Effect of Relative Humidity During 40 GHz Millimeter Wave Exposure

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Abstract

It has been demonstrated that millimeter waves (MMW) are absorbed by surface tissue, such as skin or cornea. It was shown in our laboratory that damage from MMW exposure was related to heat accumulation and transport. To study the relationship between relative humidity and ocular damage, we investigated the effect of relative humidity during MMW exposure. The ocular temperatures of rabbits were measured during exposure to 40 GHz MMW (200 mW/cm^2). To visualize the dynamic change of temperature and distribution in the anterior chamber, 0.2% microencapsulated thermochromic liquid crystal (MTLC) was injected into the anterior chamber of rabbit eye. We showed that low humidity during exposure decreased heat accumulation and transfer.

1. Introduction

Relative humidity was considered to be a factor affecting ocular change during MMW exposure [1]. But there is insufficient evidence to identify the relationship between relative humidity and MMW. The present study was designed to investigate whether relative humidity was an important factor in 40 GHz MMW exposure induced ocular damage.

2. Materials and Methods

2.1 Exposure Equipment

The 40 GHz continuous MMW were generated by an 83650B (Agilent Technologies, Inc., Santa Clara, USA). MMW signal source driving a 40 W TWT (Ka Band, ETM Electromatic Inc., California, USA).

2.2 Animals and Treatment

All animal experiments were conducted in accordance with Animal Study Guidelines of Kanazawa Medical University and the Association for Research in Vision and Ophthalmology Statement for the Use of Animals in Ophthalmic and Vision Research [2]. Specific pathogen-free pigmented rabbits (N=30, Dutch, 12-15 week-old, average weight 1.87±0.06 kg, range 1.75-1.99 kg, Sankyo Lab Service Co., Inc., Toyama, Japan) were exposed unilaterally to 200 mW/cm^2 MMW for 5 min by lens antenna. Medetomidine hydrochloride (0.4 mg/kg, Domitor®, Orion Corporation, Espoo, Finland) was injected intramuscularly for systemic anesthesia during exposure and ocular examination. A 2% lidocaine hydrochloride topical anesthetic (Xylocaine® 2% injection, AstraZeneca, Osaka, Japan) was administered to each rabbit just before injection of microencapsulated thermochromic liquid crystal (MTLC, Japan Capsular Products,

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Tokyo, Japan) into the anterior chamber before exposure. Upper and lower eyelids were retracted with tape to keep eyes open during exposure.

2.3 Setup for Animals and Treatment

A standardized exposure position of the eye was established (Fig. 1). The target was set at 135 mm horizontal from the lens antenna using red and green laser pointers indicating the target from both sides of the lens antenna. An infrared thermography camera was set above the rabbit eye to detect the temperature of upper corneal surface during exposure.

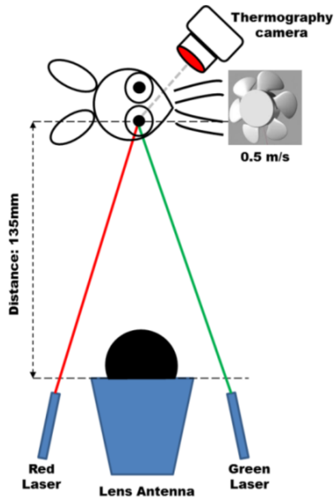

Fig. 1 Exposure system with fan.

2.4 Setup for room temperature, relative humidity

Room temperature during MMW exposure was maintained at 24±2ºC by air-conditioner. Relative humidity was controlled by a humidifier and a dehumidifier.

2.5 Visualization of Anterior Chamber Convection

MTLC are 20-30 micrometer particles which change color with surrounding temperature [3]. MTLC display a variety of colors spanning the visible spectrum for a fixed temperature bandwidth. MTLC are red at the lower temperature limit of the bandwidth, passing through yellow, green and then purple at the higher temperatures. 0.2% MTLC was injected into the anterior chamber with a 30 G injection needle. A video camera was set at 90 degree to the slit light illumination to record aqueous humor convection and change of MTLC color in the anterior chamber.

3. Results

MTLC color change occurred in the low humidity environment after 1 minute exposure (Fig.2 A). In contrast, color change occurred in the anterior chamber at 30 seconds exposure in the high humidity environment (Fig. 2E). After 1.5 minutes exposure, only the upper part near the cornea side showed slight color change in the low humidity environment (Fig. 2B), but the entire anterior chamber showed color change in the high humidity environment (Fig. 2F). At 2 minutes exposure, the upper part of the anterior chamber showed green color in the low humidity environment (Fig. 2C). At the same time, the anterior chamber indicated a temperature increase to around 40ºC in the high humidity environment (Fig. 2G). At 4 minutes exposure, the temperature of the entire anterior chamber was under 40ºC in the low humidity environment (Fig. 2D), but showed over 40ºC in the high humidity environment (Fig. 2H).

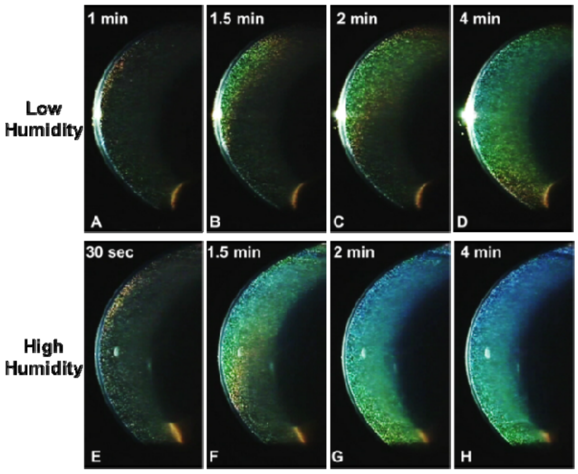

Fig 2. MTLC color change during 40 GHz 200 mW/cm^2 exposure in low (30%) and high (70%) humidity environment. Cross section view of anterior chamber. A: after 1 minute exposure; E: after 30 seconds exposure; B and F: after 1.5 minutes exposure; C and G: after 2 minutes exposure; D and H: after 4 minutes exposure. Top row: low humidity environment; Bottom row: high humidity environment.

Corneal surface temperature was detected by infrared thermography camera. The temperature increased immediately after the start of exposure. Temperature in the low humidity environment was higher than in the high humidity environment (Fig. 3).

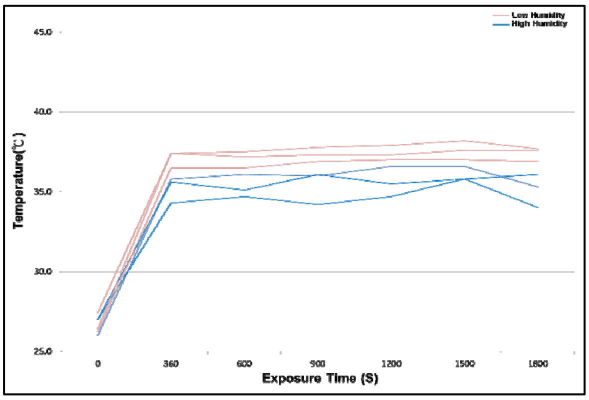

Fig 3. Corneal surface temperature under 40 GHz 200 mW/cm^2 exposure.

4. Discussion

It was suggested that aqueous humor convection has an important role in heat transfer from the cornea to the lens. Due to low humidity, tear film evaporation increased causing temperature loss, so the accumulation of heat in anterior chamber was reduced. In the high humidity environment, tear film evaporation decreased so MMW induced heat was not released with evaporating tear film at the corneal surface, and was transported to the lens. This indicates decreased tear film evaporation under high humidity environment facilitates heat accumulation and transfer to the inside of the eye.

5. Conclusion

The present study suggested different humidity environments might be an important element to control heat transfer affecting eye. The possibility of environment humidity may have an impact on MMW exposure.

6. Acknowledgements

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7. References

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