REFLECTION OF CARBON DIOXIDE (CO_2) LASER RADIATION FROM THEATRE SURFACES

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(Submitted: 18 July, 2005; Accepted: 124 April, 2006)

Abstract

This work has investigated the power of both specular and diffusely reflected beams of CO_2 laser radiation from metallic and non-metallic surfaces of an operating theatre including surgical instruments (specula) and different samples of wall paints in theatre 6 of the Aberdeen Royal Infirmary, U.K. where the CO_2 laser radiation is used for surgical treatment. Transmission of the beam through theatre clothing materials as well as relationship between incident and reflected power were also investigated. This study has revealed that linear relationship exists between incident and reflected power and that all metallic surfaces reflect a high proportion of the incident CO_2 laser radiation. The surgical instrument (vagina speculum) reflects over 55% of the incident CO_2 radiation. Other metallic surfaces (e.g. aluminum) reflect up to 60%. Specular reflectance from non-metallic surfaces was as high as 8% from the theater wall (gloss paint). Each of these values produced very high irradiance (W/cm^2) of 11.21, 12.71 and 1.66 for vagina speculum, aluminum surface and theatre wall respectively. All cloth materials tested for transmission absorbed over 97% of the incident radiation.

***Keywords**: Laser radiation, reflection, transmission and irradiance.*

Introduction

Medical applications of lasers have advanced in recent years and their application has grown from a few medical specialties in a limited number of hospitals to a viable medical instrument in the field of medicine with various uses in surgery, exploited by many hospitals. Today, there exist many surgical lasers, including the argon, carbon dioxide (CO_2), Nd-YAG, Ho-YAG lasers and others. The CO_2 laser is the most frequently used surgical laser. It is effective in the removal of pre-cancerous lesions of the cervix (Petruce et al 1985, Albert and Muller 1993). The advancement in the use of surgical lasers opens new possibilities for medical treatments. However, this viable technique is also associated with potential risks. Many laser accidents have been reported in the literature (Barat, 2003; MeyerRiemann et al 1997 and Rockwell, 1994). The major cause of laser accidents is an unwanted exposure of radiation either from direct or reflected beams of laser radiation. The potential hazards to the eyes and skin from accidental exposures caused by reflections of laser beams from surgical instruments have been of great concern to operating theatres and staff members (Wood et al, 1992).

Reflection of laser beam radiation from specularly reflective surfaces (mirror-like surfaces) can cause laser hazards. Even rough surfaces (metal) may serve as mirror-like reflectors at far infrared wavelength such as carbon dioxide wavelength of 10.6μ m (Slinny and Trokel, 1992).

Few studies have been conducted to investigate the reflection of infrared laser radiation (CO_2 and Nd-YAG) from flat metallic surface (the type used for the manufacture of surgical instruments), conducting surfaces (e.g. copper) and dielectrics that are likely to be encountered in hospital environments (Driver and Taylor, 1986, Petruce et al 1985, Wood et al, 1992). These studies have revealed that a considerable amount of the incident laser radiation is reflected by these targets, up to about 90% in some cases. Drive and Taylor (1986) concluded in their study that the high reflectance has resulted from flatness of the surfaces and that the convex surfaces of specula could reduce the hazards of specular reflection by defocusing the beam and may hence reduce the power density of any reflected portion of the beam.

Operating theatres constitute lots of surfaces of different materials, ranging from the structural components (the wall surface, electrical sockets, cabinets and all other surfaces affixed to the wall), surgical instruments, the often preferred neat smooth tile floors, and theatre clothing.

The objective of this paper is to investigate the interactions of the CO_2 laser radiation with these surfaces with particular interest in reflection and transmission of the beam in order to assess the risk of unwanted exposure of staff and patients.

Materials and Methods

The different samples of wall paints were painted on (20 x 20) cm^2 chopped wooden board. The surfaces of the board were smooth enough to mimic theatre walls. The laser is a **SHARPLAN 1020** Carbon dioxide surgical laser, operating at the wavelength of 10.6μm, and a TEMoo mode, which gives a Gaussian distribution beam output with a very low divergence and a spot size diameter of 0.26mm. The beam is delivered by a lightweight carbon fibre, 7-joints spring balance articulated arm beam delivery system. All measurements were performed in theatre 6 of the Aberdeem Royal Infirmary, Scotland where this laser is used for medical treatments. The experimental set up is shown in Fig. 1.

The output power of reflected and transmitted beams of the laser was measured using the Ophir NOVA laser power/energy monitor (meter). The head is a thermopile device designed for use at maximum power of 3W, maximum average power density of 50W/cm^2 and has a broadband surface absorber (high power density). It is designed to take measurements at a wide range of wavelengths measurement regions (100-800nm, and above 800nm). It is suitable for power measurements at both visible and the infrared wavelengths. The Thermal head and the meter have been calibrated together by the manufacturer to give direct reading of laser power. Linearity and accuracy of calibration is 1% with maximum error in measurement of <2%. To ensure that background reading does not interfere with actual measurement values, the meter has an incorporated nulling technique using an offset button that subtracts any background light. It can also be set to measure average power over a desired period of exposure.

Incident and reflected power of the laser beam was measure using the detector described above. The laser beam was incident at the target at angles of incidence (30, 45, and 60 degrees) using the articulated arm and the average power of the reflected beam was measured between 0 to 90^0 for the duration of about 10s in a continuous mode. The power output of the incident beam was measured before and immediately after each sets of

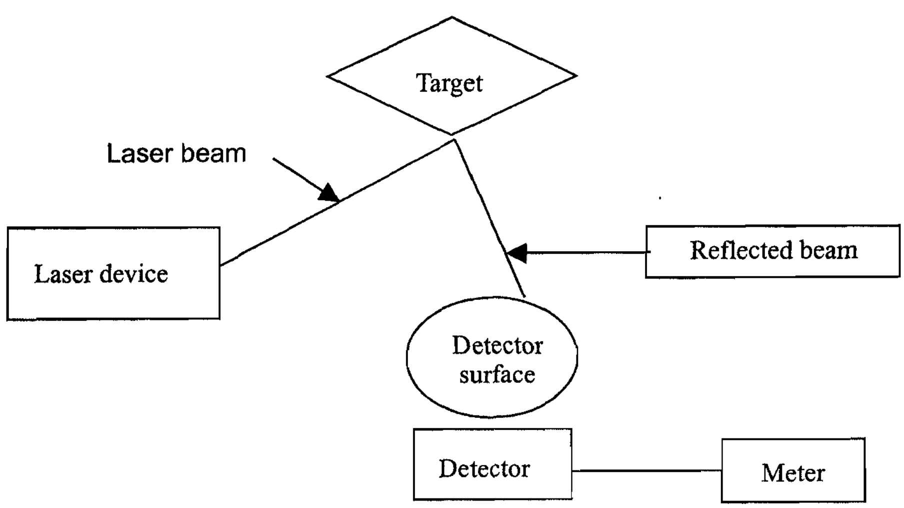

Fig. 1: A Sketch showing arrangement of experimental set-up

measurement of reflected power. The mean of these values was used as the 100% power of the incident beam and all calculations were normalized accordingly. Although in all cases, there were not many variations in the initial and final power readings.

All measurements were made with minimum power (1W) setting of the laser device. For some targets (e.g. vagina speculum) only incident angle of 30^0 was achievable due to the surface nature of the instrument.

The power of the incident laser beam was gradually increased and the reflected average power output was measured sequentially at a particular angle of incidence to investigate the relationship between incident and reflected power outputs. This measurement was however performed with only the vagina speculum. This target was chosen to represent a real clinical situation where the vagina speculum is used during CO_2 laser surgical operations of the cervix to separate the walls of the vagina for improved accessibility of treatment site.

In transmission measurement, the piece of cloth was held at the detector's head surface and the laser beam directed at normal incidence (90^0) at a distance of 30cm. The average transmitted power was recorded for the exposure duration of about 10s.

Results and Discussion

Reflected power varies linearly will incident power Fig. 2. The percentage reflectance of the actual measured values (Table 1) per incident watt from each of these surfaces has been normalized to the maximum power of the laser device (20W) as shown in Table 2. The reflected irradiance has been calculated for the worst-case of specular reflection (i.e. at angles where the highest values of specularly reflected power is measured).

Figure 3 illustrates the reflective properties of the targets to the carbon dioxide laser radiation. The flat aluminum target reflected the incident radiation beam more specularly than all other targets (this may be due to the shinny smooth nature of the surface), followed by the vigina speculum with reflected beam irradiation of 12.71 W/cm^2 and 11.21 W/cm^2 respectively. All metallic targets produced very high values of reflected irradiance (Table 2), which are more than 1000 times higher than the MPE (Maximum Permissible Exposure) limit of ($10mW/cm^2$) (Slinny and Trokel

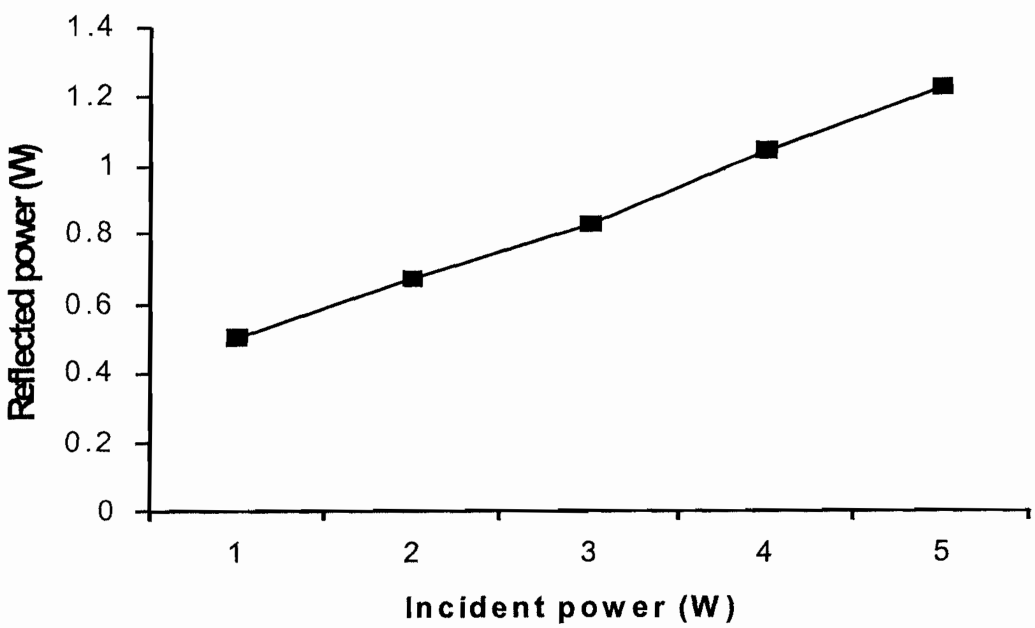

Fig. 2: Relationship between incident and reflected power

1993). The high values of reflected irradiance suggest a high risk of radiation hazards from CO_2 laser reflected beams (particularly, unintended exposure to the skin of theatre personnel).

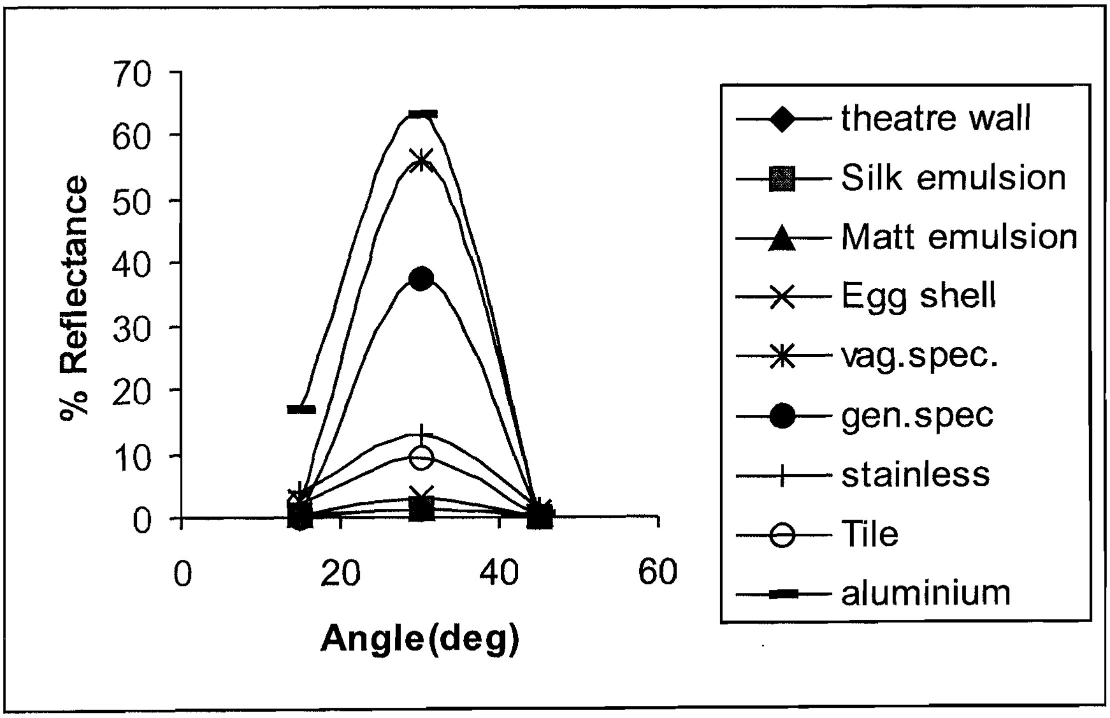

Fig. 3: Reflective properties of targets to CO_2 laser radiation. (Angle of incidence 30°)

Table 1: Measured reflected power and calculated reflectance angle of incidence and reflection 30°

Target	**Reflected power m(W)**	**% Reflectance**
Theatre wall	12.59	1.53
Silk emulsion	9.69	1.20
Matt emulsion	11.39	1.39
Egg shell	24.41	2.97
Vagina speculum	460.00	56.03
Gen. speculum	306.00	37.27
Stainless	108.00	13.15
Ceramics	76.00	9.26
Aluminium	493.00	63.53
Plastics	16.67	2.03

Table 2: Reflected irradiance (W/cm^2) of the aluminium of CO_2 (20W)

Target	% Reflectance incident watt	Normalised reflected irradiance (W/cm2)
Aluminum	63.53	12.71
Vagina speculum	56.03	11.21
General speculum	37.27	7.45
Caramics tile	9.50	1.90
Treated stainless steel	13.15	2.63
Theatre wall (gloss paint)	8.31	1.66
Matt emulsion paint	1.39	2.78×10^{-1}
Silk emulsion paint	1.20	2.4×10^{-1}
Egg shell	2.97	5.94×10^{-1}
Plastics	2.03	4.06×10^{-1}

The non-metallic target appeared to absorb more of the incident beam and reflect less (Figure 3). The result of this work has shown that even the least reflector, the silk emulsion paint; produce a reflected irradiance of 0.24 W/cm^2, a value that is still far greater than the MPE. At all angles of incidence the water-based silk and matt emulsion paint reflected less specularly. Specular reflection from the wall surface (gloss paint) is comparatively very high (Figure 4).

Table 3: Transmission of CO_2 radiation through clothes

Material	Transmitted power (mW)	% Transmittance
Lab coat (white)	6.25	1.53
Green surgical suite	8.69	2.04

Measured incident power (0.425W)

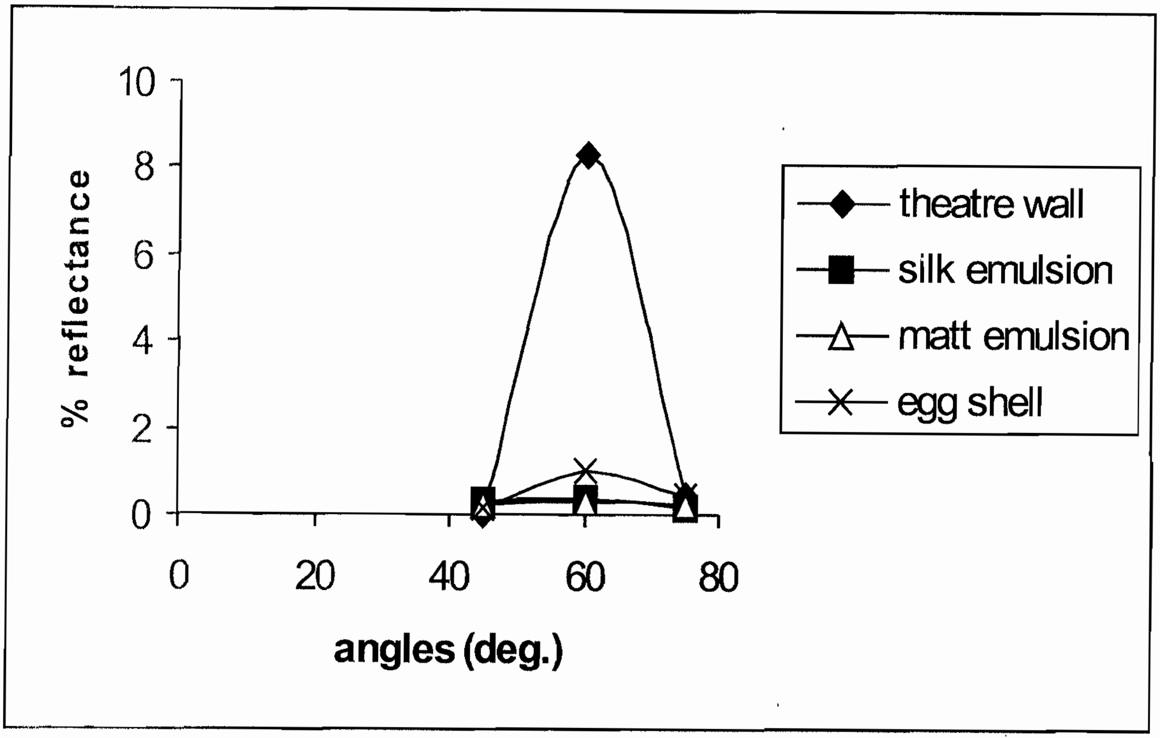

Fig. 4: Reflective properties of paint samples to CO_2 laser radiation

At close range, the non-metallic targets absorbed a high percentage of the incident laser beam and there was no significant reflection. The two clothing materials tested for transmission of the beam absorbed over 90% of the incident beam (Table 3), but the green surgical suit transmitted more because it was lighter. At close range for long exposure, both materials absorbed most of the beam and burnt. Clothing the skin may preserve it from reflected beam hazard; thick materials offer more protection from reflected beam exposures.

Conclusion

Obviously, this study has clearly shown that the reflection of CO_2 laser radiation can be hazardous to the skin.

Hazards associated with CO_2 laser radiation may occur either from theatre reflective surfaces such as walls or from surgical instrument such as stainless steel speculum. Drive and Taylor (1986) concluded that the convex surface of specula could reduce the hazards of specular reflection by defocusing the beam, but this work has shown that even the convex surface of specular still posses a very high risk of unintended exposure from specular reflection of CO_2 laser.

Occurrence of the first hazard can be minimized by reducing the use of highly reflective surfaces (metallic surfaces) in CO_2 operating theatres. Plastic products could be used where possible since they absorb most of the incident radiation.

The use of solvent- based paint (gloss, eggshell, etc) should be avoided in CO_2 operating theatre to minimize reflection radiation hazards from the wall. Skin protection can be optimized if the skin is properly covered with cloth, since cloth materials absorb most of the beam. Thick cloth materials are better for use in CO_2 laser operating theatre.

Acknowledgement

I am grateful to Dr. A. Manivannan and Dr. Christopher Green who supervised this work, and the authority of Benue State University for giving me the opportunity to study at the University of Aberdeen, Scotland, where this research was carried out.

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