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The illumination characteristics of operative microscopes☆,☆☆

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ABSTRACT

Purpose: Modern operative microscopes use light sources which possess the power to severely damage underlying tissue. Currently, manufacturers provide a safety warning of this possibility. However, they are unable to suggest specific settings due to a stated “lack of scientific publications on this topic”. We aim to radiometrically evaluate multiple otologic microscopes at variables which effect irradiance in order to determine reference emissions levels and provide guidelines for improved intraoperative safety.

Materials and methods: The optical radiance of four otologic microscopes was evaluated at variable field illumination sizes (spot size), intensity settings and working distances. The spectral emission of each microscope was separately measured. The energy absorbed in skin with representative properties was then calculated as a function of time for each microscope by accounting for the emission spectrum of the microscope and the absorption spectrum of skin.

Results: Microscopes showed a wide range of optical radiance based on model, spots size, intensity setting and working distances. Spectral emission of all four microscopes was centered in the visible spectrum with minimal ultraviolet or infrared contribution. A large amount of energy is absorbed by skin during usage of operative microscopes. The highest calculated absorption at 200 min of use was 736.26 J/cm^2.

Conclusions: Operative microscopes have the ability to cause patient morbidity secondary to the energy they impart. In an effort to decrease potential injury we recommend that physicians be aware of their microscopes properties and how to control variables which effect irradiance of the skin.

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1. Introduction

Significant improvements have been made in operative microscopes since their introduction in the early 20th century. Optics have been improved as well as illumination sources. Traditional lighting sources such as incandescent bulbs have been replaced with advanced lighting including xenon and halogen lamps. Newer light sources provide excellent illumination even at high magnification, and with a large field of illumination (spot size); however, this power can be damaging to underlying tissue. Reports of secondary damage due to high intensity lighting have been reported in multiple microsurgical fields including ophthalmology, plastic surgery, neurovascular surgery and otologic surgery [1–8]. Morbidity includes blindness, skin burns, and in cases of reconstructive surgery possible increased rates of free flap failure due to pedicle damage and secondary venous occlusion [3,8]. A review of the Food and Drug Administration's (FDA) Manufacturer and User Facility Device Experience (MAUDE) database for voluntary reports demonstrated 82 cases of soft tissue burns secondary to operative microscopes since 2004. Of these, 19 reports were otologic in nature detailing 25 ears burned [5]. Two incidences of third degree burns after otologic procedures have occurred in our department.

Light sources can be evaluated in two distinctly separate ways. Radiometric analysis measures radiant energy produced by a source. Radiometric measurements are expressed as radiance which is radiation emitted from a source ($W/Sr/m^2$), and irradiance which is the irradiation of a surface (W/m^2). Photometric analysis measures the perceived brightness of light by the human eye. Photometric measurements are expressed as luminance which is brightness perceived by a human observer measured in lux ($lumen/m^2$).

The purpose of our study was to conduct a *radiometric* analysis of multiple operative microscopes under variable conditions to further evaluate the potential for harmful levels of irradiance. Since some light source might produce radiation outside of the visible spectrum we also measured the output of energy in both the infrared and ultraviolet regions.

2. Materials and methods

After Yale IRB approval four otologic microscopes were identified in use at our institution; two Ompi Pentero 900 microscopes (Carl Zeiss: Oberkochen, Germany), one Ompi Sensera microscope (Carl Zeiss: Oberkochen, Germany) and one Ompi Pico microscope (Carl Zeiss: Oberkochen, Germany). A calibrated 818-SL/DB photodiode (Newport Corporation, Irvine, CA) equipped with a 30dB attenuator was used to measure irradiance of each microscope across multiple variables including spot size, working distance and light intensity setting. Ambient room light was accounted for and removed from the final calculations. In addition, the emission spectrum of each microscope was separately measured at intensities of 5% and 100% at a working distance of 20cm.

The total energy absorbed per cm^2 of skin, A, was calculated based on Eq. (1), where $I(\lambda)$ is the measured lamp intensity per unit area at a wavelength λ, $\sigma(\lambda)$ is the absorption coefficient of skin at λ, and L is the skin thickness, which was assumed to be 0.9 mm [9]. In Eq. (1), the term in the brackets represents the fraction of energy absorbed at a given wavelength through 0.9 mm thick skin.

$$A = \int I(\lambda)\left[1-e^{-\sigma(\lambda)L}\right]d\lambda \qquad (1)$$

3. Results

3.1. Ompi pentero

Irradiance was increased with decreasing spot size, decreasing working distance, increased light intensity settings and magnification (Table 1). Spot sizes 6 cm, and 8.5 cm showed an average decreased irradiance of 13% and 36% respectively in comparison to the smallest spot size of 3.5 cm at 100% intensity. The spectral emission of microscope was centered in the visible spectrum with minimal ultraviolet or infrared contribution (Fig. 1). Energy absorbed by 1 cm^2 of skin at working distance of 20 cm over 200 min was 736.26 J (Table 1). Microscope light source is 300 W xenon bulb.

3.2. Ompi sensera

Irradiance was increased with decreasing spot size, decreasing working distance, and increased light intensity setting (Table 1). Magnification did not have a effect on irradiance. Spot sizes of 5 cm, and 7.5 cm showed averaged decreased irradiance of 43% and 81% respectively in comparison to the smallest spot size 2.5 at intensity of 100%. The spectral emission of the microscope was centered in the visible spectrum with minimal ultraviolet or infrared contribution (Fig. 1). Energy absorbed by 1 cm^2 of skin at a working distance of 20 cm over 200 min was 219.37 J (Table 1). Microscope light is source 180 W xenon bulb.

3.3. Ompi Pico

Irradiance was increased with decreasing working distance, while it was increased with increased light intensity settings (Table 2). Magnification did not have a significant effect on irradiance. Spot size was set by working distance, with decrease irradiance at longer working distances. Good focus was seen in all working distances even though focal length of microscope is 25 cm, due to large depth of field seen at the low magnification used during testing. The spectral emission of the microscope was centered in visible spectrum with minimal ultraviolet or infrared contribution (Fig. 1). Energy absorbed by 1 cm^2 of skin at a working distance of 11 cm over 200 min was 13.92 J (Table 2).

4. Discussion

The characterization of multiple microscopes within this study revealed that large amounts of energy are released from operative microscopes and absorbed within our patients skin (Tables 1 and 2). This correlates to the clinical findings of multiple burns voluntarily reported to the FDA MAUDE database and our personal experience with two patients who sustained third degree auricular burns [5]. Traditional operative microscopes may not have possessed enough intensity to cause injury. The amount of energy emitted by the microscope depends on multiple factors including the microscope used, age of microscope bulb, working distance, spot size, magnification and

Table 1 – Optical Output of Pentero and Sensera microscope models.

Tested at fixed magnification and spot size indicated WD=Working Distance (cm)	Opmi Pentero 300 W xenon bulb Time used/remaining life (275/225) Magnification 7.1× Spot size 3.5 cm	Opmi Pentero 300 W xenon bulb Time used/remaining life (116/384) Magnification 7.1× Spot size 3.5 cm	Opmi Sensera 180 W xenon bulb Mag 15.1× Spot size 2.5 cm
	Output (mW/cm^2)		
Intensity 5%			
WD 15 cm	80	96	18
WD 20 cm	60	66	12
WD 25 cm	44	55	8.6
WD 30	31	39	6
Intensity 25%			
WD 15 cm	187	226	68
WD 20 cm	125	141	46
WD 25 cm	102	123	30
WD 30 cm	75	81	23
Intensity 50%			
WD 15 cm	400	406	136
WD 20 cm	225	265	94
WD 25 cm	192	188	57
WD 30 cm	137	137	45
Intensity 75%			
WD 15 cm	610	546	197
WD 20 cm	383	436	137
WD 25 cm	334	316	82
WD 30 cm	240	226	66
Intensity 100%			
WD 15 cm	715	746	253
WD 20 cm	490	570	177
WD 25 cm	436	433	108
WD 30 cm	316	306	91

intensity level. The results of our study allow recommendation for improved safety during the use of operative microscopes based on knowledge of independent variables responsible for total energy emitted.

4.1. *Know irradiance capabilities of your microscope before operation.*

The largest differences in emission between variables within our study existed between the model of microscopes tested (Tables 1 and 2). The irradiance of the Ompi Pentero and the Ompi Pico at 100% intensity was 570 mW/cm^2 and 42 mW/cm^2. The difference between the microscopes emission does not represent inherent danger or poor design of the individual microscope. Instead it demonstrates the high variability in microscope complexity and base illumination that exists in the market. It is important to be aware of the variance in energy emitted and know an approximate reference for your microscope.

4.2. *Be cognizant of your working distance during surgery*

Decreasing the working distance was found to universally increase the irradiance (Tables 1 and 2). Importantly, working distances of 15 cm were reported in our study for Pentero and Sensera models to further demonstrate this phenomenon. Otologic surgery is three dimensional. Often the auricle may be multiple centimeters above the surface of interest, out of focus but within the illuminated field receiving higher levels of irradiance. Working distances of 15 cm are at the edge of both microscopes focal capacity. As such calculations and references for these models are based on a working distance of 20 cm. Good focus was obtained at a working distance of 11 cm for the Ompi Pico due to the large depth of field that the low magnification possessed. When possible operate at the longest working distance which allows safe effective surgery. Remember that objects not in focus may actually be closer receiving higher levels of radiation.

4.3. *Use the lowest microscope intensity setting which provides adequate visualization of the surgical field*

Lower microscope intensities create drastically decreased energy emission (Tables 1 and 2). Auricular burns can occur when high intensity settings are in place. All four cases reported by Latuska et al. occurred at intensities greater than 50%. After our most recent thermal injury our department has placed intensity limits which automatically prevent any intensity greater than 35% without intentional disabling of the control. This feature is standard and available on Pentero models. Nearly all procedure can be performed using these

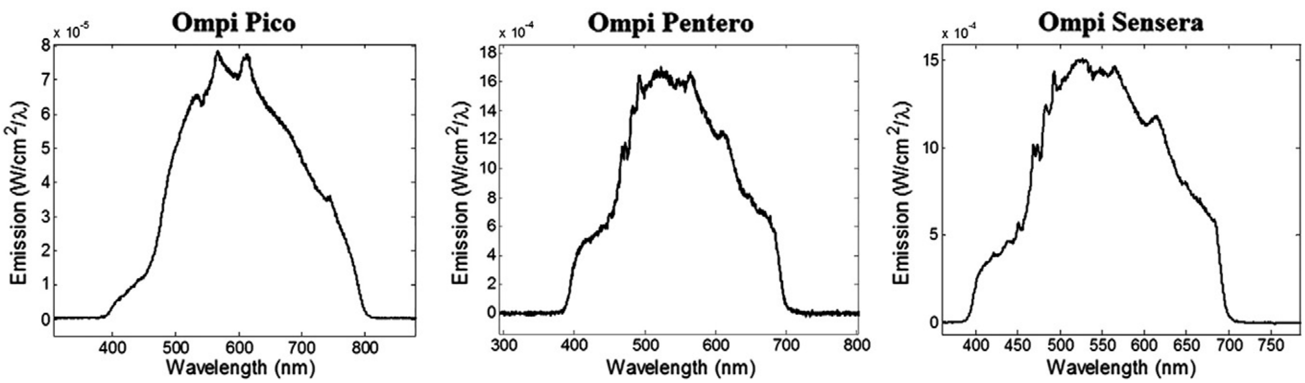

Fig. 1 – Emission spectrum of operative microscopes demonstrating the lack of infrared or ultraviolet wavelengths.

restrictions. Lastly, energy emitted at individual intensity settings varies with bulb age. Similar to prior reports in which older bulbs had a 20%–30% decrease in energy, the bulb age difference of 159 h found in the Pentro models during this study resulted in an approximately 14% decrease in emission (Table 1) [10]. Lower intensity levels may be appropriate during early bulb usage.

4.4. *Know if spot size changes the radiance of your microscope, and use smallest spot size that illuminates your surgical field. Adjust intensity settings accordingly*

Multiple microscope designs result in variable changes to energy emitted in reference to spot size. Spot size may be decreased in a microscope by focusing the same amount of energy into a smaller area, or through simple closure of an aperture. If energy is focused, energy density is increased. If an aperture design is used no increase of energy occurs. The Pentero and Sensera models both had increases in radiance with decreasing spot sizes. The spot size of the Ompi Pico increased with working distance due to spread of light from source. No ability existed to change the spot size of the Ompi Pico with a fixed working distance. It is important to use the smallest spot size which adequately illuminates your surgical field. If a larger spot size is used, thermal injury can often result which is not visible through operative vision. Intensity setting may be decreased at smaller spot sizes.

4.5. *Anticipate patient factors*

Though not tested in this study patient factors are important and may contribute to the formation of burns. In the two burns that occurred at our institution we hypothesized that residual betadine, heated metal self-retaining retractors within the field, and increased energy absorbing melanin within the patients skin may have increased the risk of burn. An additional patient factor thought to contribute to burns at decreased exposure levels but not seen at our institution are photo-sensitizing medications. Lastly, injection of local anesthetic may decrease the blood supply to the tissue leading to decreased local heat dissipation through the circulatory system. These negative patient factors may be overcome through irrigation and secondary evaporative cooling of the wound during surgery.

5. Future directions

Currently, industrial standards do not provide clear guidelines for extended exposure to non-collimated light. This limits our ability to provide direct time and exposure recommendations. In addition, multiple variables in tissue perfusion, absorption characterics, incident angles, and other patient factors would make a single recommendation of power output or length of exposure difficult to define. Future modeling of exposure limits may be accomplished through calculations based on energy absorptions presented in this paper. Energy absorbed may be converted to heat through known values of the density and heat capacitance of skin [11]. Importantly efforts must be made to account for ambient heat dissipation and heat dissipation through the circulatory system. Values may then be used to calculate exposure and time limits which create first, second and third degree burns based on the Arrhenius method [12,13].

Additionally, future studies of operative microscope intensity during reconstructive surgery may be warranted in free tissue transfer. Intensity levels of microscopes during venous and arterial anastomosis may cause damage at the histological level. If damage is found its role in flap survival should be elucidated.

Table 2 – Optical Output of Ompi Pico.

Magnification × .4	Output (mW/cm^2)
Intensity 33%	
Working Distance 11 cm	4
Working Distance 23 cm	4
Working Distance 25 cm	3
Intensity 66%	
Working Distance 11 cm	15
Working Distance 23 cm	11
Working Distance 25 cm	10
Intensity 100%	
Working Distance 11 cm	42
Working Distance 23 cm	27
Working Distance 25 cm	26

6. Conclusions

Operative microscopes have the potential to cause severe burns during surgery. Physicians should be aware of their microscopes properties and how to control variables which effect irradiance of the skin.

Conflicts of interest

None.

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