, the integration with imaging technologies (e.g., OCT) allows for more accurate monitoring of treatment progress and better control over therapy [2,8].

Efficacy and Safety of Laser Therapy

Efficacy in Treating DME: Laser therapy, including focal and micropulse photocoagulation, is effective in reducing macular edema and improving visual acuity, especially in chronic cases of DME [10]. Micropulse laser therapy, characterized by less tissue damage, shows better therapeutic outcomes and a lower complication rate compared to traditional photocoagulation [11]. However, in advanced stages of DME, it may be necessary to combine laser therapy with other methods, such as VEGF inhibitor injections [3].

Side Effects and Safety: Laser therapy is associated with the risk of retinal damage, including scarring and vision deterioration, particularly with traditional photocoagulation [6]. Micropulse laser therapy reduces these risks but may still cause minimal tissue damage [10]. New technologies, such as pattern scanning, offer more precise treatment, thereby reducing the risk of complications [8].

Comparison of Laser Therapy with Other DME Treatment Methods

Intravitreal Injections (anti-VEGF): Intravitreal injections of VEGF inhibitors, such as aflibercept, ranibizumab, and brolucizumab, are currently the standard treatment for DME, especially in cases where other methods do not yield the expected results [12]. Although injections effectively reduce edema and improve visual acuity, they require regular visits and are associated with the risk of complications, such as infections or increased intraocular pressure [13]. Additionally, the cost of injection therapy is high, and patients often prefer one-time, less invasive laser procedures [2]. In

comparative studies, laser therapy has been shown to be more effective in maintaining long-term vision stability with fewer follow-up visits [15].

Corticosteroids: The use of corticosteroids, such as dexamethasone implants (Ozurdex) or triamcinolone, is also an option for treating DME, especially in patients who do not respond to anti-VEGF injections [16]. While steroids effectively reduce edema, their long-term use is associated with serious complications, such as glaucoma and cataracts, which remain significant limitations compared to laser therapy [17]. Compared to laser therapy, steroids may offer quicker results but require close monitoring of the patient's health [18].

Surgical Treatment: Vitrectomy is used in advanced cases of DME, especially when additional complications such as vitreous hemorrhage or retinal detachment are present [19]. While surgery can restore retinal stability and remove obstructions, its use is associated with a higher risk of complications and longer recovery times compared to laser therapy [20]. For this reason, surgery is reserved for cases where other treatment methods have failed, and disease control through laser therapy is no longer sufficient [21].

Challenges and Limitations in the Use of Laser Therapy

Technical Issues: Despite being a widely used method, laser therapy in the treatment of DME faces numerous challenges related to technological limitations of the equipment. Despite advancements in devices, such as variable energy lasers, there are still difficulties in precisely selecting treatment parameters, such as laser power and exposure time [22]. The variability of tissue responses to treatment can impact the results of the procedure, especially in patients with different degrees of edema progression [23]. These technical issues may lead to the need for multiple sessions, which can increase treatment time and burden patients [24].

Clinical Limitations: Despite the documented effectiveness of laser therapy, its use has certain limitations in the clinical context. In patients with advanced retinal damage, such as the presence of scars, irreversible retinal vessel damage, or proliferative retinopathy, laser photocoagulation may be less effective [25]. Additionally, patients with high pre-treatment anxiety or concerns about the invasiveness of the procedure may resist this method, complicating treatment and potentially affecting the therapy outcome [26]. Other factors, such as age-related dementia or difficulties in accessing appropriate technology, also limit the effectiveness of this method [27].

Resistance Phenomenon: The phenomenon of resistance to laser treatment, although less commonly discussed in the literature, is possible in chronic forms of DME, where retinal vessels cannot be effectively sealed or stabilized after a series of procedures [28]. According to studies, in such cases,

patients may require additional pharmacological treatment, including anti-VEGF therapy, to maintain control over the development of retinal edema [29]. Resistance to laser treatment may also occur due to chronic increased vessel permeability that is not fully reversible after laser intervention [30].

The Future of Laser Therapy in DME Treatment

New Technologies: In recent years, the development of laser technologies has enabled the introduction of devices with higher precision, significantly improving the quality of DME treatment. Modern lasers, such as variable energy lasers, allow for more precise targeting of affected areas of the retina, minimizing the risk of damage to surrounding tissues [31]. The use of advanced imaging tools, such as optical coherence tomography (OCT), enables real-time monitoring of treatment outcomes, allowing for dynamic adjustments during the therapy [32]. These technologies not only improve the effectiveness of treatment but also reduce the number of required procedures, decreasing the burden on patients and enhancing the comfort of treatment [33].

Personalized Approach to Laser Therapy: Personalization of treatment is becoming a key element in managing DME, especially given the diversity of patients' responses to therapy. In the future, with a better understanding of the molecular and genetic mechanisms underlying DME, it will be possible to adjust laser parameters to the individual needs of the patient, which could increase the effectiveness of treatment and reduce the risk of complications [34]. Personalizing treatment will also include considering other patient comorbidities, such as diabetes, hypertension, or heart diseases, which can affect the response to therapy [35]. Optimizing the parameters of the procedure based on individual retinal responses may also reduce the risk of side effects, such as permanent retinal damage [36].

Potential for Combination Therapies: The combination of laser therapy with other modern treatment methods, such as anti-VEGF injections, represents a promising direction for DME treatment. Studies indicate that combining laser therapy with anti-VEGF therapy can lead to better treatment outcomes, enabling better control of edema and improved visual acuity [37]. Furthermore, the combination of technologies, such as gene therapy or cell therapy, may change the way laser therapy is used in the treatment of DME in the future. Gene therapies, which involve delivering genes aimed at repairing retinal damage, could complement or provide an alternative to traditional laser therapy [38]. Integrating these methods will allow for more effective and less invasive treatment, minimizing the need for multiple interventions [39].

Conclusions

Summary of Key Findings: Diabetic macular edema (DME) remains one of the leading causes of vision loss in patients with diabetes, and effective treatment is crucial. Although new therapies are still

under development, laser therapy continues to play a significant role in reducing edema and improving visual acuity. Modern laser technologies, such as micropulse therapy, reduce the risk of tissue damage. Pharmacological treatments, particularly anti-VEGF injections, used in parallel with laser therapy, lead to better outcomes.

Challenges include the precise adjustment of treatment to the individual needs of the patient, especially in the context of long-term disease management. The future of DME treatment lies in the integration of advanced laser technologies, pharmacological therapies, and innovative methods such as gene therapies. The use of artificial intelligence in diagnosis and treatment monitoring will enable precise tailoring of therapy to the patient's needs. Combining laser therapy with VEGF treatment and new pharmacological approaches offers hope for better treatment outcomes and a reduction in the number of interventions. The development of gene and cell therapies could revolutionize DME treatment, opening new possibilities in the management of this challenging condition.

Author's contribution

Conceptualization, Anna Wijata; methodology, Anna Wijata and Justyna Dutkiewicz; software, Zuzanna Adriana Przybyłek-Stępień and Ewelina Rycerz; check, Jan Szustak and Wiktoria Mączyńska; formal analysis, Anna Wijata and Maria Kąpa; investigation, Anna Wijata and Wiktoria Mączyńska; resources, Maria Kąpa and Bartosz Szepietowski; data curation, Jakub Marek Kaźmierczak, Michał Wijata; writing – rough preparation, Anna Wijata; writing - review and editing, Anna Wijata and Justyna Dutkiewicz; visualization, Anna Wijata, Zuzanna Adriana Przybyłek-Stępień and Ryszard Bartosiński; supervision, Jan Szustak and Michał Wijata; project administration, Anna Wijata and Bartosz Szepietowski. All authors have read and agreed with the published version of the manuscript.

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