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Evaluation of Thermal Response of the Anterior Chamber of the Human Eye for Early Glaucoma Detection

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Abstract

Glaucoma is an irreversible eye problem that leads to vision loss. It is characterized by increased intraocular pressure (IOP) due to the accumulation of aqueous humor in the anterior chamber of the eye. This work evaluates the thermal response in the anterior chamber of the human eyeball when exposed to 694.3 nm Ruby LASER through the cornea for early glaucoma detection by using COMSOL Multiphysics simulation software. The thermal response of the aqueous humor revealed the presence of the liquid. Using a pulse duration of 0.5 ms, the thermal response was measured in both a normal and a glaucomatous eye model. The 694.3 nm ruby LASER showed a thermal response of 309 K in a normal eye and 306 K in a glaucomatous eye, as seen in **Figure 3** and **Figure 4**. The results indicate that the 694.3 nm Ruby LASER, operating within the average human eye temperature range of 306.97 K to 308.56 K, is a safe and effective choice for glaucoma detection, causing no damage or significant physical changes to ocular tissues. The work shows that the 694.3 nm ruby LASER could be a useful tool for diagnosing glaucoma early in clinical settings.

Keywords

Anterior Chamber, Aqueous Humor, Glaucoma, LASERs, Thermal Response

1. Introduction

Glaucoma is a multifactorial disease [1]. It is characterized by increased intraocular pressure (IOP) due to the accumulation of aqueous humor in the anterior chamber of the eye. Glaucoma suspects will have an increased intraocular pressure

(IOP) of more than 21 mmHg (IOP), which is thought to cause glaucoma because it damages the blood vessels and optic nerves in the eye [2]. Diagnosis of glaucoma is mainly based on the increased intraocular pressure (IOP), medical history of the patient's family, and change in optic disc structure [3]. The main different types of glaucoma are chronic or open-angle glaucoma and acute or angle-closure glaucoma.

The significant factor in delaying vision loss due to glaucoma is its early diagnosis and treatment [4]. Early detection of glaucoma is critical to prevent vision loss; recent advancements in photothermal techniques have opened new avenues for noninvasive and precise detection of glaucoma by evaluating thermal response in ocular tissues. The thermal profile in the anterior chamber of the eye is influenced by fluid mass, volume, and the thermal properties of the surrounding tissues. LASER-based photothermal devices, with their ability to deliver controlled energy pulses, have emerged as promising tools for measuring these temperature changes.

Several technologies are in use to detect the progression of glaucoma such as Heidelberg retina tomography (HRT), optical coherence tomography (OCT), scanning laser polarimetry (GDx variable corneal compensator (VCC) access), frequency doubling technology (FDT), and blue on yellow automated perimetry. The diagnostic instruments listed above have been reported to detect glaucomatous damage [5]. A special instrument for detecting glaucoma, currently tonometer applanation has been used to measure IOP and gives a fast and accurate result. However, it is not effective in detecting early glaucoma, as most new glaucoma cases do not show elevated IOP, while in some cases of glaucoma, people have regular IOP.

This work explores the use of a 694.3 nm ruby LASER on both normal and glaucomatous eye models by employing a pulse duration of 0.5 ms, which is commonly used in clinical practice. The work aims to evaluate the thermal response of 694.3 nm ruby LASER when exposed to the eye cornea to detect early signs of glaucoma. The thermal response can indicate the amount of aqueous humor present in the eye; more liquid indicates a large volume in the anterior chamber of the eyeball, which in turn represents the existence of intraocular pressure. The work was conducted in the COMSOL Multiphysics environment.

2. Background Theory

The relation between intraocular pressure and aqueous humor in any volume in the anterior chambre of the human eyeball can be defined by Equation (1), (2) and (3).

$$p = \rho g h \tag{1}$$

where p is the static fluid pressure, ρ is fluid density, g is the acceleration due to gravity, and h is the depth of the fluid volume below the surface.

From Equation (1)

$$p = \frac{m}{V} gh \tag{2}$$

where m is the mass of the fluid is constant, V is the volume of the anterior chambre, the fluid is constant.

If the volume of the anterior chambre and the depth are considered constant Equation (2) can be written as.

$$p \propto m \tag{3}$$

The equation shows that the thermal response of the aqueous humor in the anterior chamber of the human eye is inversely proportional to its mass or volume, as defined by Equation (5). This relationship is critical for understanding how temperature changes can be used to detect early glaucoma.

$$Q = mC\nabla T \tag{4}$$

where, Q = heat energy, m = mass of hummer aqueous, C = Specific heat capacity of hummer aqueous and ∇T = temperature variation.

From Equation (4)

$$\nabla T = Q/mC \tag{5}$$

The pressure of the fluid in the anterior chambre of the human eyeball is directly proportional to the density of the fluid.

The aqueous humor in the anterior chamber of the eyeball thermal response is solved in the COMSOL Multiphysics environment with Penne's bioheat transfer equation.

$$PC\frac{\partial T}{\partial t} = \nabla(K\nabla T) + W_p C_p (T_a - T) + q_m \tag{6}$$

where, P = Density, C = Specific heat, K = Tissue thermal conductivity, W_p = Mass flow rate of blood per unit volume of tissue, C_p = Blood's specific Heat, q_m = Metabolic heat generation per unit volume, T_a = Temperature of arterial blood, T = Temperature rise above the ambient level.

The human eyeball in **Figure 1** shows the normal position of the iris; the angle between the iris and cornea is 30 degrees, and the depth of the anterior chamber is consistent with that of a normal eyeball.

3. Materials and Methods

This work was purely a simulation in the COMSOL Multiphysics environment. 3D models of a normal human eyeball and a glaucomatous eye were modeled in the COMSOL Multiphysics environment (See **Figure 1** and **Figure 2**). It indicated that the volume of the anterior chamber of a glaucomatous eye is wider than that of the normal eye, and its aqueous humor mass is heavier than that in the normal eye. The 694.3 nm ruby LASER was modeled in a COMSOL Multiphysics environment when exposed through the cornea with a plus duration of 0.5 ms. Finally, the thermal responses of both normal and glaucomatous eyes have been evaluated.

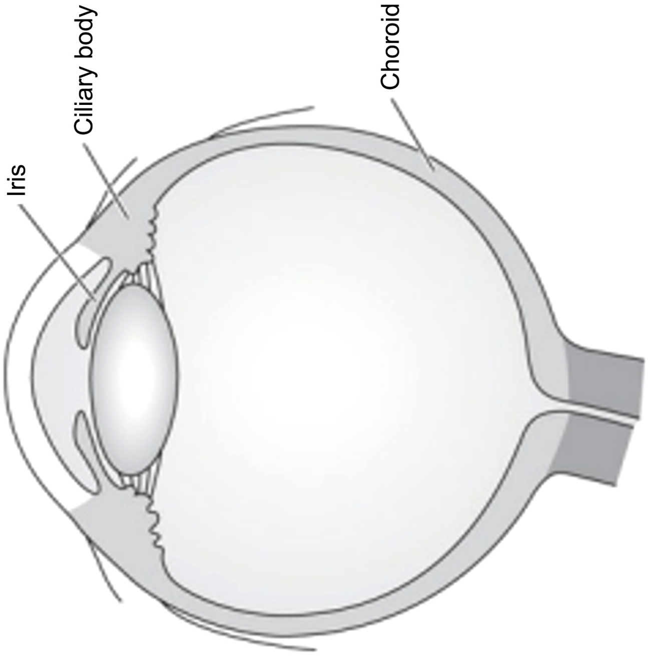
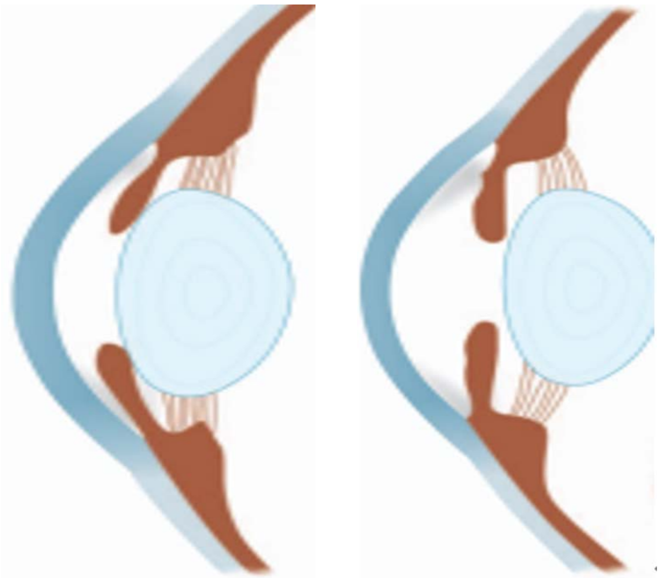


Figure 1. Anatomy of human eyeball [6].



(a) (b)

Figure 2. (a) is a normal human eye, and (b) is a glaucomatous human eye [7].

4. Results and Discussion

This work found that the 694.3 nm Ruby LASER sources had different thermal effects in the anterior chamber of the normal and glaucomatous human eyeball. To find early signs of glaucoma, equation (5) was solved, which showed that the change in thermal response of the aqueous humor is inversely proportional to its mass or volume. As seen in **Figure 3** and **Figure 4**.

Normal eye model.

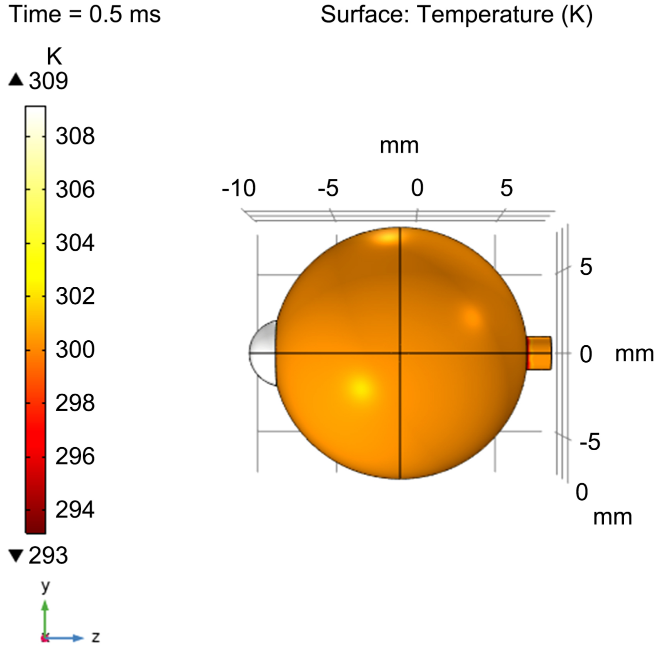


Figure 3. Indication of 309 K of thermal response by the graphic when a 3D model of the normal human eyeball was modeled in the COMSOL Multiphysics environment by using 694.3 nm Ruby LASER radiation with a pulse duration of 0.5.

Glaucomatous eye model.

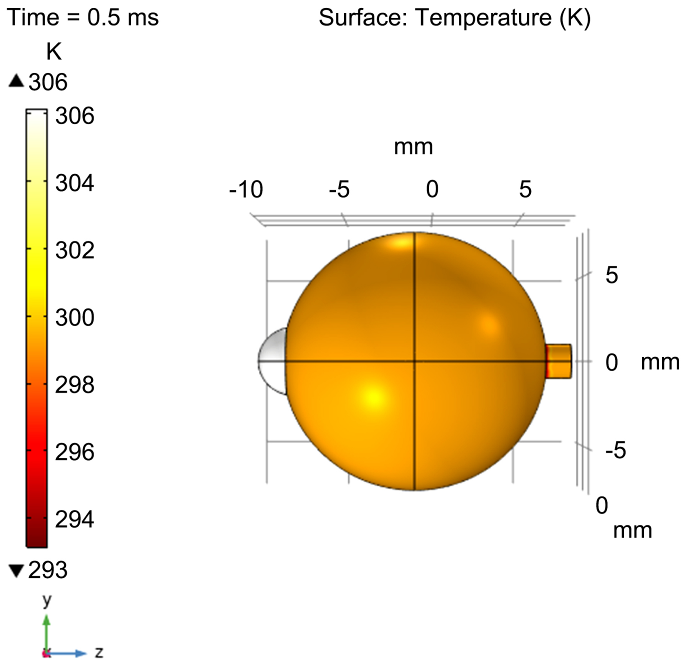


Figure 4. Indication of 306 K of thermal response by the graphic when a 3D model of the glaucomatous human eyeball was modeled in the COMSOL Multiphysics environment by using 694.3 nm Ruby LASER radiation with a pulse duration of 0.5.

In **Figure 3**, the normal human eyeball model showed by the orange collar, its thermal response was 309 K by using a heat source of 694.3 nm Ruby LASER radiation with a plus duration of 0.5 ms, and in **Figure 4** in the glaucomatous eye the thermal response was 306 K with the same 694.3 nm Ruby LASER radiation and plus duration of 0.5 ms, which indicated that the more increase in the aqueous humor mass and the anterior chambre volume , the more decrease of the thermal response in the anterior chambre exposed by LASER as the thermal response is inversely proportional with the fluid mass solved by equation (5).

The range of temperature variation of 694.3 nm Ruby LASER, is 308.97 K to 306 K for 0.5 ms pulse duration and 324.73 K to 318.82 K for 1.0 ms plus duration, it is expected that no harm or significant physical change occurs for 0.5 ms pulse duration; only the temperature of the optic tissues increases, hence, it can be concluded that Ruby LASER is preferable over other sources for a pulse duration of 0.5 ms [8]. The pulse duration of most of the photothermal devices used in clinical practice is between 0.5 ms and 1.0 ms [9]. The average temperature of the human eye is 306.97 K to 308.56 K [10]. In this work, the results showed that 694.3 nm Ruby LASER radiation with a plus duration of 0.5 ms done at 306 K of temperature variation is a good LASER intensity choice and safe for the eye because the average temperature of the human eye is between 306.97 and 308.56.

5. Conclusion

We found that the use of LASER to detect the early stage of glaucoma is possible. This work investigated the thermal response of 694.3 nm Ruby LASER, in the anterior chamber of both normal and glaucomatous human eye models. The thermal response of the aqueous humor was found to be inversely proportional to its mass, as defined by the derived equation (5). Using a pulse duration of 0.5 ms. The 694.3 nm Ruby LASER demonstrated a thermal response of 309 K in the normal eye and 306 K in the glaucomatous eye, which falls within the average human eye temperature range of 306.97 K to 308.56 K. The results indicated that the 694.3 nm Ruby LASER is a safe and effective choice for early glaucoma detection, as it causes no significant physical changes or damage to ocular tissues. This work highlighted the potential of the 694.3 nm ruby LASER as a reliable tool for noninvasive and precise early glaucoma diagnosis in clinical settings. Findings contribute to the advancement of diagnostic techniques for glaucoma, ultimately improving patient outcomes through early detection and intervention.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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