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IMPROVED SYSTEM AND METHOD FOR ILLUMINATION AND VENTILATION OF AN OPERATING ROOM

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Abstract

European patients undergoing surgery have about 2.6% chance to develop a post-operative infection. Besides pain and discomfort, these infections can lead to hospital readmission, additional surgical procedures and even the decease of the patient. The ventilation system provides clean air that descends on the patient and protects the patient from being infected by pathogens. The surgical lighting system provides adequate lighting to the wound, ensuring a high illuminance, even in challenging conditions as deep and narrow wounds. Currently, the protecting airflow is perturbed by the shape, position and heat of the surgical lighting system, causing turbulent air flows. Post-operative infections may originate as particles from outside the protective zone enter the surgical site by these turbulent air flows. To reduce this disturbance of the laminar airflow by the surgical lighting, we have developed an integrated concept of an LED-based and automated light source, mounted above a transparent ventilation chamber. This paper outlines the optical design of the new surgical light source and its performance.

Keywords: Optical design, Surgical lights, Laminar flow

1 Introduction

Currently no worldwide accepted golden standard is available for the construction or furnishing of surgical operating rooms. Different countries have different regulations concerning building and exploiting this type of high-end facilities. Nevertheless, the common goal of most rulings, legal conditions and other prescriptions is to ensure, or at least promote, patient safety during surgical interventions.

To preserve the patient from wound infections caused by wound contamination with microorganisms during surgery, a series of hygienic measures is taken. The presence of airborne particles at the operation site and on sterile instruments, potentially carrying pathogenic particles such as bacteria, can be reduced using appropriate ventilating systems. By refreshing the air in the OR frequently with filtered air, the number of colony forming units (CFU), that may lead to infections, will be reduced by dilution.

It is important to keep the area around the patient as clean as possible. This area comprises the surgical site, including the surgical wound, the sterile drapes that cover the patient’s body, the surface of the instrument tables adjacent to the operating table and the surgical team wearing sterile gowns and gloves. Typically, a protected area around the operating table is defined in which the air quality is optimal, actually corresponding to EN-ISO 14644-1 class 5 or better.

Many state of the art ORs are equipped with laminar flow ceilings (LAF). This type of ventilation continuously displaces freshly filtered air from an air pressure chamber to the OR. This ceiling is positioned above the operating table and surroundings. The inflated air temperature is slightly cooler than the ambient temperature, promoting non-turbulent downflow. In several countries, such as Germany and The Netherlands, the latter type of ventilation is mandatory for high standard operating rooms, suitable for the majority of surgical procedures. In contemporary LAFs the filtration through HEPA filters occurs just before the air enters the OR through a diffuser. This diffuser is part of the ceiling of the OR. It is a woven fabric, equalizing the air flow upon entry. The efficiency of ventilating systems in the operating room is available in literature (Chow & Yang 2004; Loomans et al. 2008; Chow et al. 2006; Méndez et al. 2008).

A surgical luminaire system comprises the luminaires and the support arms that extend from the ceiling mount. Both a primary luminaire and secondary luminaire are installed in most operating rooms. Notably, the secondary luminaire is not always used. The luminaires can be manipulated by the operating team using sterile handles attached to the luminaire or by the attending nurse who can manipulate the supporting arms or luminaires in a non-sterile manner.

The current method of lighting and ventilating a surgery room is not optimal. The presence of the surgical luminaire system and the heat generated during the utilization interfere with the down flow of the air when placed beneath the LAF ceiling (Chow et al. 2006). The influence of the luminaire on the down flow, is studied using numerical simulations of the flow by R. Van Gaever in (Van Gaever R. 2015).

To reduce the influence of the surgical lighting system on the ventilation system, an integrated system is developed in this paper. A freedom-to-operate study has been performed and resulted in 70 patents. Most of these patents were discarded from the prior-art study because they were not relevant to the integration of light and ventilation. The remaining patents have been categorized according to their effort to reduce the influence of the luminaire on the down flow:

- by using supplementary cooling for the luminaire's light sources (Ilzig 1976),
- by using less heat producing sources like LEDs,
- by designing the luminaires for minimal aerodynamic disturbance,
- by integrating supplementary ventilation originating from the luminaire using filtered (Kristensson et al. 2007; Verzicht 1992; Hofmeister 2012; Koch 2003; Hölter 1987; Hölter & Krampe 1985; Schmidt 1973; Joubert 1973; Gebruder Sulzer Aktiengesellschaft 1970; Potapenko 1967; Kummerfield 2002; Zeiner 1992),
- or other devices (Baberowsky & Glossmann 1977; Ilzig 1976).

Earlier designs placed a mobile luminaire (to be moved by a nurse outside the OR) behind a transparent dome. This way the luminaire does not interfere with the air flow in the OR. Unfortunately, only turbulent air flow can be achieved since no LAF is present. Others designed a mobile device carrying a luminaire inside a pressurized perforated chamber (Herbst 1986). All the above-mentioned solutions do not provide an undisturbed air flow in the protected area.

The ultimate solution is to integrate ventilation and illumination globally. In the past some inventors used reflectors built in the LAF ceiling, reflecting light originating from a light source in the ceiling (Herbst 1987; N.Noboru, O.Tadahiro, T.Kazuo, A.Kinichiro n.d.) or the adjacent wall (Herbst 1987) or room (Chavannes 1973). Unfortunately, no sufficient quality of illumination was achieved. Others placed fixed light sources inside the air pressure chamber equipped with a woven fabric diffuser creating diffuse light (Herbst 1986; Van Popta 1972). This does not permit one to aim the light at a particular position. Efforts have been made to counter these problems by trying to integrate ventilation and lighting. Recently, a Spanish group patented and built a laminar air flow ceiling in which a number of circular spaces is occupied by transparent hemispheres (Amat Girbau et al. 2013). The system is called Telstar Intelsun. Within these hemispheres, several LEDs are mounted on a platform which can be rotated. When the surgeon points to an area within the operating area using an infrared radiation emitting device, the position is picked up by an infrared camera. An electronic system and several servomotors direct all light sources to the given position. The inventor claims that the air flow is not disturbed by the presence of these hemispheres. Unfortunately, the system is not certified according to the European Standard ([IEC] International Electrotechnical Commission 2009). In 2014, Liu et al. published a design using free-form optics (Liu et al. 2014). The elements are located around the LAF ceiling, excluding interference with the air flow.

2 Methods

2.1 Description of the patented concept

To overcome the disturbance of the uni-directional flow by the surgical luminaire, we filed a patent (Jacobs, V., Van Gaever, R., Diltoer 2016) for a new design that switches the position of the luminaire and the ventilation, as in Figure 1. The ventilation is provided from a ventilation chamber in the plenum, which has a transparent top and bottom that allows light to be transmitted to the wound of the patient. To create a uni-directional flow, the transparent bottom of the ventilation chamber is perforated with holes. This perforation technique was formerly used in metal plates to create a unidirectional flow, before air canopies were used.

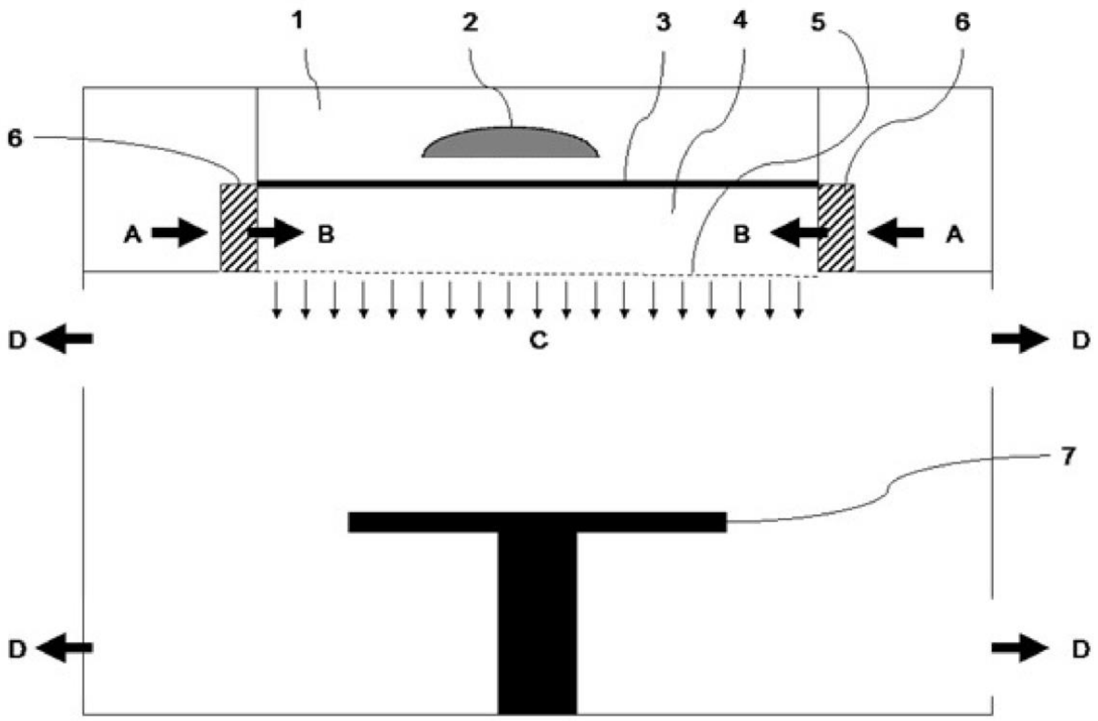
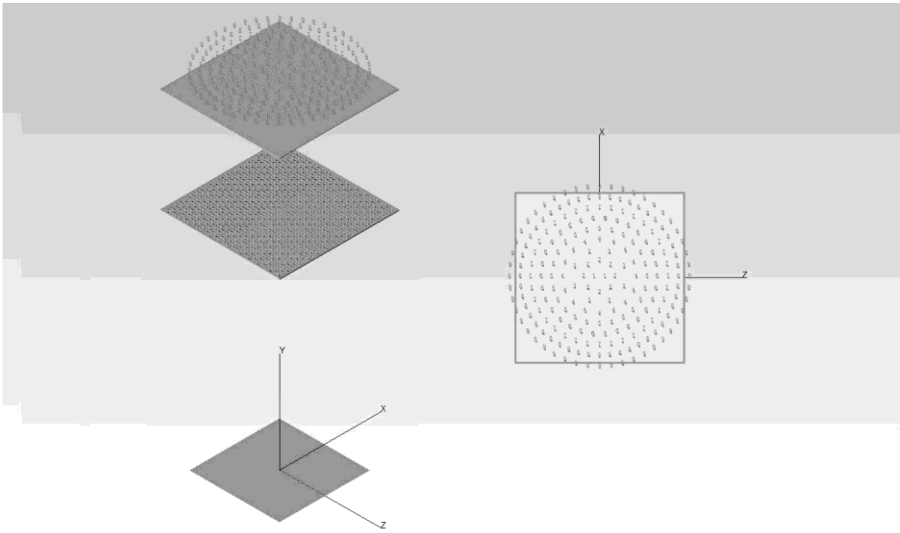


Figure 1 – Innovative concept of an OR that integrates light and ventilation. Above the patient, an air chamber can be observed, above which a lighting chamber is installed. The top and bottom of the ventilation chamber are transparent to allow light to be transmitted. To induce a unidirectional air flow from the plenum, the bottom of the air chamber is perforated. (1) light chamber with transparent floor (2) primary mobile luminaire (3) pressure rooms (4) transparent ceiling (5) perforated transparent air outlet (6) HEPA filters (7) operating table (A) conditioned air supply (B) filtered ultra-clean air (C) downward flow (D) air outlet.

2.2 Optical simulations

Figure 2(a) describes the proposed concept. It comprises 214 LEDs, which are arranged in concentric regular polygons in a single plane around a center, as in Figure 2(b). The diameter of the system is 85 cm. Each LED has a luminous flux of 60 lumen, which is a very moderate value nowadays, and it is equipped with focusing optics, resulting in an intensity distribution with a FWHM of 7° for each LED. By choosing LEDs as e.g. Osram Oslon SSL 150, the system will have a CRI of minimally 90. These LEDs are available in a color temperature ranging from 2700K to 5000K, so they comply to the European Standard ([IEC] International Electrotechnical Commission 2009).



(a) (b)

Figure 2 – (a) 3D view of the optical design for the new surgical luminaire. Above, the 214 LEDs can be found, followed by a non-perforated polycarbonate plate, followed by a perforated plate as described earlier. Below a measurement plane can be seen. (b) top view.

The transparent plates are characterized as polycarbonate plates with a thickness of 1 cm. The bottom plate has perforations in the shape of a square lattice with a mesh size of 15 mm and a diameter of 5 mm.

3 Results

The proposed surgical luminaire system complies to the European Standard ([IEC] International Electrotechnical Commission 2009). It is possible to achieve a central illuminance of 160 klx. Shadow dilution is tested using masks and a tube; using two masks, an average reduction in central illuminance of 50% is observed, while adding a tube had no influence on the observed central illuminance. This can be explained as the solid angle that the light source subtends as seen from the light field centre, is smaller than the opening angle of the top of the tube. Finally, the distance between the new surgical luminaire and the wound zone has increased compared to conventional surgical lights. A depth of illumination of 122 cm is achieved. Moreover, the thesis of (Van Gaever R. 2015) stipulates that the current configuration is superior with respect to the ventilation in the operating room, as can be seen in Figure 3, where a more homogeneous downflow is realised for a perforated plate system, compared to a laminar flow system with a CG diffuser and a luminaire. This indicates less turbulence and thus efficiently reduces the number of particles in the wound zone, which directly reduces the risk of the patient to post-operative infections. From the simulations in the thesis of (Van Gaever R. 2015) a reduction of 66% in particles at the wound zone was achieved compared to a laminar flow system with diffuser and a luminaire.

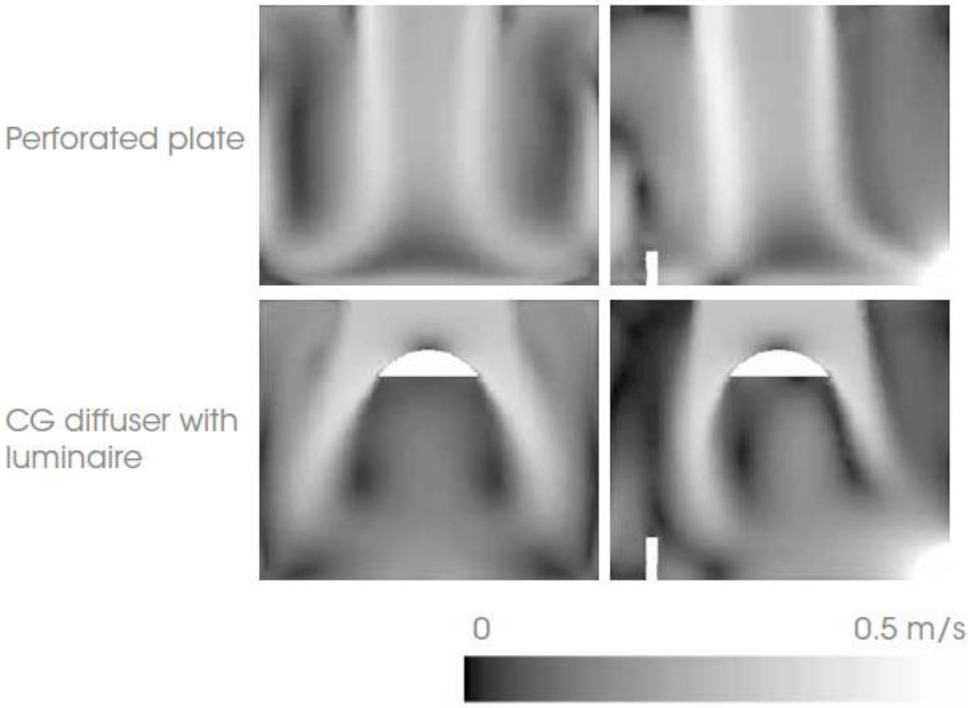


Figure 3 – Comparing the airflow of the newly designed system using perforated plates with a conventional laminar flow system with CG diffuser and a luminaire, it can clearly be seen that the airflow displays a more stable behaviour in the new system. Figure courtesy of Romy Van Gaever.

4 Conclusions

Post-operative infections may occur when pathogenic particles enter the wound of the patient during surgery. Therefore, rulings are at play in an operating room to assure that a minimum number of pathogenic particles is present and reach the protective zone comprising the wound of the patient and the instrument table. One of these measures is a laminar flow system, providing a shower of clean air in this protective zone. The surgical luminaire system provides the necessary lighting in the wound zone, yet it obstructs the flow of clean air.

In this paper an innovative and patent-pending system is presented to integrate surgical lighting and ventilation. The positions of the luminaire system and ventilation are interchanged compared to the present situation. By consequence, the ventilation chamber should be transparent, yet allow a flow of air through perforations. Also, positioning the luminaire system should be performed automatically.

The proposed system is equally performant or even better than conventional systems with respect to the lighting and air quality that is achieved: less particles enter the wound zone which directly impacts the patients' risk to a post-operative infection.

Further research should look into which luminaire positions and inclinations can be achieved using the new system, as the distance between the patient and the light source increases. This will also depend on boundary conditions as the building height of the operating room.

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