

ULTRAVIOLET RADIATION COMPARED TO AN ULTRA-CLEAN AIR ENCLOSURE

COMPARISON OF AIR BACTERIA COUNTS IN OPERATING ROOMS

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Clean air in the operating room is important during joint replacement surgery. We compared monochromatic ultraviolet radiation of 254 nm with the use of a Charnley-Howorth air enclosure by bacterial air-sampling during 113 total hip arthroplasties. Air samples were taken continuously at the edge of the wound and every 15 minutes at a site 130 cm from the operating table. We also tested the effect of occlusive clothing for all personnel.

Ultraviolet light was more efficient than the ultra-clean air enclosure, and occlusive clothing on its own or in combination also produced improvement. The implications of these findings are discussed.

Clean air in the operating theatre is especially important in certain types of surgery such as joint replacement. In a multi-centre study of more than 8000 total hip arthroplasties, Lidwell et al (1982) showed that the frequency of deep postoperative infection was directly related to the number of bacteria in the air, and

recommended a level of less than 10 colony-forming units (CFU) per cubic metre (ultra-clean air).

Ultra-clean air is usually obtained by the use of laminar flow ventilation enclosures, and the effect of these systems has been well documented (Charnley and Eftekhar 1969; Charnley 1973). However, this equipment

Table I. Infection rates reported with the use of UVC in clean orthopaedic surgery

Author	Type of surgery	Number	Antibiotics	No UV radiation		UV radiation	
				Number	Per cent infected	Number	Per cent infected
Hart 1938	Clean orthopaedic	209	No	144	3.5	65	0
Lowell and Kundsinn 1978	Hip and knee replacement*	1831	Yes	690	3.8	1141	0.96
Moggio et al 1979	Hip replacement*	1322	No	0	-	1322	1.36
Lowell et al 1980	Primary hip replacement	2035	Yes	519	2.1	1516	0.4
	Primary knee replacement	1487	Yes	63	9.52	1424	0.28

*patients with previous operations in the same area were not excluded

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is expensive, and can only be justified in certain hospitals, most often only in one operating room. It has been shown that a laminar flow unit is cost-effective only in units where more than 200 joint replacements are performed in each year (Persson et al 1988).

An alternative method is the use of ultraviolet irradiation of 254 nm (UVC) during surgery. This has been discussed since the 1930s, and a number of authors have reported that using UVC reduced infection rates to below 1% in clean orthopaedic operations (Table I).



Fig. 1a

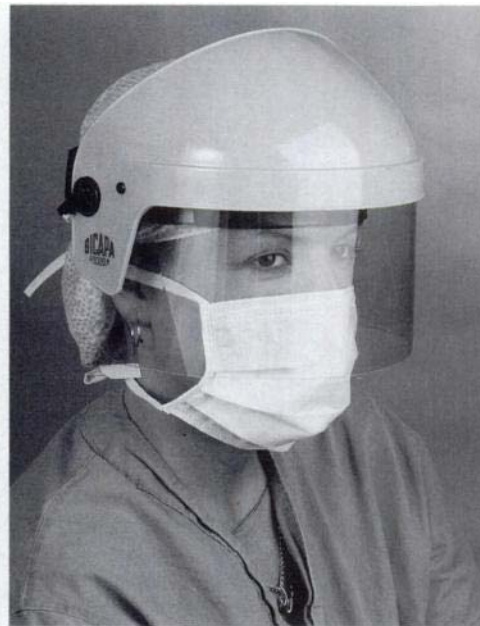


Fig. 1b

Figure 1a - The helmet used in the Charnley-Howorth enclosure. Figure 1b - The visor used to protect the head and eyes from UVC.

These studies used intensities of 25 to 30 $\mu\text{W}/\text{cm}^2$ but have been criticised because of their longitudinal design and lack of control groups (Berg, personal communication 1990).

The infection rates after other types of surgery have also decreased after the installation of UVC tubes (Table II). In 1964 the American National Research Council presented infection rates from a randomised multicentre study in five hospitals using visible blue or UVC light tubes. All types of surgery were included, and the UVC intensity used was lower than the recommended level of 25 $\mu\text{W}/\text{cm}^2$ in 58% of the operations.

There are few reports of air bacteria counts using UVC radiation. Carlsson et al (1986) found 10.9 CFU/ m^3 when combining UVC of 25 to 30 $\mu\text{W}/\text{cm}^2$ with Allander zonal ventilation during hip replacements. Berg, Bergman and Hoborn (1989) reported central air bacteria counts of about 14 CFU/ m^3 in UVC at 100 $\mu\text{W}/\text{cm}^2$ in surgery for pertrochanteric hip fractures, and Sanzen, Carlsson and Walder (1989) reported 2.6 CFU/ m^3 in the centre of the room, using a combination of UVC at 25 to 30 $\mu\text{W}/\text{cm}^2$ with Gore-tex occlusive clothing (W. L. Gore & Associates Inc, Elkton, Maryland) in hip replacement surgery (Table III).

We compared the air bacteria counts during hip replacement in an operating room equipped with a Charnley-Howorth air enclosure (CH) and one equipped with UVC tubes. We also studied the addition to the two systems of the use of occlusive clothing (CLOTH) by all theatre staff. Bergman, Hoborn and Nachemson (1985) showed a reduction of the air bacteria counts by the use

Table II. Infection rates reported for several types of surgery, before and after using UVC

Author	Type of surgery	Infection rate	
		No UVC	With UVC
Overholt and Betts 1940	Thoracoplasty	13.8	2.7
Woodhall et al 1949	Neurosurgery	1.1	0.4
Hart et al 1968	Orthopaedic	16.5	0.74
Wright and Burke 1969	Craniotomy	5.3	0.7
	Laminectomy	4.1	0.3

Table III. Reported air bacteria counts* as CFU/ m^3 with and without UVC

Author	Number	Method added	No UVC	With UVC
Carlsson et al 1986	30	Allander zonal ventilation	45.2	10.9
Berg et al 1989	20	None	24	14
Sanzen et al 1989	20	Occlusive clothing	9.8	2.6

*at the edge of the wound during surgery

Table IV. Protective clothing worn in the UVC theatre

Patient	Surgeons, scrubbed staff	Non-scrubbed staff
Disposable draping Tent over the head	Normal sterile clothing Visor	Normal cotton working dress Long sleeved cotton cardigan
Double adhesive plastic film on the operating area	Double disposable hoods	Visor Disposable plastic gloves

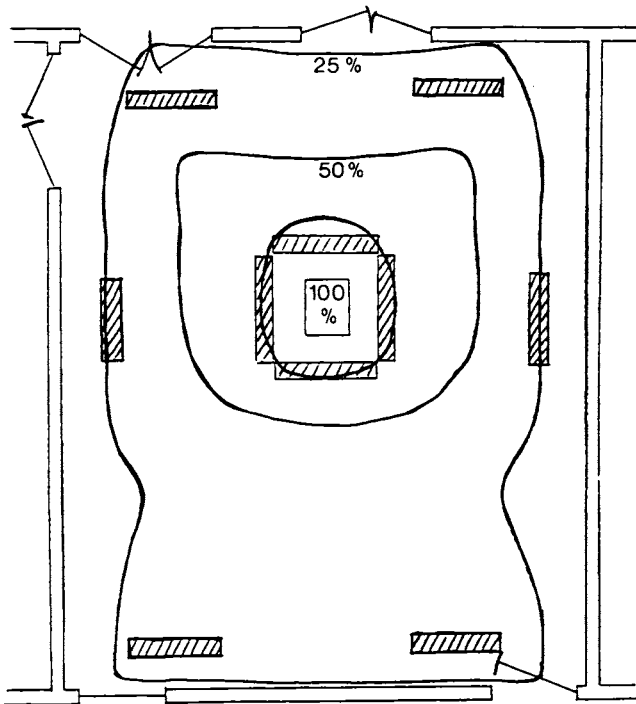


Fig. 2

Diagram to show the siting of the UVC lights (shaded), and the UVC intensity 1 m above the floor. The UVC intensity on the top of the operating table was 290 $\mu\text{W}/\text{cm}^2$ which was taken as 100%.

and trousers, disposable hoods, multi-layer face masks and clean shoes. The scrubbed operating team wore standard disposable sterile gowns with plastic reinforced sleeves and front (Mölnlycke, Sweden), and sterile surgical gloves (Berg et al 1989). When the occlusive clothing (CLOTH: Klinidress, Mölnlycke, Sweden) was used, it replaced the basic cotton working clothing and was worn by every person who entered the room.

Room 1 was equipped with a Charnley-Howorth Mark II enclosure without walls (Alfax AB, Sweden) built in 1984. Maintenance and filter changes have been performed in accordance with the manufacturer's recommendations. Standard helmets and a closed exhaust system were provided for the operating team (Fig. 1a).

Room 2 was equipped with ten ceiling fittings, each containing two UVC tubes (Philips TUV 40, Holland). The position of the fittings was adjusted to obtain an even distribution of the UVC, and its intensity (Fig. 2) was measured as described by Berg et al (1989). On the top of the operating table the intensity was 290 $\mu\text{W}/\text{cm}^2$. The room temperature was about 20°C and the humidity under 60%.

Protection from UVC for the skin and eyes differed for the patient, the scrubbed operating team and the unscrubbed staff (Table IV). Face protection was

Table V. Air bacteria counts in ultraviolet radiation (UVC) and in a Charnley-Howorth enclosure (CH), with or without the use of occlusive clothing (CLOTH)

Group	Method	Number	Air bacteria count in CFU/m ³				
			Central			Peripheral	
			Mean	SD	Per cent reduction*	Mean	SD
1	CH	14	7.67	0.27	—	0.07	0.37
2	CH+CLOTH	9	3.21	0.28	58	0.05	0.24
3	UVC	30	2.96	0.47	61	1.81	0.27
4	UVC+CLOTH	30	0.47	1.17	93	1.27	0.34
5	CLOTH	30	5.91	0.32	22	9.69	0.29
Statistical significance			1 vs 2, $p < 0.01$			1 vs 2, $p > 0.10$	
			3 vs 4, $p < 0.01$			3 vs 4, $p < 0.01$	
			4 vs 5, $p < 0.01$			4 vs 5, $p < 0.001$	
			3 vs 5, $p < 0.01$			3 vs 5, $p < 0.001$	

*compared with that for CH alone

of a special coverall, in comparison with conventional cotton material.

MATERIAL AND METHODS

The two operating rooms included in the study were of the same size, located next to each other, and both have a basic ventilation rate of 30 air changes per hour. They are used only for clean orthopaedic surgery, and by the same team of surgeons and staff.

All staff members wore short-sleeved cotton blouses

achieved by a modified visor (Bicapa, Sweden) which was used by all who entered the room (Fig. 1b).

Bacterial air-sampling was standard throughout the project. Continuous air sampling was performed centrally by means of an Andersen sampler with a sterile silicone tube attached to the edge of the wound (C value), and intermittent air-sampling every 15 minutes was performed by a Casella slit sampler at a defined place 130 cm from the operating table (P value).

The C and P values were measured during 113 Charnley total hip replacements, all using Palacos cement

with gentamicin. All patients received systemic prophylaxis with flucloxacillin and were operated in the lateral position with an anterolateral incision. The study was performed in two consecutive stages.

In stage 1, bacterial air-sampling was performed during 23 operations in the Charnley-Howorth enclosure, with the randomised addition of CLOTH. For stage 2, bacterial air-sampling was performed during 90 procedures in the UVC theatre, randomised into three groups: UVC only, CLOTH only, and both UVC and CLOTH. The 113 hip replacements were therefore considered in five groups (Table V). Smears were taken from the wound and from the surrounding skin by the method described by Blomgren, Hoborn and Nyström (1990) for bacteriological examination.

Student's *t*-test was used to evaluate the differences between groups, and Spearman correlation coefficients were calculated. Calculations were performed on the logarithms of the results as they were shown to be normally distributed. Every value given for CFU/m³ is a geometric mean value.

RESULTS

The results are given in Table V. In stage 1, using the Charnley-Howorth enclosure, the mean C value was 7.67 CFU/m³: this result was regarded as a standard for other measurements. When CLOTH was used, this figure decreased to 3.2 CFU/m³ (58%). The P value fell from 0.07 to 0.05 CFU/m³.

The difference between the C values in groups 1 and 2 was highly significant ($p < 0.01$), but the P values did not differ significantly ($p > 0.1$). In stage 2, using the UVC theatre, the mean C value with UVC only was 2.96 CFU/m³. When CLOTH was added to the UVC, the C value decreased to 0.47 CFU/m³, a 93% reduction from the standard value in the Charnley-Howorth enclosure.

Finally, when CLOTH was used as the only air-cleaning method, the C value was 5.91 CFU/m³, 22% lower than the standard. The results of the three groups in stage 2 were statistically different from each other (Table V).

None of the wound or surrounding skin smears showed any bacterial growth. We found no correlation between the bacterial counts and either the duration of the operation or the number of persons present in the theatre.

DISCUSSION

We found that the Charnley-Howorth enclosure was efficient; the bacterial level did not exceed the postulated limit of 10 CFU/m³. The addition of CLOTH produced a 58% reduction of the central air bacteria count, and as a result of this we were given permission by the University Ethics Committee to use CLOTH alone for a group of 30 hip replacements during the second stage of our study.

The second stage results showed that UVC was an

efficient air cleaner, giving a mean C value of 2.96 CFU/m³ and a P value of 1.81 CFU/m³. The combination of the UVC and the CLOTH was even more efficient, giving a C value of 0.47 CFU/m³, a 93% reduction from the standard for the Charnley-Howorth enclosure. The use of CLOTH alone was also more efficient than the Charnley-Howorth unit.

Bacterial counts in the periphery of the operating theatre were generally lower than in the centre. This is probably explained by the fact that the main sources of air bacteria are the respiratory tracts and the hair of the people at work. The air samples from the periphery were taken behind the operating team in an empty area.

We used a higher intensity of UVC than the 25 to 30 μ W/cm² mentioned in previous publications; this may explain our positive results. The operating team and staff were adequately protected from this ultraviolet irradiation and only the wound area of the patient was exposed. This area is exposed only once in most cases, and an experimental study on wound healing after UVC exposure in the rat showed no harmful effects (Brandberg, personal communication 1991).

It is difficult to study infection rates in clean surgery because of its low incidence, which would require large numbers of patients. Several thousand operations would be needed to show a significant difference between the actual infection rates in hip replacement surgery (Apley 1987). The correlation between infection rate and air contamination shown by Lidwell et al (1982) was therefore a great step forward for this type of research, allowing air-sampling techniques to be used to evaluate the degree of contamination.

The air bacteria count in an ordinary operating theatre varies between 50 and 500 CFU/m³, and the recommended level for ultra-clean air is < 10 CFU/m³. An important question is then to be considered (Apley 1987): will the infection rate decrease when the air bacteria count is reduced from 8 to 2 CFU/m³? The importance of total bacterial counts has been discussed by Hambraeus (1988), who emphasised that the number of *pathogenic* bacteria is more important than the total air bacteria counts. However, *Staphylococcus aureus* is one of the most UVC-sensitive bacteria. It may also be significant that, during surgery, all exposed surfaces, including instruments, trays and trolleys, will be continuously sterilised by the UVC.

Shortwave ultraviolet radiation of 254 nm during surgery as an air-cleaning method has been used routinely in some hospitals since the 1930s (Goldner and Allen 1973), but it has not previously been sufficiently scientifically evaluated. On the basis of our comparisons, we believe that the ultra-clean air needed for such surgery as joint replacement can be provided in the operating room by ultraviolet light and special occlusive clothing. Ultraviolet light is the less expensive alternative: we intend to report elsewhere on questions of economy, comfort and protection.

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