UNIVERSITY OF TECHNOLOGY, SYDNEY: FACULTY OF DESIGN, ARCHITECTURE AND BUILDING
MASTER OF DESIGN (BY THESIS)

A study of the Design Considerations and Emerging Technologies in the area of Major Surgical Lighting

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Figure a). Operating theatre and light dating back to 1822, St Thomas's, London.

Glossary

M.S.L.	Major Surgical Lighting
L.A.F.	Laminar Air-Flow
C.F.D.	Computational Fluid Dynamics; computer based fluid dynamics modeling
Lux (lx)	SI unit of illuminance; One lux is equal to one lumen per square metre, where 4π lumens is the total luminous flux of a light source of one candela of luminous intensity.
Photo-toxicity	harmful effects of light inc. UVB and UVC radiation
IR	Infrared
UV	Ultraviolet
CRI	Colour Rendering Index; a measure of the ability of a light source to reproduce the colors of various objects being lit by the source , developed by the International Commission on Illumination
HEPA	High Efficiency Particulate Arresting Filter; typically removing 99.97% of all air borne particles larger than 0.3 μm
OR	Operating Room
Laminar flow	fluid flow in parallel layers, with no disruption between the layers
Collimated	light with parallel rays
NA	Numerical Aperture; a dimensionless number that characterizes the range of angles over which the system can accept or emit light
Asepsis	the practice to reduce or eliminate contaminants from entering the surgical field

ABSTRACT

The basic principles of Major Surgical Lighting (M.S.L.) have not changed significantly in the last 80 years; one or more light sources located in front of a large diameter reflector(s), suspended over the patient with some ability for positioning and focus. However, over the same period, surgical procedures and methods have progressed dramatically, as have other areas of operating theatre technology.

There have also been many other developments in the field of general lighting technology that may be useful in M.S.L. that to date, have not been fully explored. New research was needed that looked at the design considerations of M.S.L., taking into account these advancements, exploring any challenges or opportunities they presented.

Current literature and research in the field of surgical lighting and related issues has been investigated and summarised. This research revealed that perhaps the most pressing design issue of M.S.L. has been created by advancements that have been made in other areas of Operating Theatre technology. The use of ultra clean Laminar Air-Flow (L.A.F.) systems, which have been shown to reduce post-operative infection by up to 50%, has been becoming more prevalent since the technology was first introduced in the 60's. However, a number of studies have also shown that the effectiveness of any laminar flow system is severely compromised by current surgical lighting design.

This research proposes the use of flexible light-guides to enable the remote location of the light source, thereby greatly reducing both the heat output and physical disruption to any L.A.F. system. New opportunities for improvements in light delivery such as adjustable spectral distribution, and dimming with the colour temperature remaining stable are explored.

Computational Fluid Dynamics are used in order to compare and evaluate existing and proposed M.S.L. designs in relation to their disruption to L.A.F. systems. It is shown that the proposed light-guide system causes negligible disturbance to laminar flow when compared with current designs, therefore further reducing rates of post-operative infection.

2. Introduction

Major surgical lighting design has developed very little when compared to the early electric powered surgical lights of the 1920's (see figure 2 below). Nearly all of the currently available major surgical lighting systems still rely on the original design principal of one or more light sources located in front of a large diameter reflector(s), suspended over the patient with some ability for positioning. However, over the same period, surgical procedures and methods have progressed dramatically, as have other areas of operating theatre technology.

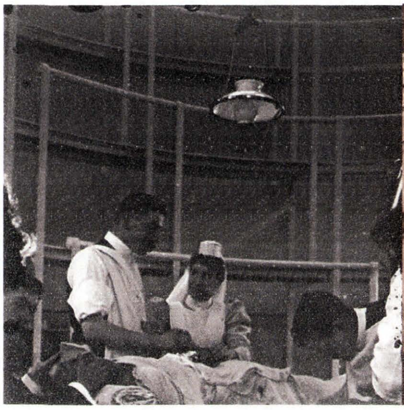


Figure 1. Circa 1900

Figure 2. Circa 1920

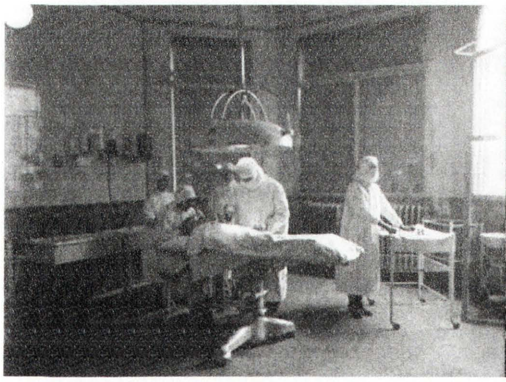


Figure 3. Circa 1940

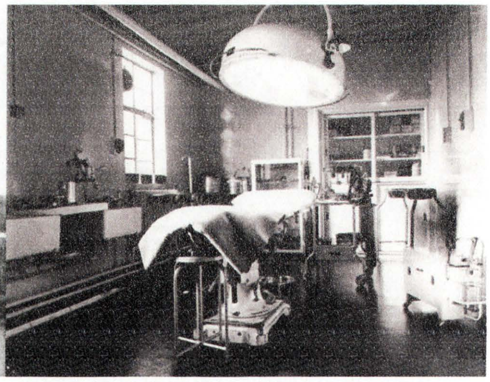


Figure 4 Circa 1950

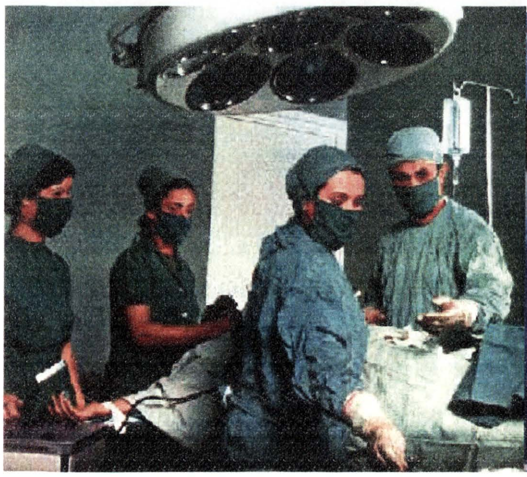


Figure 5. Circa 1970

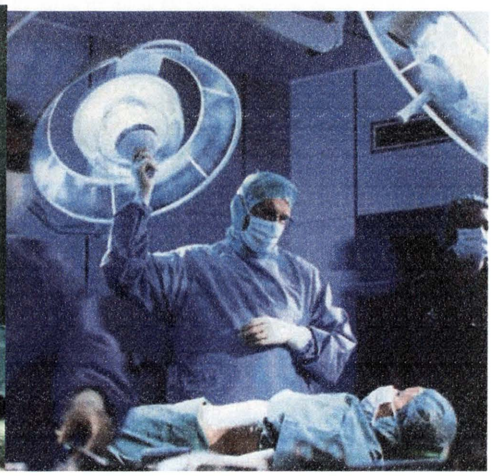


Figure 6. Circa 2000

The only major change in surgical lighting has been a continuous increase in the quantity of light required at the surgical field. For example, the suggested surgical illumination level in 1944 was1,500 lux[1], a fraction of the current standard, which is up to 160,000 lux[12]. This dramatic increase in power has increased the amount of heat (both radiant and convection) produced by these systems, as well as their inherent size. To illustrate this point, the "flagship" lamps of both Berchtold and Martin (two of the best selling brands world-wide), are both 1m in diameter and the majority of the 250 watts used by the lamp is spent producing heat.

One of the most pressing design issues of surgical lighting has been created by advancements that have been made in other areas of Operating Theatre technology. The use of ultra clean Laminar Air-Flow (L.A.F.) systems, which have been shown to reduce post-operative infection by up to 50%[2], have become an integral part of many modern operating theatres. However, a number of studies have also shown that the effectiveness of any laminar flow system is severely compromised by current surgical lighting design[3,10,18].

As more hospitals incorporate L.A.F. systems into their Operating Theatres, and available procedures become more advanced and involved, there will be greater need to develop a surgical lighting system that facilitates the optimum conditions for laminar flow, and therefore asepsis.

A survey of existing research in the area has revealed a reasonable amount of work in specific areas relating the technical issues concerning existing major surgical lighting. However there is a lack of broader based design-focused research that studies and evaluates these areas together as inter-related issues. There is also a lack of research that considers the application of new or emerging technologies, such as light guides and advanced spectral distribution control. Although these technologies have not been traditionally utilized in major surgical lighting systems, they may offer dramatic improvements in the operating theatre.

3. Background and Context

The following is a list of literature that was found to be relevant to the topic. The works are divided into a number of sub-groups, with a short synopsis of the works and their relevance to this research.

3.1 General Literature

There are a number of sources of information and research that consider the general requirements of major surgical lighting systems in their current format. These sources can be divided into three categories:

3.1.1 Literature produced by governing bodies: This includes any relevant Standards (AS/NZS 1680.2.5:1997: Interior lighting - Hospital and medical tasks, AS/NZS 3200.2.41:2002 Particular requirements for safety – Surgical luminaries and luminaries for diagnosis, IEC60601-2-41: 2000, MOD) and reports such as Operating Suite Design by the Technical Advisory Committee on Operating Theatres of the Health Commission of New South Wales. The aim of this literature is mainly defining minimum standards for surgical lighting with a particular focus on basic operation and safety issues. It was an essential starting point for this research, defining the main parameters that all M.S.L. systems should satisfy (and many don't).

3.1.2 Literature produced by private or independent sources: This includes The Illuminating Engineering Society of North America (IESNA) document Lighting for Hospitals and Health Care Facilities (IESNA RP-29-95)[11] and Healthcare Product Comparison System (HPCS) study of Surgical Lighting in February 2002. Seminal works such as Lighting In The Surgical Suite by W. Beck, M.D. Contemporary Surgery, Vol.12, No.1, Jan 1978 laid the groundwork for all following literature, such as Update on Surgical Lighting by B. Meltzer, Outpatient Surgery, June 2003. These works take a broader approach, considering issues such as surgeon comfort, ergonomics and finer points of surgical site rendering.

3.1.3 Manufacturers' sales literature: There was a wealth of information in regard to what each manufacturer believed was the most important design issues for M.S.L.s, and how their products were the best to solve or satisfy them. However, it should be noted that the purpose of this literature is to sell lights, and should be taken in that context. There were many cases of unrealistic claims and contradiction; such as features that one manufacturer may claim as an advantage a competitor will claim is a disadvantage.

3.2 Design Related Literature

There is very little literature available that deals specifically with the design considerations of major surgical lighting systems.

Prior to the development of national or international standards in this area R.A. Ersek et al[4] in 1972 then W. Beck M.D.[5] began in 1978 by looking at issues such as minimum illumination levels, shadow control, colour temperature and rendering and task-to-general lighting ratios. Beck followed this up in 1980[6] and 1982[1] by discussing the issues to be considered when choosing the appropriate surgical lighting for a given situation. Beck also added to his 1978 article with an update in 1981 "Operating room illumination: the current state of the art"[6].

H. Contzen[7] published an article in 1984 that again looked at lighting requirements for surgery, however there was little new ground broken here, besides the technical specifications reflecting the gradual increase in the required quality and quantity of light for surgery. 1999 the Journal of The Association of Peri-Operative Registered Nurses (AORN) published an article Lighting Design for the Surgical Environment[8] that further explored these issues from the point of view of nursing staff.

3.3 Hygiene

Use of light handles in the laminar flow operating theatre – is it a cause of bacterial concern? Hussein JR, Villar RN, Gray AJ, Farrington M. Ann R Coll Surg Engl, 2001 Sep; 83(5): 353-4. This study took a small sample (15) of light handles used in hip replacement procedures and cultured bacterial swabs from them, finding light handles did not pose an infection risk.

Hygiene Problems in the Building and Technical Equipping of Hospital Surgery Departments. Nosková T.; Voleková J.; Sobotová L. Ind and Built Env. 2003 Jan; 12(1): 89-92 (4). Part of this work looks at the problem areas of surgical lighting systems that have the potential for harbouring bacteria, such as seams, vents, articulated joints etc.

3.4 Safety, general

Potentials and risks of lighting in the operating room (German) Oostlander K. Krankenpflege Journal 1998 Jan-Feb; 26(1-2): 14-9. An overview of the safety issues for surgical lighting.

3.5 Retinal damage to patient and staff

Retinal light exposure from ophthalmoscopes, slit lamps, and overhead surgical lamps. An analysis of potential hazards. Calkins JL, Hochheimer BF. Invest Opthalmol Vis Sci 1980 Sep; 19(9): 1009-15.

Potential ocular hazard from a surgical light source. Fox RA, Henson PW. Australasian Phys Eng Sci Med 1996 Mar; 19(1): 12-6

Both these works attempt to define what constitutes dangerous exposure, the types of damage that can be done, etc. The main context for both these works is in the area of actual eye surgery, which however important, only represents a very small and highly specialised area of surgical procedure.

3.6 Photo-toxicity (UVB, UVC)

Halogen lamp phototoxicity. Bloom E, Cleave J, Sayre RM, Maibach HI, Polansky JR. Dermatology 1996; 193(3): 207-11. This study finds that dangerous levels of UVB and UVC are radiating from halogen lamps. To give a comparison they state that a 50 watt halogen lamp at a distance of 7cm from the skin can give 400% more chance of producing skin cancer than the noon summer sun in Michigan.

3.7 Burns

Severe burn caused by an operating room light. Bourke DL, Yee K, Mark L. Anaesthesiology 1993 Jul; 79(1): 171-3

Patient burn caused by excessive Illumination during microscopy. Health Devices 1994 Aug-Sep; 23(8-9): 372-3

Accidental hand burns caused by operating room lights. Rao VK, Dibbell DG. J Hand Surg 1988 Jan; 13(1): 50-2. This study looks at burns to the hand sustained by three different patients during hand surgery due to the fact that heat filters were not used in the surgical lighting.

3.8 Fire

Fiberoptic illumination systems can serve as a source of smouldering fires. Eggen MA, Brock-Utne JG. J Clin Monit 1994 Jul; 10(4): 244-6. Without sufficient filtering of Infra Red frequencies, high power fiberoptic light sources can start smouldering fires if the end of the light guide is allowed to rest on a flammable material.

3.9 The use of coloured lighting in operating procedures

Facial dissection plane differentiation using color-hue glasses and coloured illumination. Hoefflin SM. Plast Reconstr Surg 1998 Mar; 101(3): 865. This article claims that the use of a blue tone light and glasses "significantly assists in the differentiation and dissection" of the visually similar tissues found during a face lift procedure."

The appreciation of colour in endoscopy. Vakil N, Knyrim K, Everbach EC. Baillieres Clin Gastroenterol 1991 Mar; 5(1): 183-94

A method of eliminating errors in the perception of skin colour. Acland RD. Br J Plast Surg 1976 Jan; 29(1): 97-8

The use of supplementary blue light during Perkins applanation tonometry in theatre. Roberts C, James A, Hodgkins P. Eye 2001 Apr. 15(pt 2): 242-3

3.10 Laminar Air Flow

On the topic of the effect of surgical lighting systems on L.A.F. systems there are three primary works, Perturbations Affecting the Performance of Laminar Flow in Operating Theatres[18] by C Hartung and J Kugler presented at the 15TH IFHE CONGRESS 1998, Computational Fluid Dynamics Applications in Hospital Ventilation Design[9] by Colquhoun J; Partridge L., and Ultraclean laminar airflow ORs[10] AORN Journal, April, 1998 by Barbro Friberg. All of these works find that M.S.L. systems can severely compromise the effectiveness of a L.A.F. system

Other works with relevance are - Fraise, A.P., Hoffman, P., Burfoot, D. (2003) Ultraclean ventilation in operating theatres - beyond laminar airflow. Journal of Hospital Infection, 53, 152-153 and Indoor air quality and infection problems in operating theatres. Tinker J A, Roberts D,EPIC '98, Volume 1, pp 285-290

4. Definitions and Standards[11] (as defined by Australian Standards)

Major Surgical Luminaire (M.S.L.) ~ Single luminaire in the surgical environment which is **fail safe** and provides an adequate **central illuminance** to illuminate locally the body of the patient. It is intended to support the treatment and diagnosis, and to be used in operating rooms.

Fail safe ~ Capability of equipment to provide a minimum illuminance and to be directed on the operation area even in single fault condition

Central luminance (Ec) ~ Illuminance at 1m distance from the light emitting area of the equipment in the Light Field Centre (LFC) without any obstruction of the light beam.

Australian/International Standards
Central Illuminance 40 000lx – 160 000lx
Colour Temperature 3 000K – 6 700K
Colour Rendering Index Ra 85 – 100

4.1 General

M.S.L., in the region of the operating field, shall satisfy the following conditions
– give lighting with a radially tapered distribution and with attenuation of the cast shadow,
– light the bottom of deep cavities while keeping a lighting level high enough to avoid eye fatigue,
– give lighting directed adequately to give the necessary stereoscopic vision, quickly and without ambiguity,
– emit a minimum energy in the operating field (risk of drying-out of tissues in the operative cavity),
– not emit excessive energy unnecessarily uncomfortable for the operator,
– have an optical spectrum which renders all colours faithfully and which is characterised by colour temperature and the colour rendering index
- in order to have the lighting level appropriate to the nature of tissues and the type of cavity to be observed, while taking the characteristics of the operator's sight into consideration, any equipment may include a device to adjust brightness.

4.2 Requirements

Visual differentiation of very closely graded tissues is particularly delicate and requires high levels of illumination, especially between 600 nm and 700 nm where tissue reflection is low. Moreover, in this spectral interval, human eye sensitivity is reduced.
M.S.L. shall offer a good lighted surface homogeneity during observation on a flat surface or at the bottom of a deep and narrow cavity, despite obstacles, for example the operator's head or shoulders.

4.2.1 CENTRAL ILLUMINANCE
Without any obstruction of the light beam, the level of CENTRAL ILLUMINANCE of M.S.L. shall reach the minimum value of 40 000 lx and shall not exceed 160 000 lx for each single light head.

4.2.2 LIGHT FIELD DIAMETER and light distribution
The minimum diameter d50 where the illuminance reaches 50 % of the CENTRAL ILLUMINANCE shall be at least 50 % of the LIGHT FIELD DIAMETER d10.

4.2.3 SHADOW DILUTION
In the presence of masks simulating the head of one and two operators partly obstructing the light beams, the level of the remaining CENTRAL ILLUMINANCE of M.S.L. shall be measured with and without a tube simulating a cavity.

4.2.4 DEPTH OF ILLUMINATION
Length measured along the optical axis where the illuminance reaches at least 20 %

5. Design Issues

The purpose of an operating lamp is to illuminate the surgical site for optimal visualisation of small, low contrast objects at varying depths in incisions and body cavities. It must do this with minimal shadows, heat transmission and colour distortion. The lamp must be capable of working for extended periods of time without radiating excessive heat, which would cause discomfort and dry tissues in the surgical site.

The design issues of M.S.L.s can be arranged into twelve basic areas: brightness, colour, shadow control, uniformity of light, maneuverability, heat management, IR and UV filtering, bulb replacement, hygiene, cavity illumination, focus and depth of field and integration with Laminar Air Flow systems.

5.1 Brightness: The ideal brightness of OR lights depends on the procedures performed and the preferences of the surgeons (typically between 80,000 to 130,000 lux[12]). Some surgeons prefer an OR with very intense lighting if that is how they were trained It has also been shown that as a surgeon ages they may require higher levels of illumination.

As a rule of thumb, the more invasive the procedure, the more brightness is needed. For example, some plastic surgeries, dermatological surgery and endoscopy need less intense lighting than general surgeries.

The quality of the light's reflector system will also have a major impact on its ability to consistently illuminate the surgical field.

Other key factors that determine brightness quality are the maintenance of a broad depth of field, and consistent illumination with the lights positioned both closer to the patient and at a distance[25].

5.2 Colour: There are two main systems for defining the colour of light achieved by an M.S.L. system: Colour Temperature and Colour Rendition Index.

5.2.1 Colour temperature: Color temperature is measured in degrees Kelvin (K). Higher-color temperatures are desirable in surgery (mid-day sunlight has a color temperature of around 5,000K). If color temperature is too low, objects take on red or pink hues. If it's too high (above about 5,500K), objects can appear bluish. The International Standards for surgical lamps state that the colour temperature should be between 3,000K and 6,700K[11], and most M.S.L.s have a colour temperature between 3,500K to 5,500K[12].

5.2.2 Colour Rendition Index (CRI): This is the measurement of how accurately the light reflects an object in its "true" color relative to the available color temperature. This is based upon a test where the lamp under test is directed onto a series of different coloured tiles. The colour spectrum of the light reflected back from the tiles is then analysed.

Ra is an average of R1 = burnt pink, R2 = mustard yellow, R3 = yellow-green, R4 = light green, R5 = turquoise blue, R6 = violet, R7 = aster, R8 = lilac. This is a crude measure of how "white" the light is. Maximum value (mid-day sunlight) = 100.

R9 is the value for the rendering of the colour red, however this index is not used in calculating the general colour rendering index Ra. The International and Australian standards call for a Ra above 85, but make no mention of R9. As the surgeon is looking at predominantly red tissue, good visible red light is needed to differentiate effectively. The R9 values for conventional operating room lamps are between 20 and 95. Values above 90 allow the surgeon to recognize details more accurately in the area of the surgical field.

It is possible to have a "good" value of Ra with a low value of R9 because Ra is just an average figure. Lamps with a good Ra but poor R9 are usually very harsh white light with a lot of glare in surgery due to too much blue light. It is also possible to have a lamp with a good R9 value and poor Ra value. Such lamps give a visibly yellow/red light rather than a white light.

The optimal MSL should have a high Ra as well as a high R9. This provides a good "white" light that has a good mixture of the visible colours, that also has the correct percentage of visible red light.

5.3 Shadow control: As well as correct colour, the operating lamp must be able to deliver the light to the surgical site around various obstructions. Hands, heads and instruments may all intrude over the surgical field. This is usually remedied through the use of large diameter (up to 1m) reflectors or by shining multiple smaller light heads (up to 9) onto the surgical field from different angles. The effect of this is that obscuring any part of the beam(s) will only reduce the intensity in the field and will not throw any shadows from the object causing the obstruction.

The beams of light shining from the side also have the effect of "under lighting" any obstructions as they can shine underneath the obstructing object. However, it is important that lights maintain contour shadows in order to provide adequate "modeling" of the operating field. The light should not "flatten out" the subtle differences in tissue and vasculature. Illuminating the surgical site with a number of point sources from different angles instead from a homogenous reflector, improves visual perception as it increases visual contrast, making it easier to see different surfaces and surface textures. This is a distinct advantage that multiple head designs have over large single head designs.

5.4 Uniformity of Light: It is very important that an M.S.L. produces uniform illumination across the whole diameter of the illuminated area. This enables all objects within the illuminated area to be seen clearly and without causing undue eyestrain

The Standard for operating lamps clearly defines the conditions under which light intensity measurements should be taken and sets standards for the uniformity of the illumination across the diameter of the light field: The minimum diameter (d_{50}) where the illuminance reaches 50% of the Central Illuminance shall be at least 50% of the Light Field Diameter (d_{10}) where the illuminance reaches 10% of Central Illuminance[11].

Some operating lamps have specially designed "dimpling" on the reflectors and/or lenses, which mix it into a homogenous beam and to direct it to the target.

5.5 Maneuverability: An M.S.L. should be lightweight, and the handle easy to operate, so the light head is simple to maneuver and position as needed. It should be easy to focus and dim. The suspended overhead lights should not drift when correctly installed, so that the procedure does not have to be interrupted while the lights are re-positioned. Adjustment of suspension should be simple, requiring as few tools as possible. At the high-end of the market, systems such as the Harmony System from Steris have touch-button controls for the pattern size, power intensity and focus of the lights[25].
Maneuverability is particularly important during bilateral procedures, due to the often lengthy and involved nature of these procedures. Less expensive models often can't rotate 360° due the use of a wiring loom instead of slip rings at the joints[26].

5.6 Heat Management: There are two methods used by manufacturers to reduce or manage the heat output of their lights. One is the utilisation of the latest generation of bulbs, providing an improved ratio between the visible and the Infra Red spectrums. For example, the Heraeus G8, uses a gas discharge lamp rather than the traditional filament lamps. These generate a lot less Infra Red energy per lumen of visible light to be filtered and dispersed.

The other method employed by some M.S.L. systems now is the use of increasingly sophisticated internal and external mechanisms of dispersing heat. Some systems use cold-mirror reflectors to keep the heat from hitting the OR team and surgical field. Some are designed to push the heat to the back of the light head, away from the heads of the surgical team and the operating field. Once the heat leaves the light head, the airflow systems in most ORs help disperse the heat[25].

Some manufacturers caution that there can be a maintenance trade-off with vented lights. A vented light can collect dust and cleaning fluids. If you are not vigilant about upkeep, this can affect light output over the life span of the light. To correct this issue, there has been a movement by some manufacturers to using sealed-off light heads[25]. In order to solve the resultant heat build-up, some manufacturers are running airlines in the suspension arm to remove the excess hot air.

5.7 IR and UV Filtering: An operating luminaire can generate a significant amount of radiated energy in the Infra Red and Ultra Violet spectrum (wavelengths /800 nm, ≤400nm). It is of paramount importance to reduce these emissions to a minimum in order to protect exposed tissue in the operating site from local temperature rise or high levels of radiation due to absorption of this energy. It is common practice to use high quality filtration systems to remove a high percentage of the unwanted Infra Red and Ultra Violet frequencies.

The Infra Red frequencies can be reduced in any one, or combination of the following ways:
Method 1. To use a filter in front of the light source to absorb the Infra Red, known as an absorption filter.
Method 2: To use an Infra Red reflection filter in front of the light source to reflect the infrared away from the patient.
Method 3. To use dichroic filter behind the light source which selectively reflects only the required visible wavelengths of light and allows the unwanted Infra Red to pass backwards through the reflector. A second filter is placed in front of the light source to filter out any of the remaining Infra Red that has not been rejected by the reflector.

The above methods are generally very effective at removing most of the Infra Red energy, however there is still energy in the remaining visible spectrum. The purely visible spectrum will cause a temperature rise in the operating field due to the absorption of visible light that is proportional to the total amount of light emitted (Illuminance) onto the operation site. This is known as *"Total Irradiance"*.

The correct scientific method of expressing the amount of energy an operating lamp radiates (in the direction of the surgeon and patient) is Watts per Square Metre per 1,000 Lux. This is the measure used to make comparisons between different products from different manufacturers. The Australian and International Standard calls for a maximum of 6 W/m^2/1000lux. For example, an operating luminaire giving a total illuminance of 120,000 Lux should not exceed 720,000 mW/m^2 [720 W/m^2] total irradiance[11].

Some manufacturers state a "temperature increase in the head area" or a "temperature increase in the field". These are not standard ways of measuring the temperature increase caused by an operating lamp and do not give useful figures for comparing products as the manufacturers do not give full details of the conditions under which these measurements are taken.

As well as the visible and infrared frequencies, there are also ultra violet frequencies, which are damaging to humans as they can cause radiation burning, most commonly known as sunburn. It is also potentially damaging to the eyes. Tungsten halogen light sources emit appreciable levels of ultra violet[13], which must be filtered out. Like infrared, the ultra violet is invisible to the human eye so it does not aid visualisation. Both the Australian and International Standards call for a maximum UV radiation of 10 W/m^2[11].

Accurately filtering out the hot infra red and dangerous ultra violet frequencies and then carefully balancing the remaining visible colours is what produces the "cold", colour corrected light necessary to provide the best possible conditions for effective surgery.

5.8 Bulb Replacement[12]: The perfect M.S.L. bulb should be long lasting, easily sourced and easy to replace. Difficult-to-replace bulbs are a pet-hate for many surgeons and maintenance staff, but a few manufacturers have found solutions to this problem. Many of the newer lights now have snap in/snap out bulbs, which don't require any extra tools, but older lights and some less expensive models require removing the cover plate with a screwdriver. Some bulbs are very expensive to replace. They can range from $40 to $400.[12]

Single-bulb lights and multi-bulb lights both have their advantages and disadvantages. Most multi-bulb lights can continue to be used even if one of the bulbs burns out, but the downside is they typically give off more heat, and they require re-lamping more often[12].

Many single-bulb systems come equipped with a backup bulb mechanism that activates if a light burns out during a procedure. If bulbs need to be changed, the process should be simple, so as not to bring the OR to a standstill[12].

5.9 Hygiene: Hygienic design considerations are extremely important within the modern operating theatre and with concerns over "super bugs", that are immune to antibiotics, this is an issue of increasing importance.

The normal method of cleaning down operating lamps is to wipe them down after operations using proprietary disinfectants. If lamps are not sealed, if they have ventilation slots or dirt traps, contaminants will get into the lamps and small gaps and harbor germs. This creates cross contamination risks for the medical team, the patients and for the maintenance team when they carry out servicing[12].

For optimum infection control, a surgical lighting design should eliminate exposed fasteners, open articulation joints and dirt traps to make sure that cleaning is both easy and effective. Some existing designs are virtually impossible to clean down effectively because the manufacturers have not considered the problems of cleaning[12].

5.10 Cavity Illumination: The ability for the operating lamp to penetrate deep cavities is of crucial importance to most surgeons. The operating lamp has to shine light from a wide enough range of angles so that light can get past any obstructions, which get between the lamp head and the patient. These are typically the surgeon's head, shoulders, hands and surgical instruments.

The light must be able not only to get around these obstructions but also to penetrate the surgical cavity with sufficient intensity to provide good illumination for both the bottom and the sides of the surgical cavity.

The Australian and International Standard test is to simulate a cavity by locating a cylinder 75mm long with a bore of 50 mm diameter at 1m below the MSL. A photo sensor is placed at the base of the bore and the measured light level is expressed as a percentage of Central Illuminance. 210 mm solid opaque disks are then placed in specified locations between the operating lamp and the cylinder in various positions. This disk simulates the heads of the surgical team. Light levels are again measured and expressed as a percentage of Central Illuminance.

5.11 Focus and Depth of Field: Some designs of M.S.L. are fixed focus but more sophisticated designs allow the focal point of the lamp to be adjusted by the user. This control can be used to change the diameter of the illuminated area and to vary the intensity of the illumination correspondingly.

With a fixed focus lamp the user would have to physically move the lamp head towards or away from the surgical site to vary the diameter of the illuminated area, which is imprecise and can be very inconvenient at times.

The use of multiple reflector systems makes it relatively easy to arrange focusing. The central reflector remains stationary (because it is always pointing down the centre axis of the lamp head) and the peripheral reflectors are rotated radially towards or away from the central axis of the lamp head to vary the spot size.

Where a single large reflector is used, focusing is quite difficult. Some manufacturers claim that the surgeon does not need to focus the lamp because the prism diffuser provides sufficient depth of field but simple physics shows that a beam can't be collimated and diverging at the same time.

Where large single reflector types of lamp have a focus system, it is usually a "defocusing" system rather than a focusing system. The light source is positioned at the optimum point relative to the reflector surface for normal use, operation of the "focusing" system then moves the light source relative to the reflector to an optically worse position which in effect, defocuses the illuminated area.

5.12 Integration with Laminar Air Flow theatres:

5.12.1 Introduction: It is well-known that airborne contamination with bacteria-carrying particles is one of the dominating causes of postoperative infection in surgery. One large multicenter study of over 8,000 joint replacement operations showed a direct linear correlation between air counts of bacteria and the rate of postoperative infection.[14]

James D. Heckman, MD, 1998 president of the American Academy of Orthopaedic Surgeons (AAOS) when asked to name the most significant advancements of the 20th Century in orthopaedic surgery, he replied, "perhaps the most significant advance....has been the development of sterile techniques such as laminar flow"[15]

Laminar airflow is defined as an airflow in which the entire body of air within a confined area moves with uniform velocity along parallel flow lines (ie, laminar) with a minimum of eddies [16]

Dr Charnley, the pioneer of artificial hip and knee joints, developed the idea of laminar flow in the early 1960's. He realised that a major source of infection was air-bourne skin cells from the surgeons and staff, which were contaminating the wounds, and if there was some way to stop these particles from reaching the surgical site infection rates could be dramatically reduced.

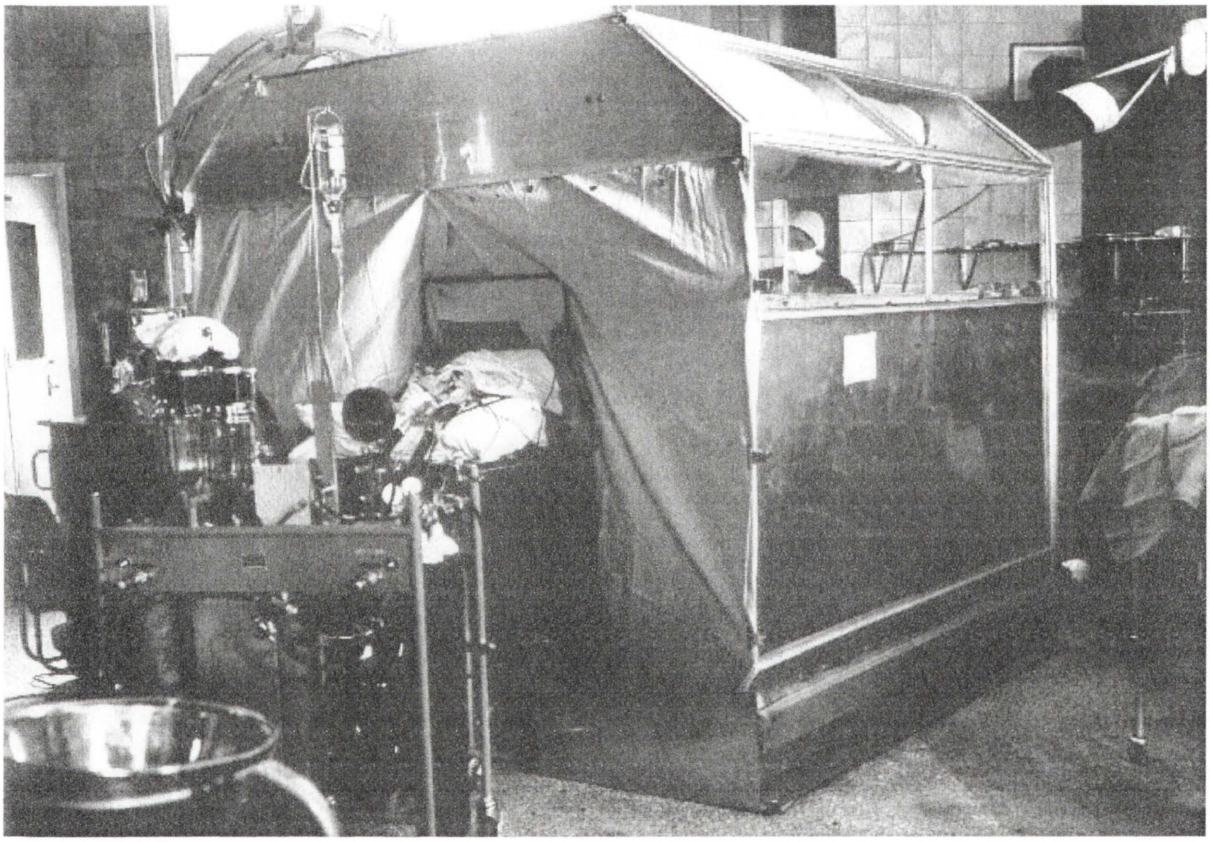


Figure 7. Dr. Charnley's original "greenhouse" laminar flow theatre, 1962.

The concept of a surgical Laminar Air Flow (LAF) system is that air is chilled to three or four degrees below room temperature in the theatre, then passed through large HEPA filters in the ceiling to make it micro biologically clean, before being directed at low velocity (around 0.2m/s– 0.3m/s) down onto the patient in a laminar flow. The reason for chilling the air (around 17°C - 18°C) is to make it denser than the theatre air so that it continues to fall smoothly as it moves towards the patient, thereby reducing turbulence and contamination risk. This clean air then "sweeps" over the patient and past the surgeons, keeping any air-borne skin cells and bacteria away from the surgical field[3].

The bacteria-carrying particles are generated almost exclusively by the OR staff members. During moderate physical activity, every person sheds skin scales, generating approximately 1,000 bacteria-carrying particles per minute.[17]

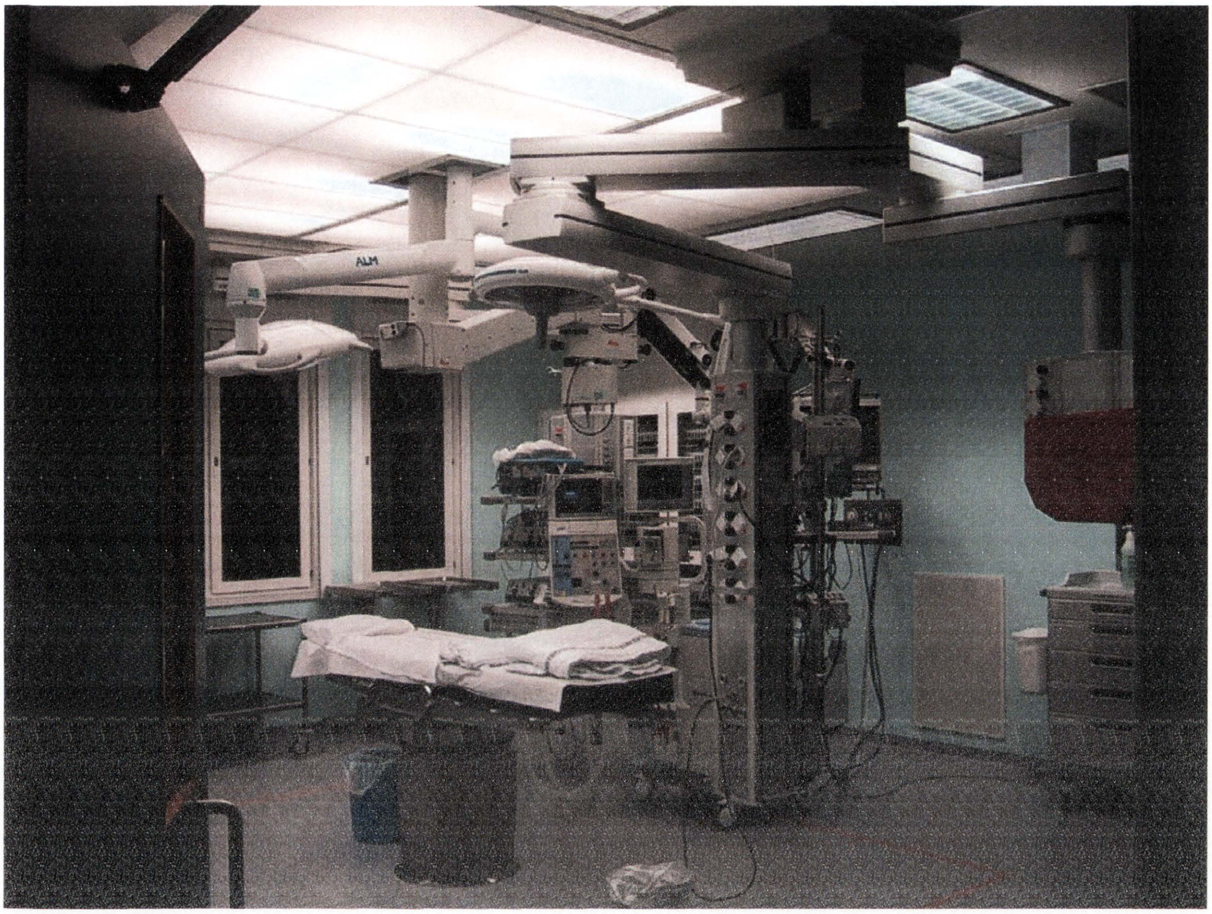


Figure 8. Modern LAF system.

5.12.2 Integration: Conventional theatre lamps interfere with the low speed, laminar flow of filtered air due to their shape and the waste heat that they produce.
As shown in Fig.8 above, the sheer size of the light heads and articulated arms of the theatre lights provide significant disruption to the laminar flow from the inlet panels above.

With large solid lamp head constructions, if the lamp is positioned over the patient pointing directly downwards, it is in the "windjammer" position relative to the laminar flow. The clean air is blocked and has to flow around the large lamp head causing turbulence immediately below the face of the lamp head. As the laminar airflow is at a relatively low speed it is unable to overcome this effect within the confines of an operating theatre. The swirling clean air below the lamp draws in contaminated air from outside the "clean zone".

Friberg[10] found "An OR lamp positioned directly over the wound in a vertical LAF effectively destroys the airflow, not only by its presence in the airstream but also by counteracting the downstream by an upstream convection of air caused by the lamp's heat"

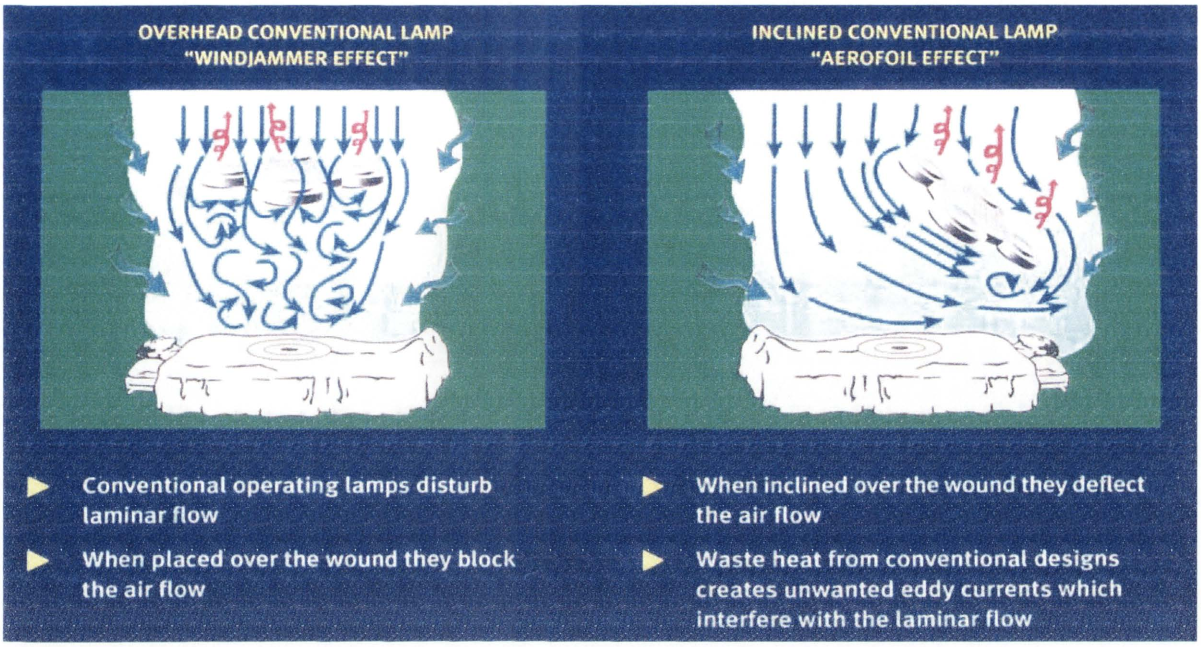


Figure 9 The disruptive effects of conventional operating lamps on laminar flow.

During many types of surgery and orthopaedics in particular, the lamps heads will be positioned at an angle to the laminar airflow. In this position, a solid lamp head will act like an airplane wing. When the air stream collides with the lamp it will be separated into 2 streams, one will travel over the top of the lamp head and the other will pass under and across the face of the lamp head. The top stream has further to travel than the bottom stream, which creates a relative low-pressure area under the lamp head. Other parts of the laminar flow are drawn to this low-pressure area deflecting the clean air away from the surgical site.

Halogen bulbs produce a substantial amount of heat; the processes of heat filtering and colour correction also introduce losses, which will be dissipated as heat. The aim of good operating lamps is to produce "cold light" to project onto the patient and to dissipate the waste heat elsewhere. This is usually done by ventilating the lamp to allow the heat out or by absorbing the heat into the lamp head and structure.

In order for an M.S.L. system to be successfully integrated with L.A.F. system it must either dissipate the heat very evenly so that it does not create significant eddy currents in the air, which will rise to interfere with the clean air coming down, or preferably, not introduce any heat at all. It must also present a minimal cross-sectional area to the direction of the laminar flow.

Large, solid, conventional operating lamps are clearly not suitable for laminar flow. Lamps that have ventilation slots are particularly unsuitable for use in conjunction with LAF systems as the localised exhaust of hot air will create greater turbulence, as well as introduce air that has passed over unsterilised surfaces (i.e. the inside surfaces of the lamp).

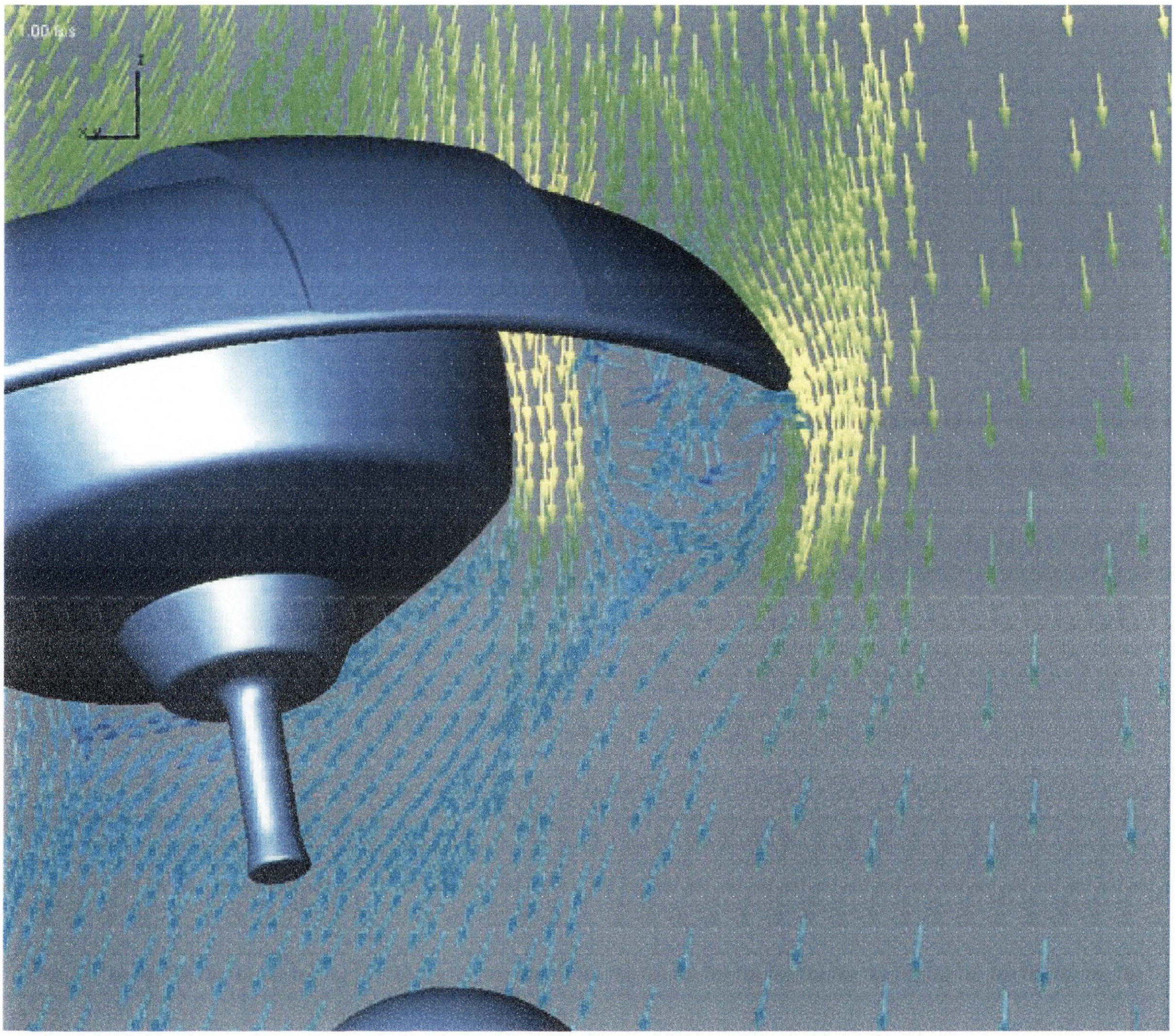


Figure 10: Laminar/Turbulent boundary of Heraeus G8 (source: G8 sales literature)

The M.S.L. that has been designed specifically to minimize disruption of LAF is the G8 by Heraeus. This fact is a major selling point for the light, and features heavily in the sales literature. It is without doubt the best M.S.L on the market in regards to integration with L.A.F. due to its open design and the use of a low power discharge lamp. However, as can be seen even in the G8 sales literature above, this improvement is still relatively insignificant when viewed in context with the level of disruption that it still causes. This is due to the fact that the basic design principle of a light source and reflector positioned above the surgical field will always present a significant disruption to laminar airflow.

6. Design Opportunities

As discussed in the previous section, the main design challenges currently presented by M.S.L. are the protection of delicate tissues from over exposure and the integration of M.S.L. systems with L.A.F systems. Most of the other design issues such as brightness, bulb replacement, colour rendering have found solutions of various forms in the M.S.L. systems currently available.

6.1 Protection of delicate tissues: None of the current M.S.L. systems remove all of the IR or UV frequencies they produce. Due to the fact that the size and weight of a light head must be kept to a minimum to facilitate articulation and maneuverability, it is not feasible in the current arrangement to house the multiple filter layers required for a complete removal of all IR and UV frequencies. The only possibilities are to wait for more effective filtering technologies or to look for a whole new approach towards illuminating the surgical field.

Even if 100% of the IR and UV frequencies were removed, there would be the secondary issue of managing the extra heat produced as a direct result of filtering this extra energy. Also, there would still be the issue of heating effect due to the absorption of the visible frequencies. There is no way of solving this with the present arrangements, it would require some kind of light source with a large range of colour filters capable of providing selective and adjustable spectral distributions, again impossible with the current restrictions on size and weight.

6.2 Integration with L.A.F. systems: The direct linear correlation between air counts of bacteria and the rate of post-operative infection[14] shows that if it were possible to provide an undisturbed laminar flow of sterile air to the surgical site it would reduce the rate of post-operative infection to a fraction of current rates. A number of works[18,10] have shown that M.S.L. systems are a major source of L.A.F. disruption. Any design solution that is capable of producing a significant reduction to the disruption of L.A.F. systems could therefore potentially save thousands of lives and millions of dollars.

The cost of post-operative infection is a major problem in surgery - medically and economically. In a 1995 lecture at the Swedish Institute for Infectious Disease Control, the total extra cost for one infected joint prosthesis was reported to be approximately $100,000 USD[19]. The medical consequences of infection depend on the type of surgical procedure the patient is undergoing (eg, an infection around an aortic graft results in a mortality rate of 30%

to 70%; a deep infection after a hip or knee arthroplasty has a mortality rate of 2% to 6% and the risk of lifelong physical disability of approximately 60%)[19]. Only anecdotal documentation exists in the medical literature regarding patient suffering and reduced quality of life due to postoperative infection. The on-going and indirect costs for society are obviously considerable.

Any design solution that significantly reduced disruption to L.A.F. would need to present a minimal cross-sectional area to the direction of flow, and introduce little or no heat into the sterile area as well. These requirements cannot both be satisfied with the current methods of illumination, but could possibly be solved by locating the light source remotely and bringing the light to the surgical field via light guides.

7. Light Guide technologies

7.1 Existing Products

Light guides are already commonplace in the modern Operating Theatre, usually fibre optics (glass fibre bundles) utilised for head-mounted illuminators for surgeons, or in endoscopy and other similar procedures. The light source is nearly always a short distance away (less than 2m) and usually only a relatively low amount of light is required.

The only four surgical applications of fibre optic lighting other than head lamps and endoscopy are the “LightMat”, “SaphLite” and “Bard Light” by Lumitex (see appendix) and the “DeepSite” fibre optic illuminator by Steris (see appendix).

The Lumitex “LightMat” and “SaphLite” are ingenious applications of light guide technology. By applying a fibre optic illuminator to the surface of the surgical equipment used for holding the sides of the surgical cavity apart, light can be introduced to a deep cavity without any of the usual problems of shadowing caused by the surgeon’s head. “Bard Light” is a rigid side-emitting light guide predominantly designed for use during vaginal examinations and procedures. However, none of these products has been well accepted by the current market, partly due to unresolved glare and obstruction issues, and in part because of the reticence of many surgeons to use unconventional equipment[20].

The Steris "DeepSite" is a high output fibre optic illuminator that is intended to be positioned beside or in front of the surgeon, mounted on an articulated arm, focused directly into the surgical field. These are particularly useful during deep cavity procedures where a single collimated beam is required, and where conventional over-head systems run the risk of being blocked by the surgeon. By placing the light source between the surgeon and the patient it ensures continuous illumination of the surgical field giving the surgeon greater freedom to move around as necessary.

7.2 Solid core vs. Liquid core

Traditionally, light guides used in most applications including surgical have been solid, either fibre optic bundles or plasticised acrylic. Glass fibre optic bundles however have the problem of severely attenuating the light over longer distances (>5m) as well as breakages with repeated flexing. Plasticised acrylic light guides are limited in the amount of heat, and therefore light they can be exposed to before being damaged. However liquid light guides (usually pure water) are capable of carrying up to 50% more light (see fig. 41 in appendix) with less attenuation over any given length than an equivalent solid core light guide[21]. Liquid core light guides do not suffer from the degradation over time of plasticised acrylic light guides, or the ongoing breakages of glass fibre optic light guides. They also have typically tighter minimum bend radii than their solid counterparts.

The Numerical Aperture (NA) of a light guide refers to the range of acceptance angles at which rays of light will be transmitted by the light guide (an NA of 0 means no light is transmitted, an NA of 1 means all angles are accepted). Due to the fact that liquid light guides typically have a NA of between 0.5 and 0.6 and fibre optic light guides have an NA of between 0.22 and 0.25, the angle at which light is accepted into a liquid light guide is almost triple that of a fiber optic light guide (70° compared to 25°)[21]. This has a dramatic impact on the amount of light that can be gathered from a lamp and focused reflector.

Liquid Light Guides also offer higher transmission, typical 1m glass or fused-silica fibre-optic bundles transmit only 40% to 60% of incident light, mostly due to packing losses – in contrast, liquid light guides transmit 70% to 90% [21].

7.3 Light sources

Light sources currently available range from simple 50w quartz-halogen units (low output, low colour temp.) through to forensic illuminators with a 500W xenon gas discharge (high output, high colour temp.) with a wide range of remote selectable and "tunable" filters.

7.4 Dangers

High power light guide systems present two safety issues not encountered by conventional M.S.L. systems:

a) If the end of the guide is allowed to rest on flammable material it is capable of starting a fire in the theatre[22]. This is remedied by either effective filtering of Infra Red energy within the light source, or the use of long (>5m) lengths of light guide, which serves to remove any remaining Infra Red energy from the visible light.

b) If a light guide is accidentally shone at close range into an eye, permanent damage or at least temporary blindness may result, depending on brightness and the length of time of the exposure. For all dangerous theatre equipment (ranging from scalpels to high pressure oxygen tanks, and including light guides) there are strict handling procedures in place to ensure the safety of both patient and staff.

8. Proposal

As discussed above, the two main problems that Surgical Lighting present to LAF systems are the disruption of flow due to the large cross-sectional area of the lamp, and the localised convection currents introduced by the heat output of the lamp. Both of these issues have been shown to dramatically reduce the effectiveness of LAF systems by introducing turbulence to the laminar flow, therefore contaminating the air reaching the surgical field.[3,10]

In order to achieve greater integration of MSL systems with LAF systems, a novel method needs to be proposed that is able to provide the quality and quantity of light required for Major Surgery without introducing the heat load or large cross-sectional area associated with conventional MSL systems. Fibre optic illuminators currently used in surgical theatres offer a "cool" light source with minimal cross sectional area, however they are unable to provide the quantity or quality of light over longer distances required by Major Surgical Lighting.

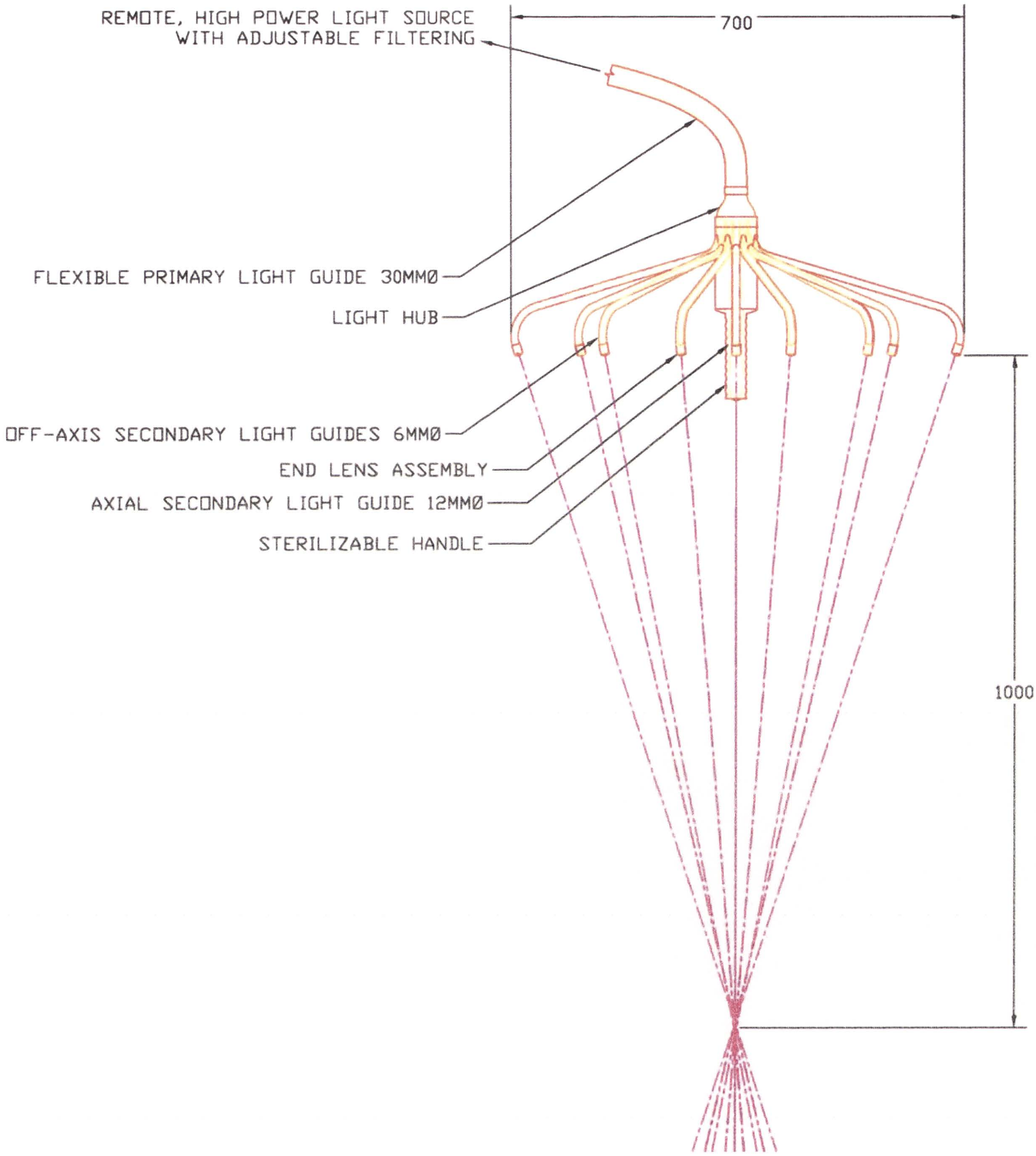


Figure 11. Proposed light guide head.

One solution to this problem (as shown in fig. 11 above) would be to locate a high power light source remotely (up to 10m away) such as a focused 500 watt Xenon lamp, and transmit the light via a high capacity flexible liquid light guide (30mmØ) through the ceiling cavity and down to the surgical field along an articulated arm. At the end of this arm the light could then be split through a "hub" into a number (say 16) of smaller rigid light guides (6mmØ), splayed out into an circular array, with all the ends pointing slightly inwards to all focus on the same spot 1000mm below. The ends of these guides would have precision lenses that could be simultaneously adjusted depending on the requirements of the surgeon. This method offers a number of advantages over conventional Surgical Lighting methods:

8.1 **Removing Heat Source**: By locating the light source remotely (either away from the laminar flow region, or outside the theatre all together) nearly all heat and therefore convection-related turbulence is prevented from entering the laminar flow region. This not only dramatically increases asepsis, but also increases the safety and comfort of surgeons and other theatre staff and reduces tissue desiccation, particularly during lengthy surgical procedures.

8.2 **Reducing Drag:** Through the use of flexible light guides to transmit the light, the cross sectional area presented to the laminar flow is dramatically reduced, as is any related turbulence, again increasing asepsis. It also provides a more open view and access to the patient for other surgical staff in comparison with the conventional systems.

8.3 **Less Restricted Light Source**: By locating the light source outside the theatre it provides the opportunity of using light sources that can provide a greater quantity and quality of light, as well as other technologies that would be otherwise unsuitable or impossible using conventional systems for reasons such as size, weight etc.

8.4 **More Effective Filtering**: Far greater control is possible over the UV and IR content of the light. For example, a 5m liquid light guide can effectively remove all of the UV and IR components, rather than just a portion of them as in the case of conventional M.S.L.s.

8.5 **Spectral Distribution Adjustment**: With the remote location of the light source it becomes possible to modify the spectral distribution of the visible light, through the use of filters, to best suit the procedure being performed. Colour differentiation is a primary method of identification by surgeons for every type of tissue, organ or disease, however subtle the differences may be with surrounding tissues and organs. Increasing the particular frequency component of the light reflected by the particular tissue, organ or disease of interest will increase the surgeon's ability to identify and work on that tissue[23]. Similarly, surgeons are often required to differentiate between two very similarly coloured tissues. Through accurate filtering, it is possible to remove all frequencies that are common both tissues and all unnecessary frequencies as well, leaving only the frequencies that differentiate the two tissues. This would also greatly reduce the Total Irradiance and all the associated effects, such as the drying of delicate tissues.

8.6 **Automatic Spectral "Tuning":** By mounting a camera on the light head, focused on the surgical field, it is possible for the light source to automatically and continuously "tune" the spectral distribution of the light output to provide the best rendering of the surgical site, again reducing Total Irradiance.

8.7 **Independent Adjustment of Brightness and Colour Temp:** In conventional surgical lighting the only possible method of adjusting light output is by dimming the lamp itself, which inevitably results in the colour temperature shifting as well. This a serious issue, particularly when performed during an operation. However dimming methods such as shutters and filters become possible with the remote location of the light source and the use of a focused beam required for light guides, providing stable colour temperatures whilst dimming. Conversely, it is not possible with current MSL designs to adjust colour temperature without also affecting light output. However, there is a wide variation of colour temperatures that surgeons prefer to work under (typically, most surgeons prefer to work under the colour temperatures they trained with, hence most older surgeons prefer warmer colour temperatures and younger surgeons prefer colder colour temperatures)[12]. This method provides for the adjustment of colour temperatures independent of light output.

8.8 **Hygiene:** Increase in hygienic protection of the theatre by reducing the need for maintenance technicians to be entering the theatre. Reduced surface area of luminaire and the absence of venting and other details reduce the hygiene risk presented by the luminaire.

8.9 **Multiple Theatre Illumination:** Greater efficiencies of energy and maintenance are possible through the use of one light source to illuminate a number of theatres.

8.10 **Reduced Weight:** The proposed light head would be a fraction of the weight of a convention light head, therefore increasing ease of maneuvering, reducing the load capacity and size of any articulated support mechanisms, and reducing installation costs. This reduction in weight also creates new possibilities in system design, such as portable floor units which would be invaluable in field hospitals during war or disaster relief, or even just to share between theatres in poorly funded hospitals, instead of tying up such a significant investment to be used in only one theatre.

8.11 **Single light source for multiple illuminators:** This system also creates the possibility for the first time of using the same light source for all surgical illumination, such as Major Surgical Lighting, head mounted lighting, endoscopes, side lighting such as Steris “DeepSite”, and illuminated equipment discussed above such as Lumitex “LightMat”, “SaphLite” and “Bard Light”. This means that not only will the light qualities of these various light sources be matched for the first time, but that when adjustment in either light levels or colour is required, only a single adjustment is necessary.

9. Testing

In order to determine whether the above proposal was likely to provide any significant reduction in disruption to L.A.F. in the surgical field, (an therefore a decrease in post operative infection rates) it was necessary to test this design against existing M.S.L. designs in the context of a Laminar Flow theatre.

The three most appropriate testing methods were:

1. Flow visualization using a 1:1 model of a typical Operating Theatre built inside a large smoke chamber, comparing the degree of smoke "contamination" of the "sterile" smoke-free laminar air flow at the surgical site under the various light sources to be compared.

2. Air borne particle counts taken at the surgical field during a number of actual surgeries performed under the various light sources to be compared.

3. Computer modeling of any disruption to the laminar air flow caused by the various light sources to be compared using Computation Fluid Dynamics (CFD) analysis.

Method 1 required the prohibitive expense of building a mock Operating Theatre in very large smoke chamber and would have provided largely qualitative results. Method 2 required the development of a working prototype of the proposed design (not in the scope of this research) and approval of its use in medical trialing, giving only quantitative results. Method 3 required the production of a 3-D computer model of a typical Operating Theatre and the running of a CFD analysis of the various light sources to be compared, providing both quantitative and qualitative results. For the above reasons Method 3 was selected.

Test Procedure

A 3-dimensional computer model of a typical Operating Theatre was created by Bassett Applied Research, complete with patient, surgeon, anesthetist, theatre nurses and associated equipment, each with their respective aerodynamic and heat load parameters. A typical L.A.F. system was positioned in the ceiling above the patient.

3-D computer models of three different light heads were then introduced into the laminar flow, positioned so as to represent a typical surgical suite arrangement. First was an industry standard, **Martin ML1001/Berchtold C 950** (both closed light head, 1m diameter, 250 watt halogen lamp). Second was the head that claims to be the least disruptive M.S.L. currently available, the **Heraeus G8** (open head, 85 watt gas discharge lamp, 730mm diameter.). Finally, a computer model was produced of the "**Lightguide**" light head, proposed above, comprising of 16 curved light guides radiating from a central hub (700mm diameter).

Figure 12. Martin 1001/Berchtold C950 computer model

Figure 13. Heraeus G8 computer model

Figure 14 Proposed “Lightguide” computer model

10. Results

The three different light heads were graphically analysed using four of methods, a) streamlines, b) vector lines, c) temperature distribution and d) speed distribution.

a): **streamlines** were used to give a general overview of how each light-head integrated with the LAF system in the context of a surgical suite, and graphical representation of the general flow of air in the surgery.

b): **vector lines** were used to give a more detailed view of the actual path of the airflow as it is disrupted from laminar to turbulent flow. It is a useful graphical tool to identify the "problem" areas of a laminar flow system that by its very nature requires uniform and low velocity in order to remain laminar.

c): **temperature distribution** is a very important consideration when integrating MSLs with a LAF system. Any area on the surface of the light head that has a temperature over 30°C (shown in red) can create convection currents capable of compromising the laminar flow around it.

d): **speed distribution** gives a general overview of the air flow speed of the LAF system.

10.1 Streamlines (figs. 15, 16, 17): This method of comparison gives a good overview of the disruptive effects of the different light heads on the same situation. The ML1001/C950 (fig. 15) model is severely disruptive, diverting a large amount of sterile air away from the surgical field. The G8 (fig. 16) is less disruptive, although still diverting a significant quantity of sterile air away from the surgical field. The Lightguide model (fig 17) shows no disruption at all with all sterile air arriving at the surgical field in a continuous laminar flow.

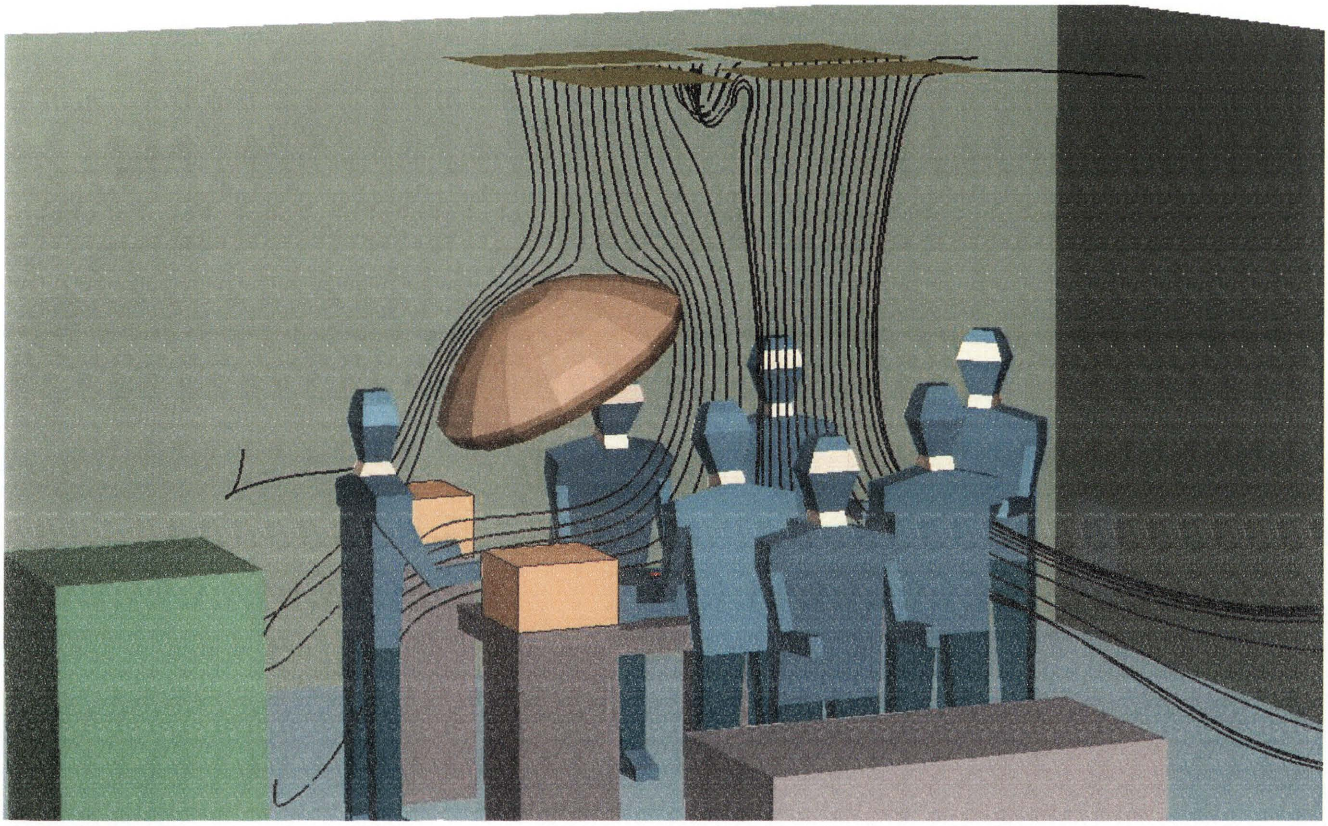


Figure 15. ML1001/C950 Streamlines

The streamlines illustrate way in which the shear size of the ML1001/C950 splits the laminar flow and directs the stream in two different directions. The variation in spacing between the streamlines also indicates the pressure differential created, with a high pressure zone along the top surface of the light head and a low pressure zone directly underneath it.

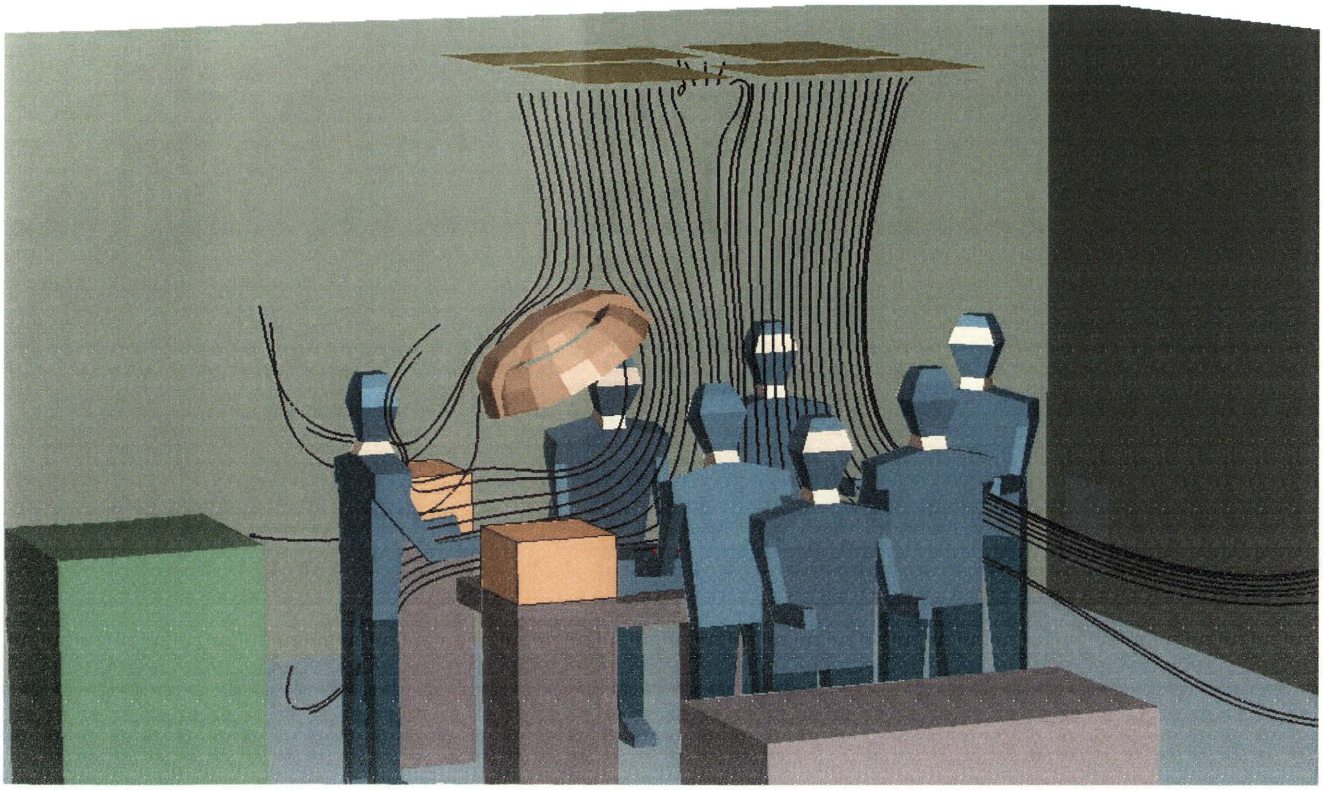


Figure 16. G8 Streamlines.

Surprisingly, the streamlines indicate that despite the sales pitch, the shape of the G8 is actually more disruptive to laminar flow than the ML1001/C950, with the possibility of non-sterile air being mixed back into the sterile airflow.

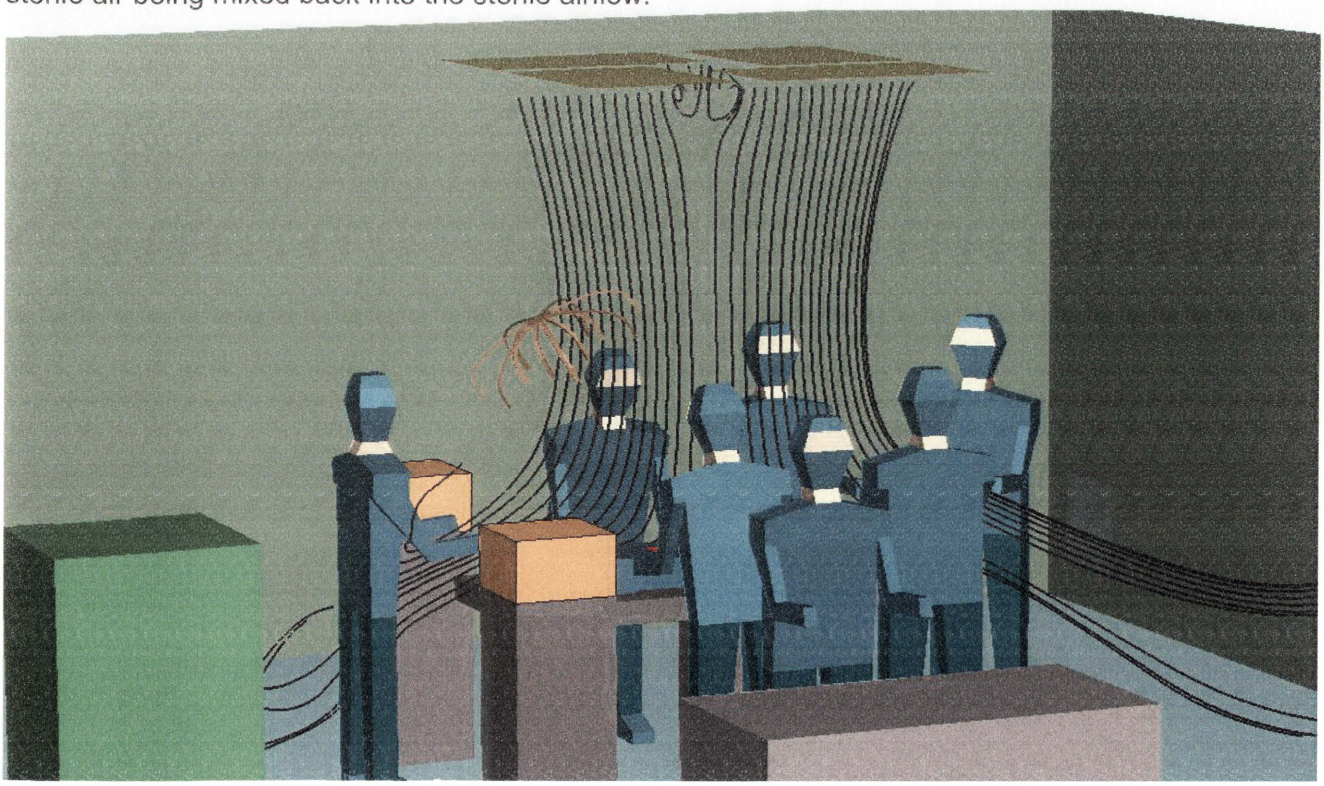


Figure 17. Lightguide Streamlines

No disruption evident.

10.2 Vector Fields: (fig. 18- 23): Vector fields are able to give a more detailed view of the typical vectors of individual air streams, therefore describing any actual turbulences that may occur. They also give a clear picture of variation of speed. Again, the ML1001/C950 (fig 18) can be seen to be causing significant turbulence (particularly in the area immediately in front of the light-head, drawing contaminated air from outside the sterile flow into the surgical field, compromising any asepsis that may have been otherwise achieved. Surprisingly, the G8 (fig 20, 21) appears to be creating as much, if not more turbulence than the ML1001/C950. This appears to be due to the fact that the ML1001/C950 has a closed, flat face, where as the open face of the G8 actually seems to be enabling turbulence to develop within the cavity of the light head. Again the vectors for the Lightguide (fig 22,23) are undisturbed, showing a smooth laminar flow of sterile air through the open "fingers" light head.

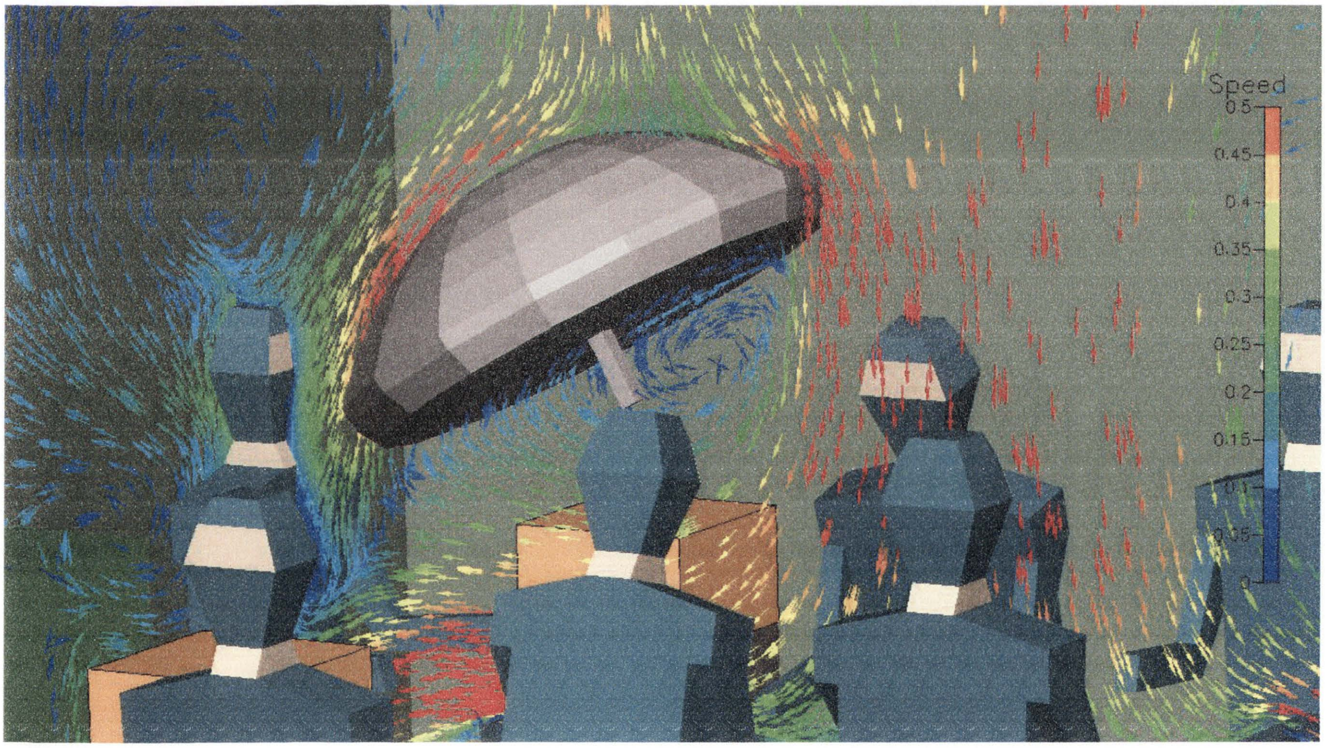


Figure 18. ML1001/C950 Vector Fields (side view)
Turbulence created directly below light head, laminar flow split in two directions, air speeds well above and below the optimal of 0.25m/s

Figure 19. ML1001/C950 Vector Fields (end view)

Turbulence created directly below light head, possibility for non-sterile air to contaminate LAF from the sides

Figure 20. G8 Vector Fields (side view)

The hollow nature of the front face provides the opportunity for a vortex to be created

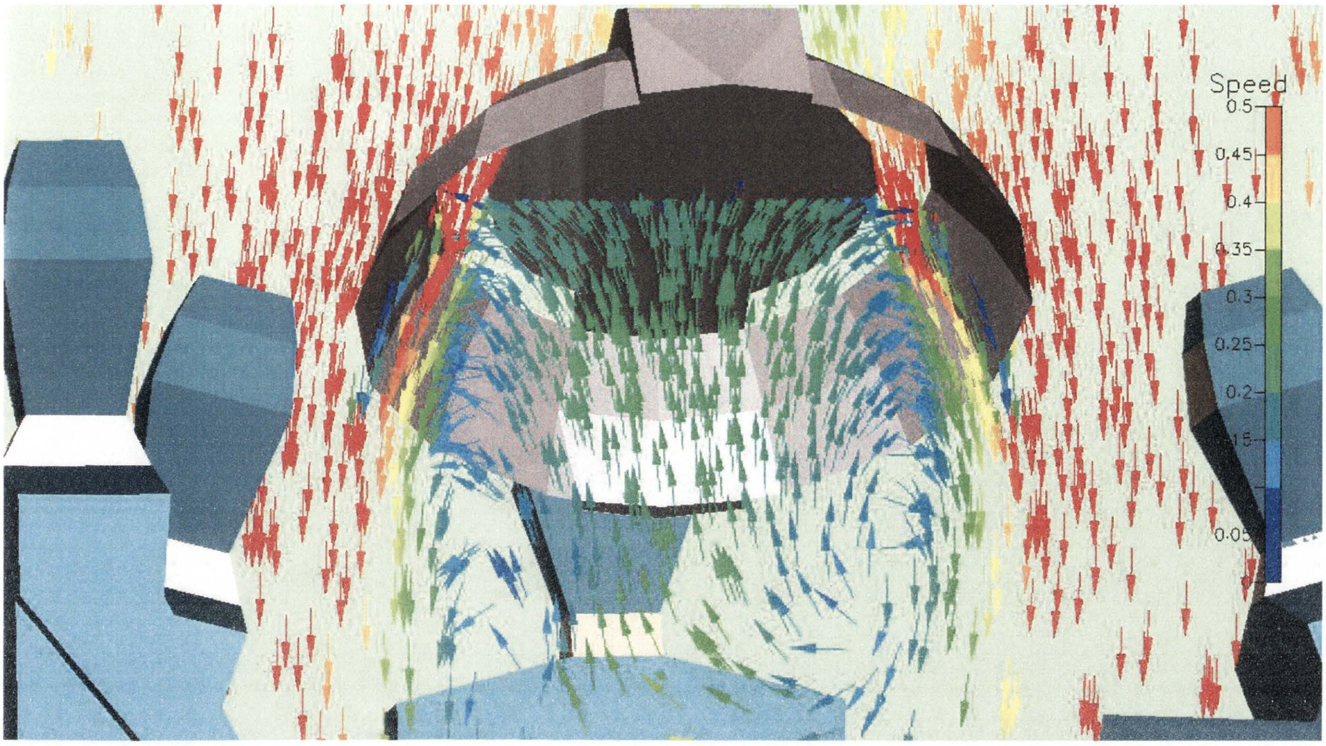


Figure 21. G8 Vector Fields (close-up)

Extreme turbulence with the head itself, stretching down towards the surgical field

Figure 22. Lightguide Vector Field (side view)

No turbulence (the higher density of vectors around the light head only signifies that this was an area of closer analysis by the CFD program). Some slowing evident directly below the "finger" on the analysis plane, but this is corrected immediately by the undisturbed air flowing between the fingers.

Figure 23. Lightguide Vector Field (end view)

No turbulence, minimal slowing below the central hub, immediately corrected back to the original speed

10.3 Temperature Distribution (fig 24 – 29): ML1001/C950 temperature distribution (fig 24, 25) shows the entire rear surface of the light head is red, which is actually off the scale of temperatures that are compatible with laminar airflow. G8 (fig 26, 27) shows the back of central body that houses the lamp to also be above permissible temperatures, although the surface area in question is significantly less (almost one quarter) than the ML1001/C950. The Lightguide (fig 28, 29) shows no heat at all and even temperature distribution across the laminar flow, as all IR and UV energy is completely removed well before it reaches the light head.

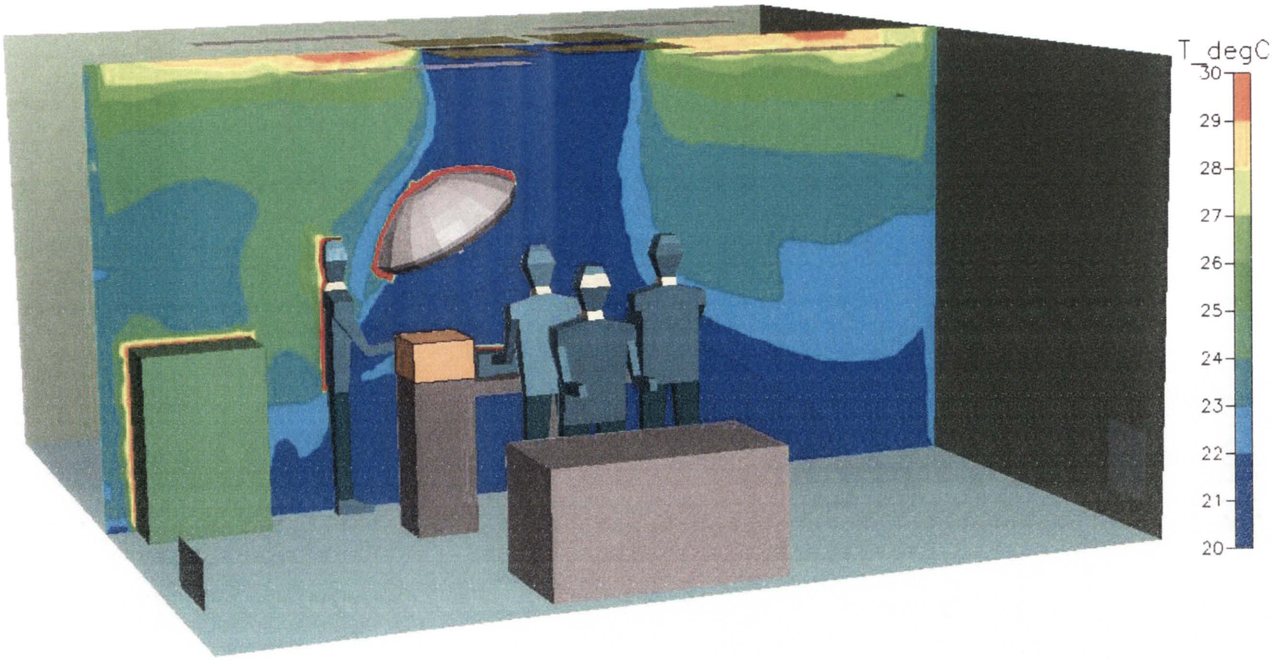
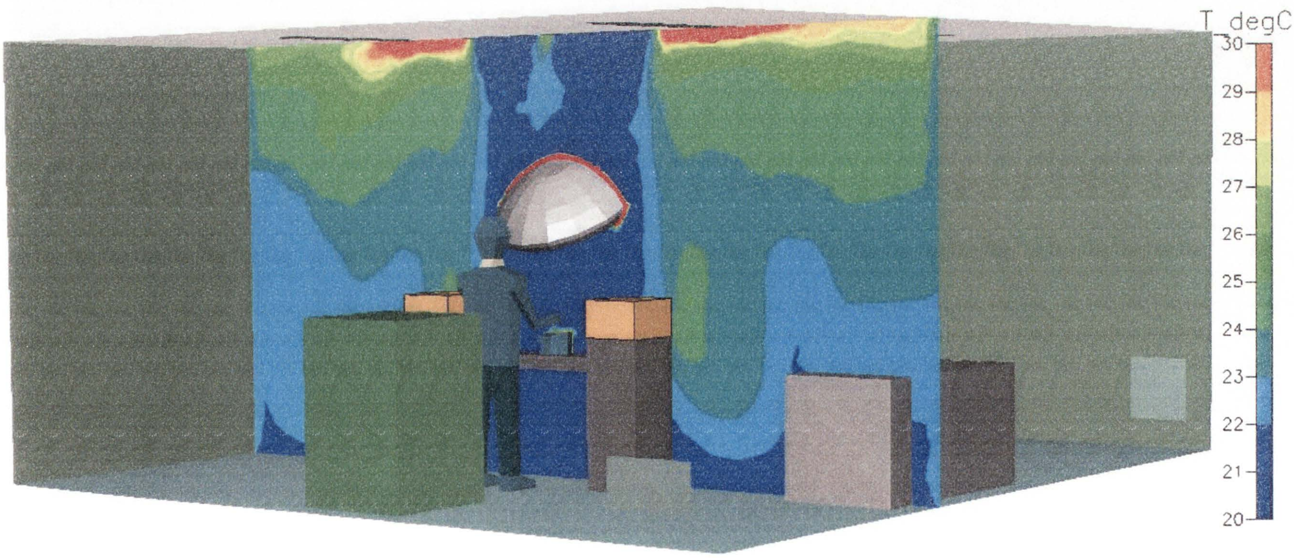


Figure 24. ML1001/C950 Temperature (lateral)

Total top surface above 30°C



1000

Figure 25. ML1001/C950 Temperature (transverse)

Total top surface above 30°C

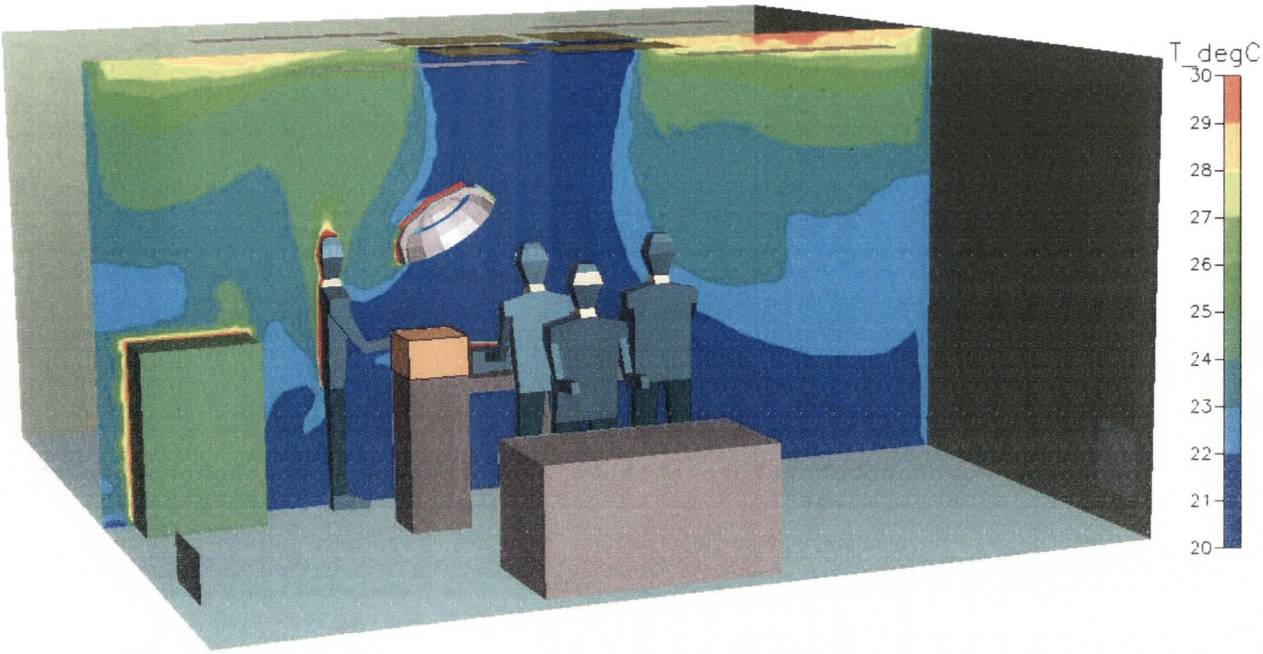


Figure 26. G8 Temperature (lateral)

Inner hub surface above 30°C

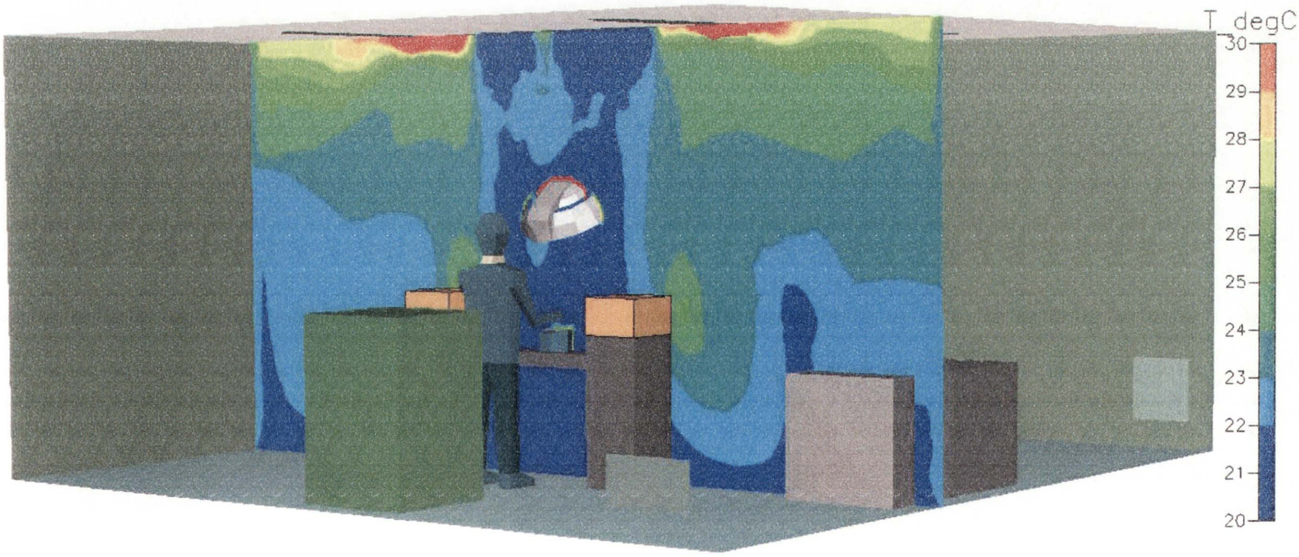


Figure 27. G8 Temperature, (transverse)

Inner hub surface above 30°C

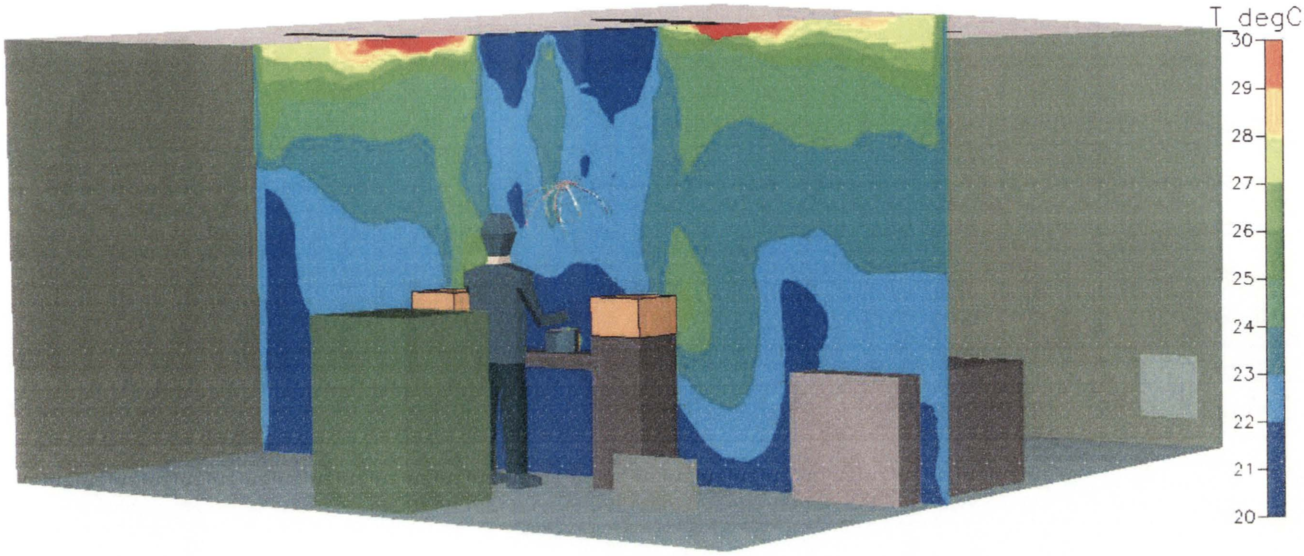


Figure 28. Lightguide Temperature (transverse)

No effect on temperature

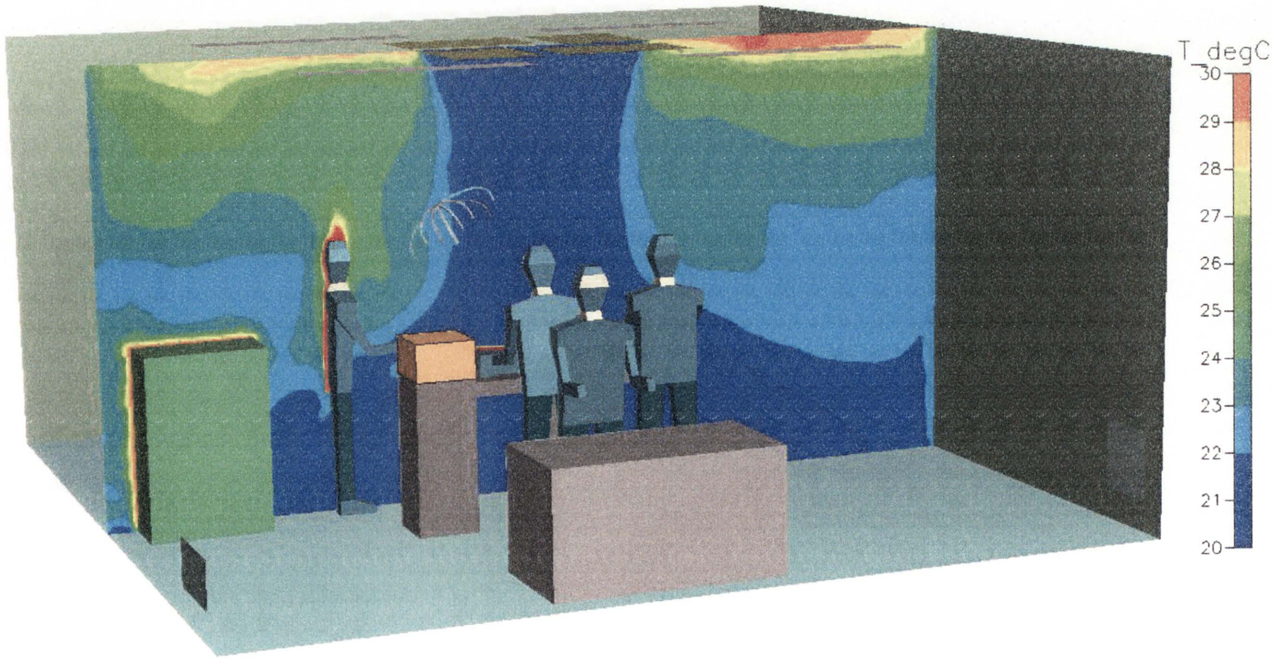


Figure 29. Lightguide Temperature (lateral)

No effect on temperature

1020

10.4 Speed Distribution (fig 30 – 38): As shown in the Vector Fields images, both the ML1001/C950 (fig 30, 31, 32) and G8 (fig 33, 34, 35) light heads create significant variations to the speed distributions of the airflow around them. In regards to air speed G8 appears to create slightly less disruption than the ML1001/C950. The images for the Lightguide (fig 36, 37, 38) show some effect, although minimal. It should be noted however, that these images are directly along the axis of the "fingers" of the Lightguide, and that the disruption of the airflow between the fingers would be even lower.

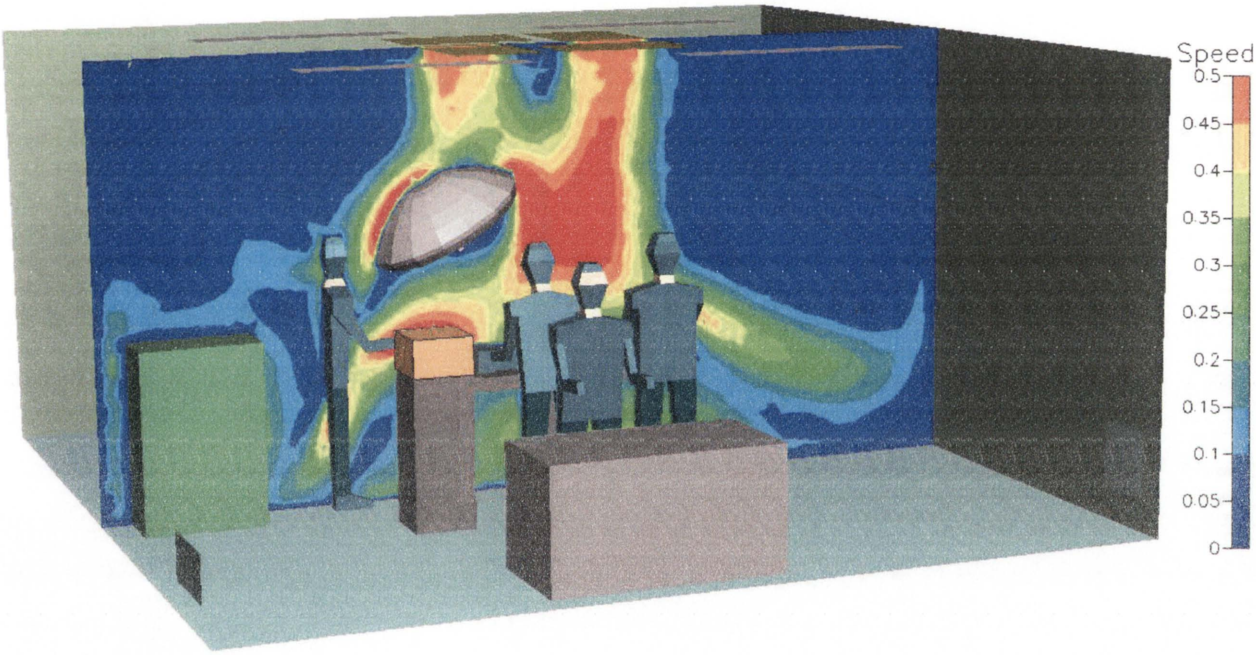


Figure 30. ML1001/C950 Speed (transverse)

Low speeds induced directly below lamp head, large area of high speed flow induced to the right of the light head

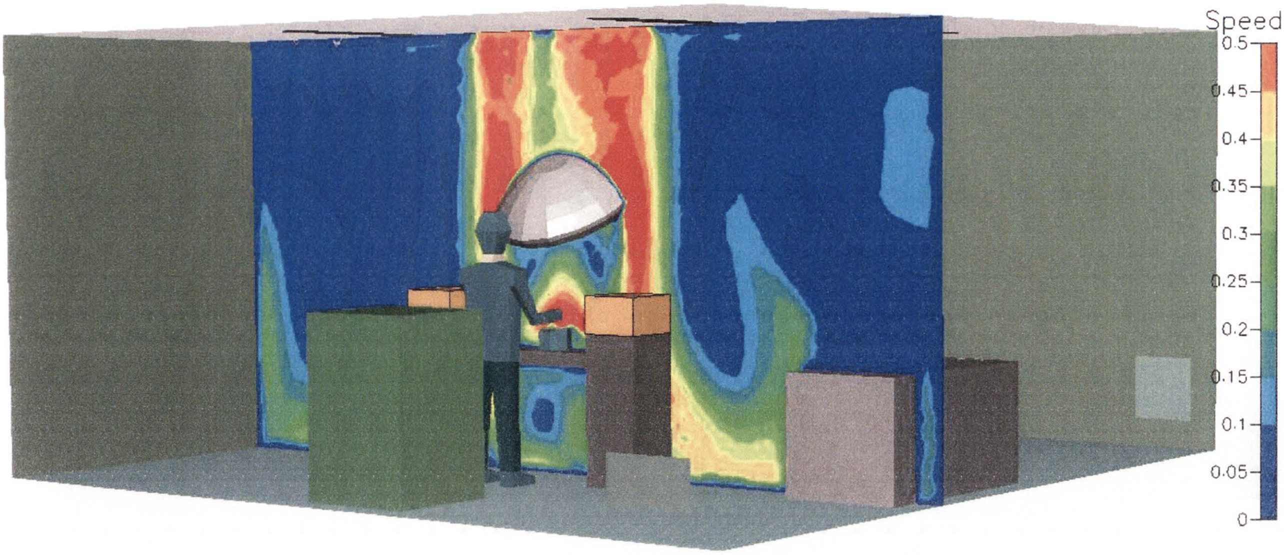


Figure 31. ML1001/C950 Speed (transverse)

Lower speeds induced directly below lamp head.

Figure 32. ML1001/C950 Speed (close up)

Low speeds induced directly below lamp head, large area of high speed flow induced to the right of the light head, and directly above the light head.

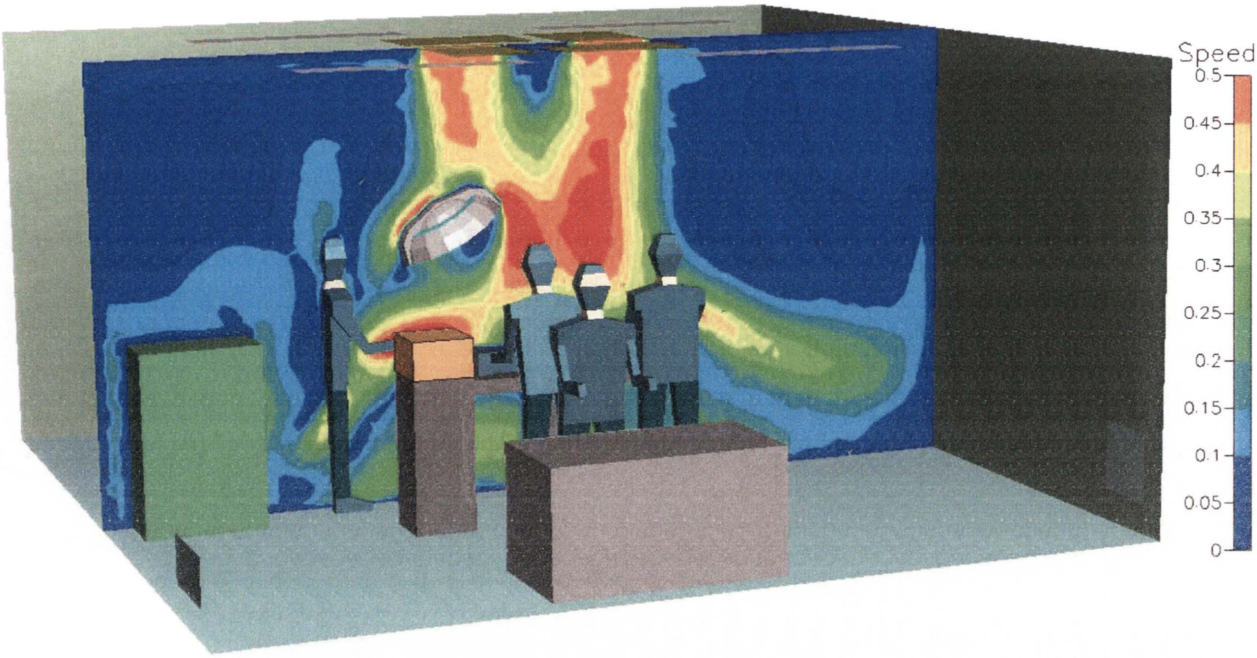


Figure 33. G8 Speed (lateral)

Some slowing below the light head and to the right, not as pronounced as ML1001/C950

Figure 34. G8 Speed (close up)

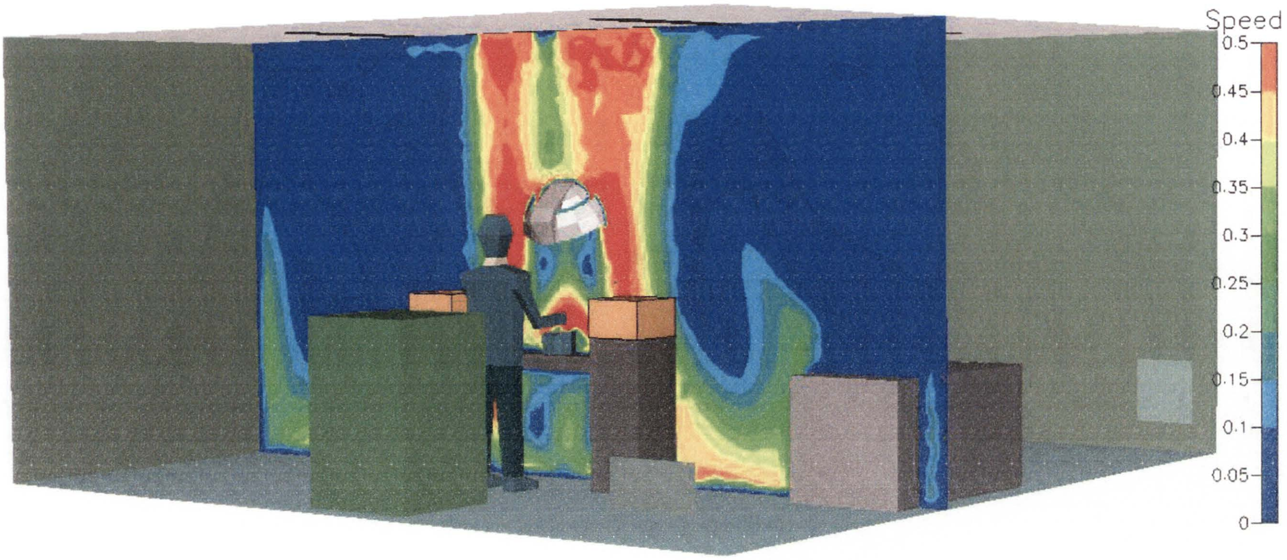


Figure 35. G8 Speed (transverse)

This analysis plane shows a similar disruption pattern to ML1001/C950, although smaller due to light head design.

Figure36. Lightguide Speed (lateral)

Minimal disruption

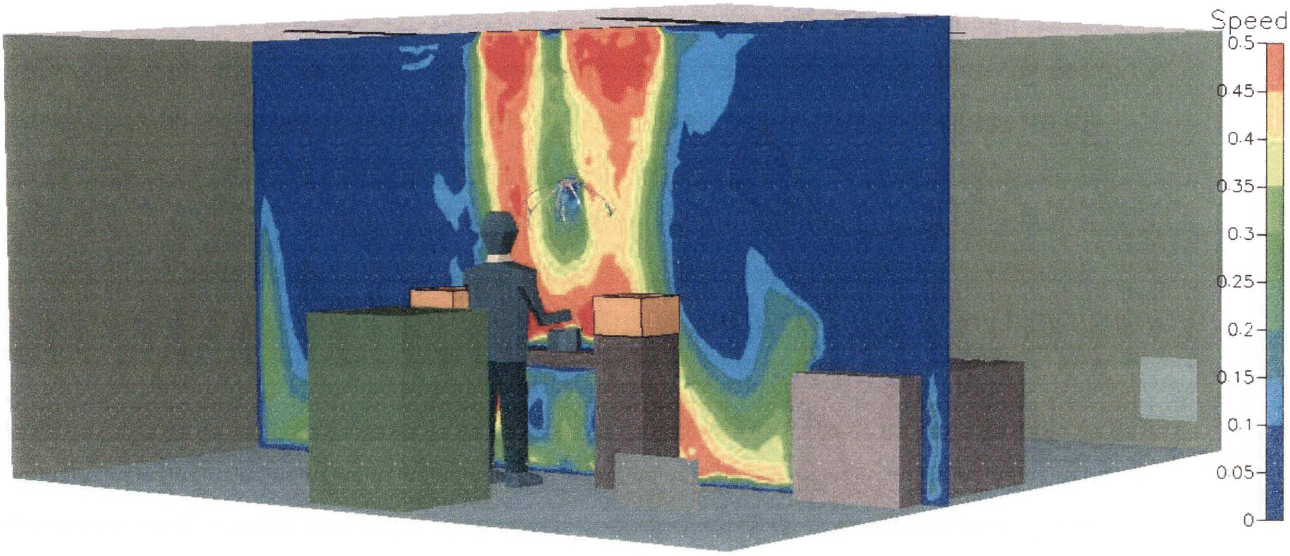


Figure 37. Lightguide Speed (transverse)

Some slowing below hub, immediately corrected

Figure 38. Lightguide Speed (close-up)

Minimal slowing below hub.

1060

11. Conclusion.

The design issues concerning M.S.L. systems have changed dramatically over the last 100 years, however the basic design principle of a light source and large reflector positioned above the patient has remained unchanged. Improvements have been made by degree in areas such as the quantity and quality of light provided, however this is due more to advances in lamp technology rather than M.S.L. design. Some design issues such as integration with L.A.F. systems appear to be irresolvable with the current direction of M.S.L. design. This novel proposal for theatre lighting has evolved by imposing the air-flow characteristics of the L.A.F. system as an additional design constraint on the MSL system.

Current attempts to integrate L.A.F. and M.S.L systems have been relatively unsuccessful due to unavoidable fact that the design principle of positioning a high power light (and therefore heat) source and large reflector(s) over the surgical field introduces significant turbulence (and therefore contamination) to the otherwise sterile laminar air flow. It should be noted that the proposed removal of the light source and associated reflector(s) is currently only possible with the introduction of flexible liquid light guides capable of transmitting large quantities of light over long distances with minimal attenuation, still viewed as an emerging technology.

By re-evaluating the basic design principles of an M.S.L. system, and considering current or emerging technologies that were not available in previous times it has been possible to propose completely novel method of M.S.L. that has been shown to be well suited to the integration with L.A.F. systems, as well as offering a number of other features and possibilities that were previously unavailable. In comparison, it has been definitively shown that currently available M.S.L. designs are unsuitable for integration with L.A.F. systems, due mainly to the physical disruption and convection currents that they introduce to a L.A.F. system.

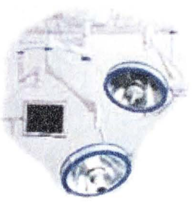
This work paves the way for the creation of a truly integrated Laminar Air Flow surgical suite capable of significantly reducing the rate of post-operative infection currently achieved with L.A.F. systems, greatly reducing costs, both economic and human.

Appendix

Comparison of Current Products [24]

Berchtold: Chromophare
www.berchtoldusa.com
Price: US$10,000 and up for top-end system
Key features: The system generates up to 130,000 lux from a 150-watt halogen bulb, and eliminates 99 percent of thermal radiation. The system has a colour temperature of 4,500 degrees Kelvin. A lightweight suspension and single-point attachment makes the lights easy to maneuver. The top-end system can be integrated with Berchtold cameras and the Hermes voice-activation system.

Burton: Visionary
www.burtonmedical.com
Price: US$4,500
Key features: The Visionary is a compact surgical light priced to compete with used and refurbished lights. The system generates 81,000 lux, a 4,000 degree Kelvin colour temperature, a heat-reducing reflector and filtration system and 360-degree rotation. Burton offers a five-year warranty on the system.



ConMed: CM570
www.conmedis.com
(503) 614-1106
Price: US$19,500 (dual head)

Key features: The 130,000-lux CM570 was designed by surgeons for surgeons. The light is said to be exceptionally cool and easy to maneuver. The light head is made from a polymer plastic that does not become hot to the touch even after 10 hours of continuous operation. Colors are rendered at a 4,500 degree Kelvin color temperature and the system has a CRI of 94. You can integrate the CM570 with flat-screen monitors and three digital-camera systems.

Getinge Castle: PrismaVision PRV3 Camera
www.getingecastle.com
Price: US$10,000 (lights plus incorporated camera in handle)
Key features: There are two available controllers with this system. One is wall-mounted and the other is a "mobile" unit that allows you to take the controller to whichever room you want along with the VZ camera, which is also portable. ALM pioneered the incorporation of camera systems within the surgical light head. The latest model from ALM incorporates a one-sixth-inch IT CCD Sony sensor with 25X optical motorized zoom lens. It also incorporates an image stabilizer features to minimize the typical "shaking" that occurs while moving the light arms for repositioning.

Heraeus: Hanaulux G8
http://www.heraeus.com.
Key features: Incorporates a gas discharge lamp with a double ring style reflector to provide cool light with a minimum disruption to laminar airflow systems. Luminosity of 150,000 lux, a luminous field of 22–30 cm, colour temperature of 4,200 Kelvin and Ra 93. Long service life of the bulb of 3,000 hours and the low power consumption of only 85w.

Medical Illumination International: System One
www.medillum.com
Price: US$3,900 (single head), US$7,500 (dual head)
Key features: The 102,000 lux System One, a new light priced to compete with the used-

light market, features a 20-inch diameter, multi-faceted reflector designed for excellent shadow control, a color temperature of more than 4,000 degrees Kelvin, an adjustable light pattern, and a 48-inch depth of field with electronic on/off and four-stage dimming. A newly designed single-action yoke/arm arrangement is said to improve maneuverability.

Skytron: Stellar
www.skytronsurgical.com
Price: under US$20,000
Key features: Focusability and maneuverability are the major features that Skytron promotes for its Stellar (ST 2323) lights. The system has sterile, fingertip control over focus and depth of field. Via a proprietary reflector system, the Stellar retains 90 percent of its brightness positioned up to 60 inches from the surgical field. In most procedures, the lights are kept about a meter from the surgical field. However, this feature is key for cardiovascular, neuro, orthopedic and GYN surgeries, where the lights need to be moved to a greater distance so as to prevent tissue damage. The five- or seven-bulb systems produce up to 240,000 lux of brightness with no harsh shadows, according to Skytron.

Steris: Harmony
www.steris.com
Price: US$20,000 and up
Key features: "Space age" 130,000 lux, 4,400 degree Kelvin surgical lighting system includes push-button control, single-hand maneuverability, the ability to integrate at any time with monitors, video cameras and endoscopic equipment; and intensity configuration for procedures ranging from endoscopy to cardiothoracic surgery. Its auto-diagnostic system automatically adjusts intensity so that an OR staff member doesn't have to make adjustments mid-case.

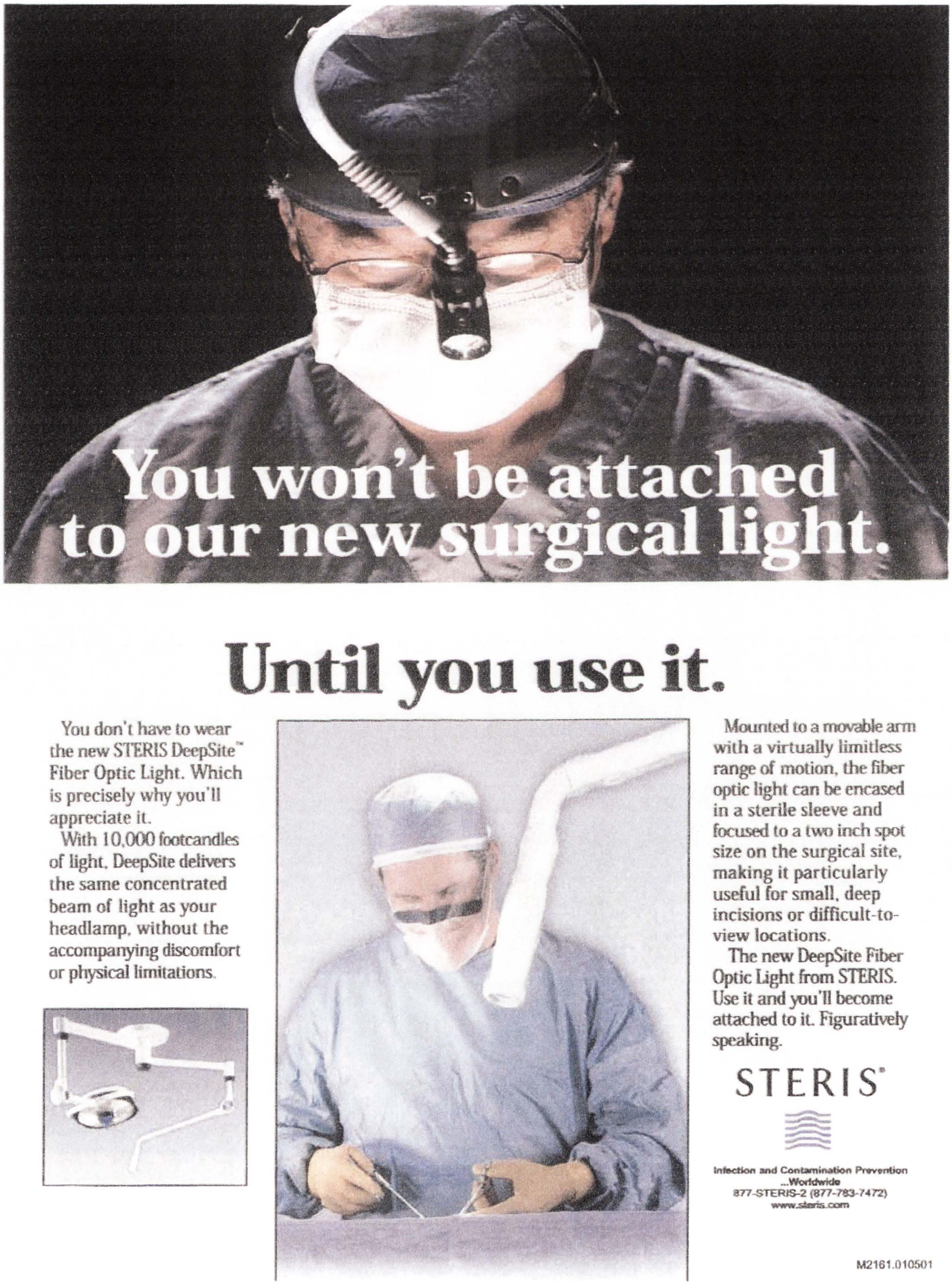


Figure 39: Sales Brochure - Steris "DeepSite"

Figure 40: Sales Brochure - Lumitex "Bard Light"

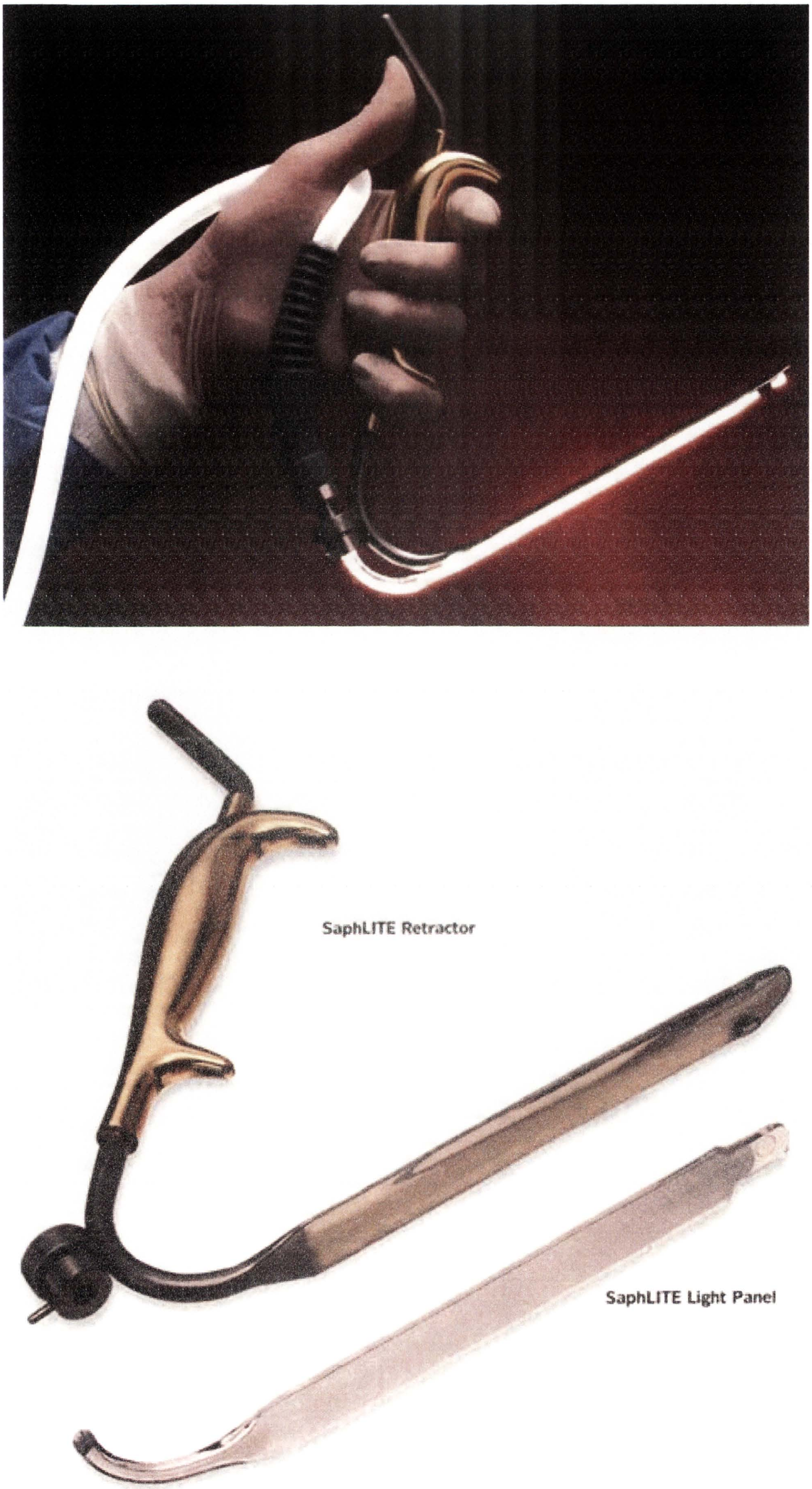


Figure 41: Sales Brochure - Lumitex "SaphLite"

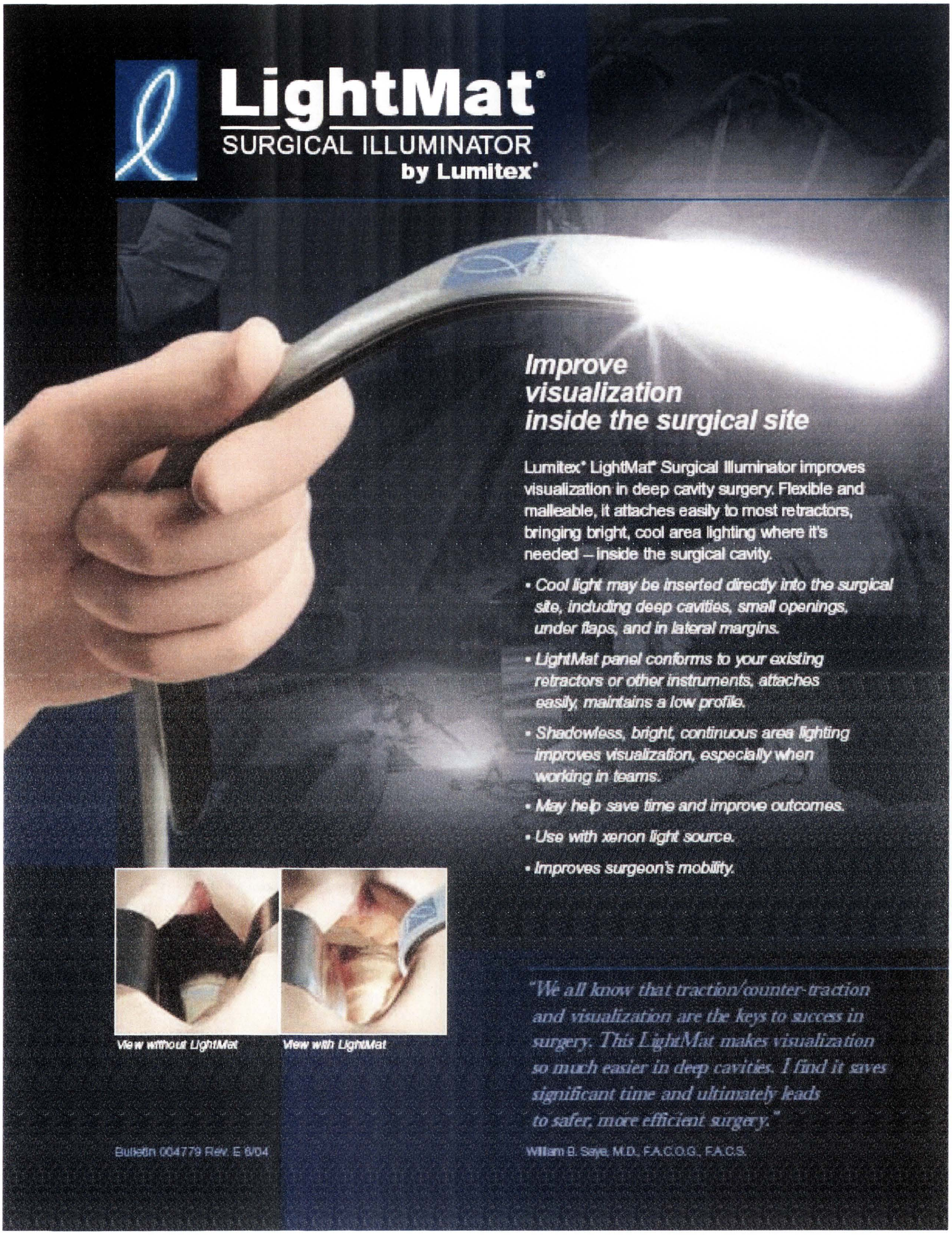
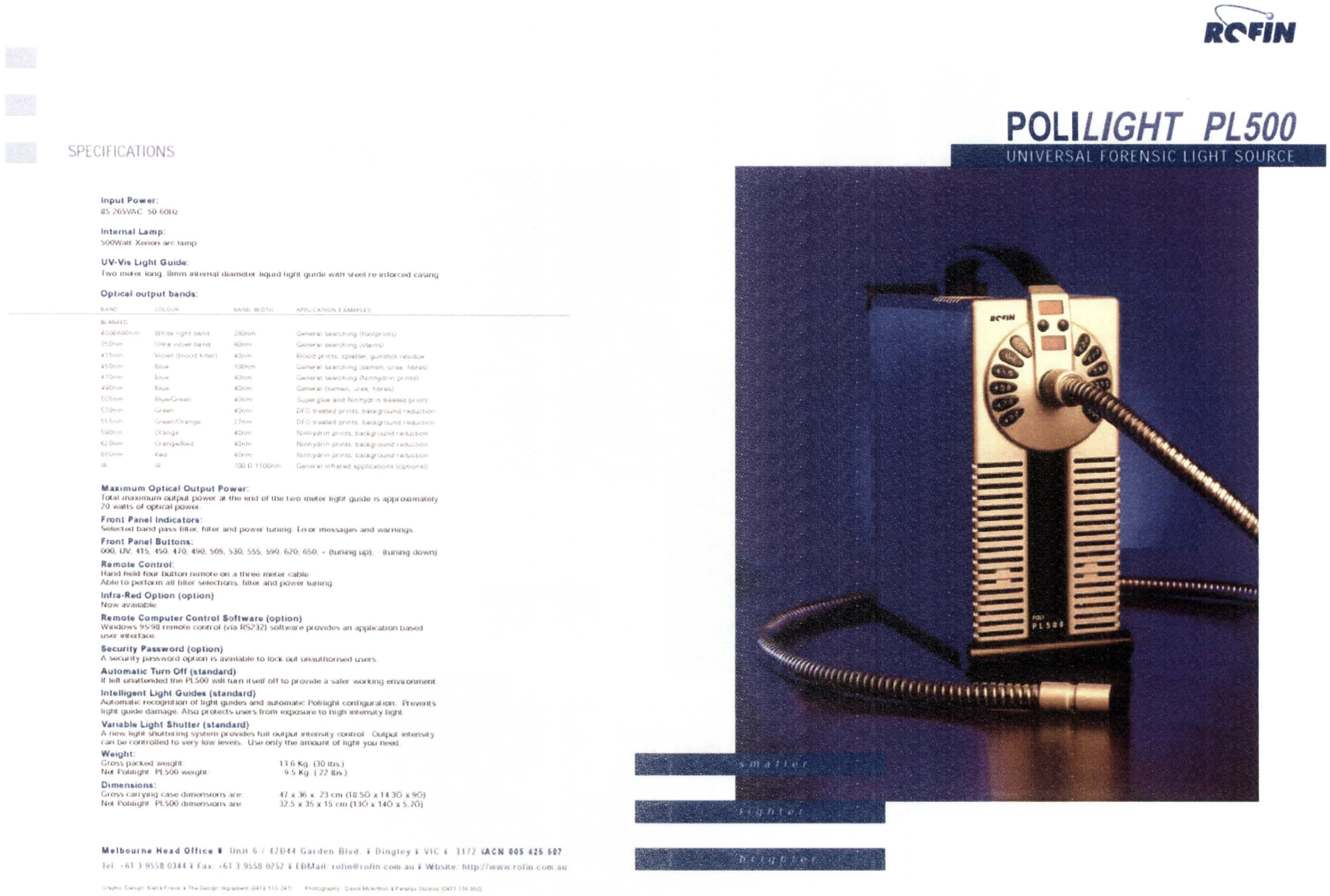


Figure 42: Sales Brochure - Lumitex "LightMat"



RCFIN

POLILIGHT PL500

UNIVERSAL FORENSIC LIGHT SOURCE

smaller

lighter

brighter

SPECIFICATIONS

Input Power:
85-265VAC 50-60Hz

Internal Lamp:
500Watt Xenon arc lamp

UV-Vis Light Guide:
Two meter long, 8mm internal diameter liquid light guide with steel re-inforced casing

Optical output bands:

BAND	COLOUR	BAND WIDTH	APPLICATION EXAMPLES
BLANKED			
400Ø680nm	White light band	280nm	General searching (footprints)
350nm	Ultra violet band	80nm	General searching (stains)
415nm	Violet (blood filter)	40nm	Blood prints, splatter, gunshot residue
450nm	Blue	100nm	General searching (semen, urea, fibres)
470nm	Blue	40nm	General searching (Ninhydrin prints)
490nm	Blue	40nm	General (semen, urea, fibres)
505nm	Blue/Green	40nm	Superglue and Ninhydrin treated prints
530nm	Green	40nm	DFO treated prints, background reduction
555nm	Green/Orange	27nm	DFO treated prints, background reduction
590nm	Orange	40nm	Ninhydrin prints, background reduction
620nm	Orange/Red	40nm	Ninhydrin prints, background reduction
650nm	Red	40nm	Ninhydrin prints, background reduction
IR	IR	700 Ð 1100nm	General infrared applications (optional)

Maximum Optical Output Power:
Total maximum output power at the end of the two meter light guide is approximately 20 watts of optical power.

Front Panel Indicators:
Selected band pass filter, filter and power tuning. Error messages and warnings.

Front Panel Buttons:
000, UV, 415, 450, 470, 490, 505, 530, 555, 590, 620, 650, + (tuning up), - (tuning down)

Remote Control:
Hand held four button remote on a three meter cable.
Able to perform all filter selections, filter and power tuning.

Infra-Red Option (option)
Now available.

Remote Computer Control Software (option)
Windows 95/98 remote control (via RS232) software provides an application based user interface.

Security Password (option)
A security password option is available to lock out unauthorised users.

Automatic Turn Off (standard)
If left unattended the PL500 will turn itself off to provide a safer working environment.

Intelligent Light Guides (standard)
Automatic recognition of light guides and automatic Polilight configuration. Prevents light guide damage. Also protects users from exposure to high intensity light.

Variable Light Shutter (standard)
A new light shuttering system provides full output intensity control. Output intensity can be controlled to very low levels. Use only the amount of light you need.

Weight:
Gross packed weight: 13.6 Kg. (30 lbs.)
Net Polilight PL500 weight: 9.5 Kg. (22 lbs.)

Dimensions:
Gross carrying case dimensions are: 47 x 36 x 23 cm (18.50 x 14.30 x 90)
Net Polilight PL500 dimensions are: 32.5 x 35 x 15 cm (130 x 140 x 5.70)

Melbourne Head Office ¥ Unit 6 / 42D44 Garden Blvd. ¥ Dingley ¥ VIC ¥ 3172 ¥ **ACN 005 425 507**
Tel. +61 3 9558 0344 ¥ Fax: +61 3 9558 0252 ¥ EÐMail: rofin@rofin.com.au ¥ Website: http://www.rofin.com.au

Figure 43: Sales Brochure: Rofin "Polilight 500", page 1

POLI*LIGHT* *PL500*

UNIVERSAL FORENSIC LIGHT SOURCE

The Polilight *PL500 is a state-of-the-art Forensic Light Source that has been under development for more than two years. It© design is built on the previously highly successful Polilight models, however, new microprocessor control, power supply and electro-optical technologies introduced by Rofin Engineers, have resulted in a quantum leap in performance.*

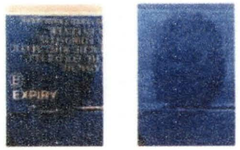
The result is a Forensic Light Source which has a far greater output power, which is smaller and lighter, is highly intelligent and is designed for even greater reliability and ease of use.

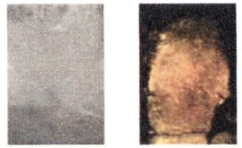
Applications of a Forensic Light Source:

Applications for portable forensic light sources have been developed now for over ten years, but even today more applications are being discovered and developed for use at the crime scene and in the laboratory. Replacing the large, expensive and inflexible lasers previously used, applications cover a wide range of forensic investigation.

Well documented Polilight* usage includes the location and capture (photographic) of latent fingerprints, footprints, bloody fingerprints and blood patterns, fibres, powders, stains, paintD chips, gunshot residues, tattoos, bruises, semen, and also include a variety of forensic document applications including obliterations, alterations and forgeries.

Other noted applications are, location of bone fragments, drugs with cutting agents, lipstick residue, saliva, fire accelerant, and an unlimited number of possible contaminates such as greases, industrial chemicals and plant samples.





Long Life 500Watt Xenon Lamp:

The Polilight PL500 with its new concept 500Watt Xenon arc lamp and unique optical design delivers almost 3 times more optical power at the output end of the light guide compared to the 300Watt Polilight PL10. The result is a dramatic increase in light output power, and more power means finding more evidence more easily. The 500Watt Xenon lamp has a life of at least 1000-3000 hours.

Changing a lamp takes only a few minutes since the lamp module simply clips into a pre-aligned housing ensuring rapid and accurate lamp installation. A built in meter advises the user of the lamp life.

500Watt Universal Power Supply:

The Polilight PL500 power supply has been totally redesigned to incorporate the latest switch mode power supply technology which provides a unique unity power supply. This means that the Polilight PL500 can accept any input AC voltage from between 85 and 265V and at any frequency between 50-60Hz, and still supply the Xenon lamp with stable 500Watt power.

The new power supply incorporates the new requirements for EMC (Electro-Magnetic Compatibility) regulations. Power output can be varied between 300D500 Watts using the front panel switches or the remote control.

A FLOURESCENT POWDERED PRINTS REVEALED ON PLATE

B ARDROX ENHANCED FINGERPRINT ON PLASTIC

C BACKGROUND PRINTING ELIMINATED TO REVEAL BLOOD FINGERPRINT

D RHODAMINE TREATED FINGERPRINT ON PLASIC SHEET

Sales Brochure: Rofin "Polilight 500", page 2

MAIN IMAGE SHOWS THE NEW ERGONOMIC DESIGN AS COMPARED TO THE PREVIOUS MODEL

Easy to use Front Panel Design: (PICTURED TO THE RIGHT)

The Polilight PL500 is designed with the user in mind and incorporates state of the art microprocessor control with stepper motor driven filter selection, filter tuning and power selection. All filters are individually selected at the touch of a single button on the front of the instrument. The selected centre wavelength of the band is shown on an LED display with a second LED displaying the extent of filter tuning and output power selected.

After initial power up, the Polilight PL500 will automatically go to the 450nm broad band blue filter which is the most commonly used filter for general crime scene examination. For safety the default power setting is set to low.

Liquid Light Guide:

The light output from the Polilight PL500 is via a unique and flexible 8mm (internal diameter) liquid light guide designed to collect and transmit the light output with high efficiency. The new light guide is connected to the light source by a unique plug and twist mechanism which makes fitting and removing the light guide extremely rapid and easy.

The output light is focused using a quartz lens producing an even light spot. The stainless steel protective sheath ensures the long life of the light guide in the field.

Ergonomic Design:

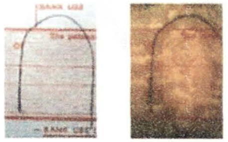
The Polilight PL500 is smaller and lighter than existing Polilight models, even though the optical power output is three times higher. The Polilight PL500 is designed with crime scene applications in mind and is designed to be carried on aircraft as carry on or checked baggage.

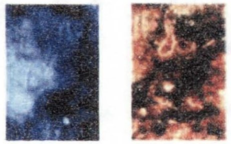
The unit is built in an aluminum case with bumpers on all corners to provide shock protection. A reinforced carry case is provided for easy transportation of the Polilight PL500 and its accessories.

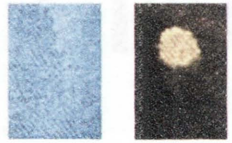
Remote Control Operation: (PICTURED ABOVE)

A small hand held remote control provides the option of operating the Polilight PL500 from up to three meters away. Filter selection, filter and power tuning can all be performed through a simple four button remote control.

Sales Brochure: Rofin "Polilight 500", page 3







THE MOST POWERFUL AND INTELLIGENT FORENSIC LIGHT SOURCE

Easy Maintenance:

A major design objective of the new Polilight PL500 has been to dramatically reduce any potential maintenance down time. The new 500Watt Xenon lamp unit is designed into an easy access position and lamp change over time has been reduced by 90%. The power supply replacement time has been reduced by 95%. These savings have been achieved by adopting a modular construction design and by applying ten years of light source servicing experience. Instrument down time and possible service charges will be significantly reduced as a result.

(THE NEW EASE OF LAMP REMOVAL IS PICTURED ABOVE)

DFO TREATED FINGERPRINT REVEALED ON BANKSLIP

VACUUMINGS FROM SCENE OF CRIME ILLUMINATED TO SHOW DETAILED FIBRES

SEMEN STAIN ON FABRIC REVEALED BY THE POLILIGHT

Tunable High Power Optical Filters:

The high powers resulting from the 500Watt Xenon lamps would damage and drastically reduce the lifetime of the filter types used in previous Polilight models. So unique new filters were specifically developed for the highly powered Polilight PL500 to ensure long life and purity of light. The new filters are specifically designed to withstand the very high optical energy output by the Polilight PL500. Purity of the light band produced was critical and high rejection of stray light essential to the success of previous Polilight models.

The new Polilight PL500 filters are interference type filters and can be tuned to achieve the precise output bands required.

Safeguards:

The use of microprocessors within the new Polilight PL500 has allowed us to incorporate some new safety designs not able to be implemented on any other light source.

The Polilight PL500 monitors its internal temperatures and will turn off the lamp rather than let any potential damage occur. Should any internal electrical levels not be within acceptable limits the unit will not allow the power supply to attempt to strike the lamp. Light flashes occurring between filter changes have been eliminated. All these features are designed to provide protection to the operator, and the instrument, against any accidental or ill advised usage.

Output Light Bands:

Instead of the 10 bands supplied with the Polilight PL10 and six bands of the Polilight PL6, the new Polilight PL500 has twelve bands in the UV/Visible range. The new bands are the blue 470nm and 490nm. These bands add flexibility to investigations since they are narrower than the general investigation wide blue 450nm band. The continuous tunablity of the Polilight filtering system makes it possible to select any peak wavelength in the range 385 to 665nm. Future Infra-Red options will add another four IR light bands.

***Rofin Australia Pty Ltd** has been producing Forensic Light Sources for over 10 years, and now has over 1000 users. Already over fifty countries have experienced the reality of using a Polilight in their daily investigations. Following the reputation, of reliability and performance associated with the name Polilight, we are proud to introduce the new Polilight PL500. The most powerful and advanced Forensic Light Source todate.*

- RUGGED CONSTRUCTION AND PORTABILITY
- 3X THE POWER OF PREVIOUS POLILIGHT
- MORE SELECTABLE VISIBLE FILTERS
- SINGLE PUSH BUTTON CONTROL
- MICROPROCESSOR CONTROLLED
- EASY TO OPERATE
- REMOTE CONTROL
- POWER TUNING
- FILTER TUNING
- EASY TO USE

ROFIN

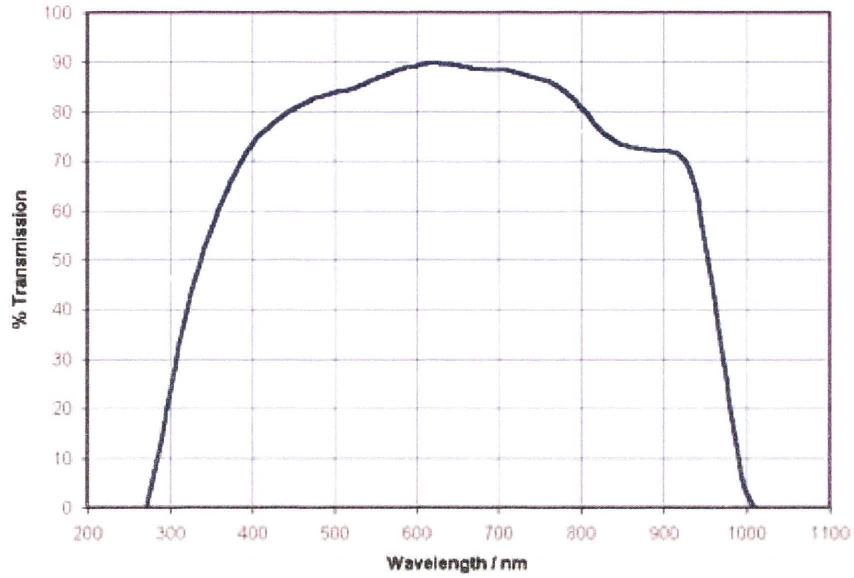


Figure 44: Transmission Spectrum for liquid light guide[21]

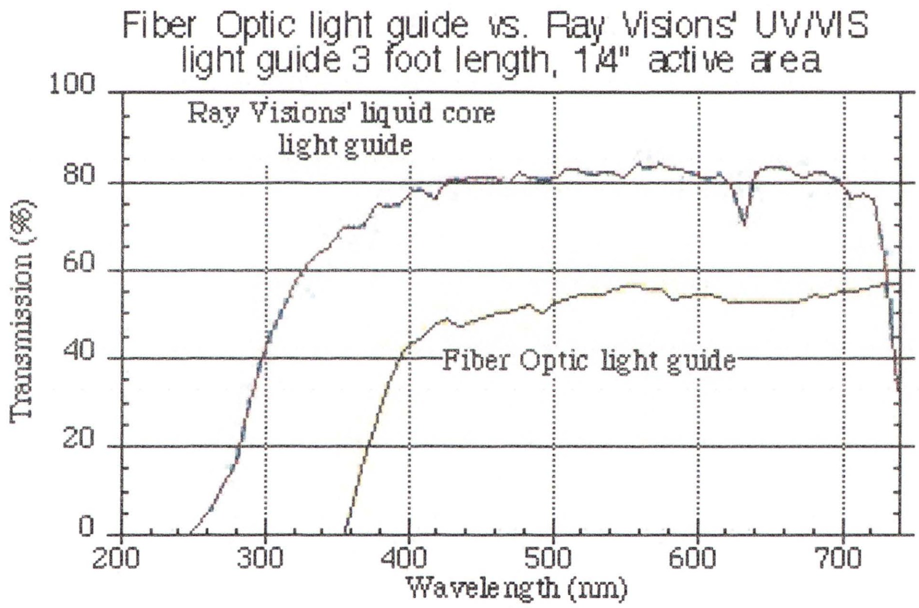


Figure 45: Comparison of Transmission Spectrum for liquid core vs. fibre optic light guide (courtesy: Ray Visions Inc, USA)

Interview with Stuart Clifton of S. C. Medical

Background

Stuart Clifton is one of the more knowledgeable people in Australia in the area of M.O.T. lighting, particularly in the area of marketing. He owned and managed the Australian agency for Berchtold for many years, holding the lion's share of the market. Since then he has started a bio-medical engineering consultancy S.C. Medical, working closely with architects and hospital specifiers and administrators, advising on medical equipment. He is a member of the Australian Standards Technical Committee HE 003 (Medical Electrical Equipment), and has been involved in the creation of AS/NZS 3200.2.41[12]

Interview

For the last 35 to 40 years Chromophere/Berchtold have been the main supplier of major operating theatre lighting systems in Australia, however in the last 3 to 5 years this has begun to change, and Martin are now outselling Berchtold, on a combination of price and service, or at least a perception of these. Minor suppliers include Heraeus, Dr Mach, ALM, Angenieux and Amsco. These smaller players all varying popularity from time to time depending on exchange rates, new "gimmicks",

Major surgical lighting systems were traditionally chosen by the head theatre nurse, in more recent times it can be the surgeon or biomedical engineer, and in the last couple of years it is become common for the builder to specify the system, usually a purely price driven exercise.

Unfortunately the actual quality of a light has very little to do with its sales success. It is debatable whether Martin really offers better prices and service, but the sales manager has been more pro-active in her approach to the acquisition of new clients.

It is also very difficult to say what is the "best" system due to the wide variety of medical procedures performed, range of preferences of clinicians due to age, training etc. The "perfect" system would need to be cheaper, able to provide a range of brightness levels at a range of colour temperatures

The rate of replacement in regional areas is between 20 to 40 years, in cities it is 10 to 20 years, and in some cases as low as 5 years. Rural areas tend to be more conservative in their choice of lights, preferring reliability, low maintenance requirements, ease of maintenance and availability and cost of replacement bulbs and other parts to the latest styling or technology.

Self illuminating spreaders such as the Lumitex light guide promised to solve many of the issues in major surgical lighting, however they haven't really taken off, perhaps due to a combination of unresolved technical problems such as light distribution, and the unfamiliar nature of them to clinicians trained using traditional overhead major surgical lighting.

Heraeus are the only company to have thoroughly researched the issues of major surgical lighting, and are attempting to use this research with the release of their G8 light.

Laminar flow compatability is an important sales point and everyone claims to be laminar flow compatible, however true laminar flow is never achieved in reality due to the "non-aerodynamic" nature of the lighting systems as well as heat from the light, let alone the presence and movement of the surgeon and staff about the patient. There are more and more surgeons insisting on the availability of laminar flow systems.

Interview with Frank Clarkson, Bio-medical Engineer for RPA Hospital, Sydney.

Background

In his role as Senior Bio-medical Engineer at the Royal Prince Alfred Hospital, one of Frank's responsibilities is the maintenance of the variety of Surgical Lighting systems in use throughout the hospital. He also advises on any purchases of Surgical Lighting made by the hospital. In a career spanning many years, his hands-on experience of the day-to-day issues in the maintenance of a wide range of Major Surgical Lighting systems is invaluable for this research.

Interview

There are many issues considered by a hospital prior to the purchasing of an M.S.L. system, and these can vary depending on the situation and reasons for the purchase. In the case of the recently built surgical wing at RPAH, there is the preference of the surgeon, the requirements of the architect and specifier, the advice of the bio-medical engineer and the head theatre nurse, and then there is what the builder wants to supply. In the case of a simple equipment upgrade/replacement, only the advice of the surgeon and the bio-medical engineer may be sought.

One of the problems faced when selecting an appropriate M.S.L. system is the fact that the preferences of every surgeon who uses the surgical suite will vary dramatically, and that no M.S.L. system can be all things to all surgeons. For example, the preferred level of illumination can be anything from 80,00 lux to 130,000 lux, and preferred colour temperature can range from 3,500°K to 5,500°K,with younger or more specialised surgeons often preferring higher light levels and higher colour temperatures.

Once an M.S.L. system is in use, bulb life, availability and cost are the main issues for the maintenance of Surgical Lighting. The perfect M.S.L. bulb should be long lasting, easily sourced and easy to replace. Difficult-to-replace bulbs are a pet-hate for many surgeons and maintenance staff, but a few manufacturers have found solutions to this problem. Many of the newer lights now have snap in/snap out bulbs, which don't require any extra tools, but older lights and some less expensive models require removing the cover plate with a screwdriver. Some bulbs are very expensive to replace. They can range from $40 to $400.

Single-bulb lights and multi-bulb lights both have their advantages and disadvantages. Most multi-bulb lights can continue to be used even if one of the bulbs burns out, but the downside is they typically give off more heat, and they require re-lamping more often.

Many single-bulb systems come equipped with a backup bulb mechanism that activates if a light burns out during a procedure. If bulbs need to be changed, the process should be simple, so as not to bring the OR to a standstill.

Another major issue is the availability and cost of manufacturer servicing. This can vary dramatically from no service available, to service available at reasonable cost, through to service available at extremely high cost.

Other issues are ease of cleaning, durability of parts and finish (particularly lens and reflector), regularity of re-adjustment needed and ease of these adjustments. Some M.S.L. systems require specialised tools for adjustment

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