Postoperative Wound Infections:

A Further Report on Ultraviolet Irradiation with Comments on the Recent (1964) National Research Council Cooperative Study Report

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SINCE THE DAYS of Lister and Von Bergmann, surgeons have tried to avoid infections of clean wounds. Although Lister was the first to emphasize that air was the major source of infecting organisms, gross contaminations by contact were soon recognized as responsible for most infections of that day and the air as a vector came to be ignored. Contamination through contact was progressively reduced but because it was recognized that all pathogenic bacteric could not be kept out of the wound, increasing emphasis was placed on leaving the wound in the optimum condition for natural defense mechanisms. However, as elective clean operations of larger magnitude and longer duration were performed more frequently, postoperative infections became more serious. Numerous surgeons, including ourselves responded with modifications and attempted improvements aimed principally at control of contact and endogenous sources of bacteria with only small success.

The Third Route of Wound Contamination. In 1933 we demonstrated[11, 12, 14, 20] that every open wound, the instruments, drapes, and sterile supplies were constantly showered with organisms sedimenting from the air that were given off predominantly from the respiratory tracts of the occupants of the operating room. We were compelled to recognize this third route as very important in the contamination of clean wounds in 1934 after thorough studies of our sterilization procedures, scrubbing technic, room preparation, skin antiseptics and preparation, aseptic ritual and operative technics failed to reduce satisfactorily our infection rate following large, clean operations. Various masks, head hoods and ventilated helmets were investigated in detail for their ability to control expired air, but a completely effective and yet practical and comfortable device was not found. Discouraged by these attempts and desiring to eliminate airborne organisms from whatever source, we turned to direct ultraviolet irradiation which was known to be highly bactericidal. These efforts proved highly successful[11-20, 22-26] and we came to rely on direct ultraviolet irradiation as the simplest and most effective means to control bacterial contaminants spread by this third route. Protection of personnel and patients from ultraviolet irradiation proved to be only a minor inconvenience.[21] Ultraviolet irradiation was found to be effective regardless of the variety or source of airborne organisms.

Cyclic Periods of Bacterial Contamination of the Air. Every surgeon should keep in mind the well known cyclic periods oc-

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curring particularly during the fall, winter and spring months when upper respiratory infections and the bacterial carrier state are highest. Epidemics of wound infections particularly staphylococcal and streptococcal are not infrequent during such periods and have been repeatedly documented.[6, 20, 26, 30, 31, 41] Prior to the installation of ultraviolet irradiation we had two such epidemics at Duke during the period 1930–1936. In each, after the epidemic nature and source of infections had been recognized, the operating rooms were closed except for emergency operations. During these epidemics nine fatalities occurred from unexplained infections within the two periods totaling 108 days. We have had no similar experience since we began to use ultraviolet irradiation in 1936. In fact, only one death (neurosurgical) has been caused by unexplained infection since our clean operations have been performed within the field of ultraviolet irradiation.

Parenthetically, two other developments since 1936 should be mentioned. Modern air-conditioning with its rapid air change and bacterial dilutional effects has further reduced air contaminants when compared to 1936 when our ultraviolet units were installed. Nevertheless, the constant air sedimentation and surface buildup of pathogenic organisms from many sources still exist in the most modern operating rooms (Table 1). This is particularly critical in long operations with large exposed wounds. Secondly, although marked improvements have been made in filtration efficiency of surgical masks[8, 9, 33] none give an airtight fit and most masks generally used are still inadequate to prevent the nose and throat bacteria from contaminating the surrounding air.

In our experience[12, 26] and that of many others,[3–6, 28] unexplained postoperative infections in clean operative wounds have been predominantly staphylococcal. We do not feel these have developed principally

TABLE 1. *Operating Room—Team 5*
Bacterial Buildup—Sterile Supply Table
Per 66 cm². Area (Petri Dish)

Hours	Colonies with UV	Colonies without UV
1	0	8
2	1	28
3	0	43
4	0	48 (op. ends)
5	0	43
6	1	0 (UV 15 min.)

as the result of the increase in antibiotic resistance staphylococci.[3, 27, 43] Prior to the discovery of effective antibiotics when postoperative staphylococcal infections were at least as common, all these organisms were *resistant.* Regardless of resistance, ultraviolet irradiation is lethal to all organisms including the spore formers, even anthrax.[38–40]

Recent Duke Studies

In 1959 a cooperative study, sponsored by an *ad hoc* committee of the Committee on Trauma of the National Research Council, was organized among five participating hospitals to investigate the efficacy of ultraviolet irradiation for the control of postoperative infections.[35] By random selection approximately half of the operations were carried out under ultraviolet irradiation. We at Duke, having accumulated 23 years' experience with ultraviolet irradiation were convinced of its value for clean operations. We declined, therefore, to participate in the NRC Cooperative study in which random selection was employed since, in our opinion this would have subjected half of our patients undergoing clean operations to a greater risk of infections.* Instead, we

* This increased risk was subsequently substantiated by the NRC Cooperative report[35] where it is stated (p. 43) "On the basis of the observed infection rate in irradiated refined clean wounds, it may be concluded that about 30 of the 128 infections (in the controls) could have been prevented by ultraviolet irradiation."

organized a separate parallel study which admittedly lacked the virtue of random selection but had as good a control as we could devise. The Veterans Administration Hospital which is part of the Duke Medical Center was not equipped with ultraviolet lights and we utilized this hospital as our control. The two hospitals operate with a common senior and house staff and employ the same surgical and sterile technics.

The study consisted essentially of three parts:

(1) A retrospective review of postoperative infections in the Duke Hospital was carried out for various clean operations performed between January 15, 1941 and December 31, 1958. This starting date was chosen since it marked the termination of our previous detailed infection review.[26]

(2) From December, 1958 to May, 1962 (the same years covered by the NRC Cooperative Study) a continuing study of postoperative infections was carried out in our two hospitals. A nurse and a bacteriologist were assigned full-time to this project. The operating room logs were checked daily and the basic information of each operation recorded on specially designed punch-cards. The charts of postoperative patients were checked several times a week and a close rapport was maintained with the surgeons. Any suggestion of infection became the focus for bacteriologic study and was checked by one of four senior surgeons on our staff who were engaged in the project. The following was continued for 3 months after operation. During this study 16,133 operations were reviewed and analyzed.

(3) A separate study was made of 878 consecutive closed and open cardiac operations performed at the Duke Hospital in the 15-year interval between January, 1950 and January, 1965. Of these, 354 were closed procedures for acquired mitral disease and 524 were open heart procedures for a variety of cardiac lesions. These procedures were followed and analyzed for postoperative wound infections and also postoperative bacterial endocarditis.

Results

Once ultraviolet irradiation was installed in our operating rooms, the results obtained in controlling the air as a vector of organisms and in reducing unexplained infections in clean wound were immediate and dramatic and have been maintained since that time. Table 2 presents a summary of our more recent studies of clean operations, performed under direct ultraviolet irradiation between 1941 and 1965 and also our summary data reported previously for the 1936 to 1941 period. These studies were made by surgeons in our institution representing the fields of general, thoracic, cardiac, orthopedic, and neurologic surgery. In this group of more than 23,000 clean operations the overall unexplained infection rate was 0.34%.

Table 3 shows the results of the Duke study which paralleled the NRC Cooperative Study during 1959–1962. The infections rates in the Veterans Administration Hospital without irradiation were approximately five times higher for undrained clean wounds (refined clean), three times higher for drained clean wounds, and approximately twice as high for contaminated wounds as in the Duke Hospital with ultraviolet irradiation. In the categories "clean drained surgical wounds" and "contaminated surgical wounds," a number of possible sources of infections are always present. Therefore, the role of airborne contaminants in infections following these operations is difficult, if not impossible, to determine. Factually, to obtain a valid evaluation of a single factor such as ultraviolet irradiation in the control of postoperative wound infections, *only refined clean operations should be considered.* Because of this, in prior Duke studies of ultra-

TABLE 2. *Duke Medical Center Study—Unexplained Infections in Refined Clean Wounds—Summary of Six Studies 1936–1965**

Period	General & Thoracic No.	General & Thoracic Inf.	Cardiac No.	Cardiac Inf.	Orthopaedic No.	Orthopaedic Inf.	Neurosurgery No.	Neurosurgery Inf.	Total No.	Total Inf.
1936–41	1609	2			391	3	463	1	2,463	6
1941–59	2239	4			4591	26	6116	22	12,946	52
1950–65			878	5					878	5
1959–62	2862	5			2220	5	1817	5	6,899	15
Totals	6710	11	878	5	7202	34	8396	28	23,186	78
% Infections	0.16		0.57		0.47		0.33		0.34	

* In these six separate studies there was only one death (neurosurgical) which was ascribed to an unexplained infection.

violet irradiation, we had confined our investigations to refined clean operations. In this parallel study however, 1959–1962, we included these other categories of wounds principally because they were included in the NRC Cooperative Study.

The incidence of postoperative wound infections and postoperative bacterial endocarditis for 878 consecutive closed and open cardiac operations* performed between January, 1950 and January, 1965 are given in Table 4. In the 354 closed procedures for mitral valve disease there were no wound infections and only three instances of postoperative endocarditis, all late (2 years, 2½ years and 5 years).

The 524 consecutive open heart procedures studied were performed on 515 patients. Congenital heart disease accounted for 361 procedures and 163 of the operations were for acquired heart disease. As with most series of cardiac patients, their state of general health ranged from robust to the chronically ill and debilitated. Certain factors which added to the risks of postoperative infection in these patients are given in Table 5. Fifty-seven of the operations were for the implantation of one or more prosthetic valves. Ivalon,® Dacron® or Teflon® patch material was used in an additional 126 cases. Thirty-four of these patients had to have their chest incisions reopened within the first 48 hours postoperatively either because of postoperative bleeding or mediastinal clot tamponade. Over 100 of these patients had a postoperative tracheostomy.

All these open heart patients were given prophylactic antibiotics starting the evening before operation and continuing for at least 7 days postoperatively. Ordinary procaine penicillin and streptomycin were the antibiotics used except in penicillin-sen-

* According to the wound classification criteria of the NRC Cooperative Study any clean operation in which a drain was utilized at its conclusion was excluded from the "refined clean" category of operations and placed in the category "other clean." We have adhered to this criterion in our classification of wounds also except for all clean thoracotomies, such as open heart procedures, where the respiratory tract was not entered before final closure of the chest. Even though in these clean operations an underwater pleural or mediastinal catheter drain was always used for a day or two for the drainage of blood or fluid, we have elected here as in the past to classify these operations as "refined clean." These and the fact that we have never eliminated clean operations from our "refined clean category" on the basis of their being non-elective constitute the only differences in clean wound classification between our studies and those of the NRC Cooperative Study.

Obviously, our inclusion of these two types of clean operations in our "refined clean" category (considered by the NRC Cooperative Study more likely to develop infections) could have influenced our results, if at all, only in the direction of more infections in our refined clean category. Such an effect was not observed.

TABLE 3. *Duke Medical Center Study 1959–1962—Comparison as to Postoperative Infections*

	Duke Hospital with Ultraviolet Radiation			Durham V. A. Hospital without Ultraviolet Radiation			
Category	# Total	# Infected*	% Infections	# Total	# Infected*	% Infections	Ratio Infections Duke: V. A. Hospital
Refined clean	7046	22*	0.3	2875	43*	1.5	1:4.8
Other clean	1881	28*	1.5	357	16*	4.5	1:3.0
Contaminated	2913	125	4.3	1061	78	7.4	1:1.7
Totals	11,840	175	1.5	4293	137	3.2	1:2.2

* As in the NRC Cooperative Study these data do not include stitch abscesses or erythema around sutures, these being considered as reactions about a foreign body in the skin. Included are all operations where pus even in small amounts had to be evacuated from the subcutaneous tissue.

sitive patients when Erythromycin-streptomycin were used.

In these 524 consecutive open heart cases there have been only two instances of postoperative bacterial endocarditis and neither of these occurred in the immediate postoperative period. One of these endocardial infections developed in a 35-year-old man following implantation of a Starr-Edwards aortic prosthesis for severe aortic insufficiency. Five months after operation he developed fever and petechiae followed by an embolus to his right superficial femoral artery. This was removed by embolectomy and microscopic section revealed it to contain hyphae of a fungus. Cultures identified it as being of the genus trichosporon. Despite intensive treatment with antifungal agents, this patient died within 2 months of onset of symptoms of mycotic erosion of the root of his aorta. Even though this patient did not develop his endocarditis until 5 months after operation, it is quite possible that the fungus infection originated at the time of his operation.

The only other instance of bacterial endocarditis following these 524 open heart procedures occurred in a patient 2 years after a second open heart procedure for resuturing a leaking mitral Starr-Edwards valve. He was successfully treated with antibiotics and has been asymptomatic for the past 6 months. It is highly unlikely that this patient's endocarditis, occurring 2 years after operation, originated at the time of operation.

In this series of 524 consecutive open heart patients there have been five wound infections. One of these occurred in the subcutaneous tissue of a chest incision 2½ weeks after repair of an ostium primum defect and after the wound had appeared to heal normally. Ten days after operation this patient developed abdominal discomfort which we thought was due to a tender distended liver associated with some cardiac failure. After 2 days of watching, and much to our embarrassment, we finally took this patient to the operating room and removed her gangrenous ruptured appendix and drained the purulent peritonitis. She recovered very promptly thereafter, but not before developing a small area of fluctuance in the subcutaneous tissues of her right thoracotomy wound which as noted had previously appeared to heal normally. This was drained of fecal smelling pus that grew the same organisms as had been found in her peritoneal drainage. This wound healed secondarily without further difficulty. We do not think this wound infection was related in any way to her original operation.

Another patient who underwent valvulotomy in 1960 for aortic stenosis, and who had severe cerebral embolization and prolonged postoperative coma requiring tracheotomy and a respirator, developed a small area of subcutaneous infection at the upper end of his chest incision which required opening the skin wound over a 2–3 cm. length. Cultures from this grew Aerobacter aerogenes and staphylococcus albus coagulase negative. This patient later died because of the original embolic brain damage and autopsy revealed no other infection present. A third patient, who had a closure of an interatrial septal defect in 1959, developed a subcutaneous hematoma in the lateral aspect of her operative wound. Though no pus or inflammation were encountered when this small hematoma was evacuated on the seventh postoperative day, later cultures from the opened wound grew staphylococcus aureus coagulase positive and we have included this as a primary wound infection.

Two other patients developed superficial wound infections around stitches that required the skin incision to be opened for two to three centimeters. Cultures from both of these wounds revealed staphylococcus aureus coagulase positive. Both of these wounds healed promptly after a day or two of compresses followed by dry dressings.

These are the total wound infections in this series of 524 open heart patients. All were mild and none delayed the patient's discharge from the hospital. There were no instances of sternal infection, mediastinal infection or empyema. Compared to other reported series of open heart operations of approximately the same number of cases done in these same years (Table 6), these data show a markedly low infection rate for early postoperative bacterial endocarditis and wound infection.

TABLE 4. *Infections after Cardiac Surgery—Duke 1950–1965*

	Closed Heart	Open Heart	Total
Operations	354	524	878
Wound infection	0	5[1]	0.6%
Early S. B. E.	0	1[2]	0.1%
Late S. B. E.	3[3]	1[4]	0.5%

[1] 3 mild subcut., 1 hematoma, 1 endogenous.
[2] Fungus 5 mo. postop.
[3] At 2, 2.5 and 5 years.
[4] Enterococcus 2 yr. postop.

Comparative Analysis

Duke Study and NRC Cooperative Study

Our parallel study and the results of our 29 years' experience indicate that when ultraviolet irradiation is used as an adjunct to good surgical technic it is of great value in lowering the rate of unexplained infections. These further data on ultraviolet irradiation are compared with the results of the NRC Cooperative Study in Table 7. Note that the most important comparison concerns the category of refined clean operations. Both studies showed significantly lower infection rates for this category when ultraviolet irradiation was employed. With refined clean operations the NRC Cooperative Study hospitals showed improvement in infection rate ranging from 15 to 44% with an overall average of 24% (Table 8). Although in the Cooperative Study there was neither significant benefit nor detriment with ultraviolet irradiation for the "other clean" and "contaminated" categories, as contrasted to the Duke study, these data in Table 7 show the notably higher infection rates in the NRC Cooperative Study for all categories of wounds, with and without ultraviolet irradiation.

In addition to these higher infection rates, rather wide variations in frequency of infections for different categories of wounds (Table 9) and for different operations (Table 10) were reported by the NRC Cooperative Study. These wide variations among the participating hospitals are difficult to explain, since, theoretically, wound classification, presence of infection

TABLE 5. *Open Heart Operations—Factors Predisposing to Infection*

	Cases
One or more prosthetic valves	57
Prosthetic patch material	126
Reopening for bleeding, etc.	34
Tracheostomy	over 100
Diabetics	2
Active SBE (K. Aerobact.)	1

and numerous other factors evaluated were uniformly judged and recorded. Perhaps patient population, bacterial carrier states, operative technics or other unknowns contributed to the wide variation but this cannot be determined. The suggestion has been made [35, 36] that sources of bacteria other than through the airborne route were responsible for many of these infections and ultraviolet irradiation could not be expected to have demonstrable benefit. Interestingly, as shown in Table 8, the hospitals of the Cooperative Study with the lowest overall infection rates tended to have the greatest improvement with ultraviolet irradiation for refined clean operations which may support this suggestion.

Another interesting comparison of the Duke and NRC Cooperative Studies may be made based upon the clean wound subclassification shown in Table 11. In both studies, approximately 75% of all operations analyzed were classified as clean and 25% as contaminated. In the Duke series the "refined clean" cases comprised 61.5% of all operations and 81.6% of the clean operations. In the NRC Cooperative Study the "refined clean" were 42.8% of all operations and 56.9% of the clean operations. Thus "other clean" were 18.4% of the Duke clean cases, but 43.1% of the NRC Cooperative Study group clean cases. By definition the "other clean" category of the Cooperative Study included all clean wounds which were drained, not closed primarily, or not performed electively. In all our studies at Duke we have not eliminated operations from our refined clean category simply because they were nonelective. We can only assume therefore that the factors accounting for this wide difference in subdivision of clean wounds between the two studies were either the less frequent use of drains in clean wounds or the more frequent primary closure of clean wounds in the Duke study. If it is true that at Duke we do drain fewer clean wounds, or close primarily more clean wounds than indicated by the hospitals of the Cooperative Study and in this way convert more of our clean operations to the refined clean category with its lower infection rate, then certainly, a large part of our confidence to do this has come from our low infection experience with ultraviolet irradiation.

In all of our past [18, 19, 21, 38-40] and more recent bacteriologic studies the lethal effects of direct ultraviolet irradiation on airborne bacteria and bacteria that have sedimented on exposed surfaces (Table 1) have approached 100%. The NRC Cooperative Study found the mean colony count reduction by ultraviolet irradiation varied from 31% to 74% in the 16 operating rooms of the five participating hospitals. Though the bactericidal effect found by the NRC Cooperative Study was somewhat less than has been consistently found by the Duke studies,* both studies nevertheless, demonstrate the effectiveness of ultraviolet irradiation in markedly reducing airborne and sedimented bacteria in the operating room.

* Because of an error in calibration over half of the operations in the NRC Cooperative Study were performed under less than what we have recommended [21, 22] as optimum bactericidal levels of ultraviolet intensity. Although the NRC Cooperative Study Report states that this had no effect on the ultimate infection results observed, it may explain in part the slightly lesser bactericidal effects obtained in the NRC Cooperative bacteriologic studies. In addition, the ultraviolet intensity in the peripheral parts of the operating rooms in the NRC Cooperative Study was less than that employed at Duke.

TABLE 6. *Cardiac Operations—Postoperative Infections (SBE, septicemia, wounds)*

Nelson *et al.*	1955–64	SBE 2.0% Septic 1.6% Wds. 1.2%	4.8%
Kittle and Reed	1957–60		15.0%
Reed	1960–64		2.0%
Yeh *et al.*	1957–66	SBE only	4.5%
Amoury *et al.*	1956–65	SBE only	2.3%
Geraci *et al.*	1963	SBE only	10.0%
Firor *et al.*	1963–66	Wound	5.7%
		SBE	3.2%
Attar *et al.*	1965 (pros. valv.)	Wound	8.1%
Sellers *et al.*	1965	Wound	8.0%

TABLE 7. *Comparison of Results—Duke and NRC Cooperative Study**

		With Ultraviolet Radiation				Without Ultraviolet Radiation			
		Total Number Operations	Infected No.	Infected %	Ratio Infections Duke: Cooperative Study	Total Number Operations	Infected No.	Infected %	Ratio Infections Duke: Cooperative Study
Refined clean**	Duke Med. Center Study	7046	22	0.3	1:9.2	2875	43	1.5	1:2.5
	Cooperative Study	3277	94	2.9		3379	128	3.8	
Other clean**	Duke Med. Center Study	1881	28	1.5	1:4.9	357	16	4.5	1:1.7
	Cooperative Study	2458	180	7.3		2576	192	7.5	
Contaminated**	Duke Med. Center Study	2913	125	4.3	1:3.6	1061	78	7.4	1:1.8
	Cooperative Study	1822	282	15.5		2029	275	13.6	
Total	Duke Med. Center Study	11,840	175	1.5	1:5.0	4293	137	3.2	1:2.3
	Cooperative Study	7,557	556	7.4		7984	595	7.5	

* Data taken from Postoperative Wound Infections: The influence of ultraviolet radiation of the operating room and of various other factors. Report of an Ad Hoc Committee of the Committee on Trauma NAS-NRC, Annals of Surgery **160**:2, 1, 1964.

** (1) CLEAN WOUNDS—Nontraumatic, uninfected operative wounds in which neither the respiratory the gastrointestinal, nor the urinary tract was entered.

a. Refined Clean
NRC—Elective, primarily closed and undrained wounds.
Duke—Same as above except
(1) includes clean thoracotomies with temporary intercostal drainage for fluid, and
(2) all clean, non elective operations.

b. Other Clean—not primarily closed, non elective, or mechanically drained through the incision or through a separate stab wound.

(2) Contaminated wounds—Here includes clean contaminated, contaminated and dirty.

TABLE 8. *NRC Cooperative Study*—Refined Clean Wounds—Improvement Infection Rate with Ultraviolet Radiation*

Institution	Infection % Total Operations	Infection % All Clean Operations	Improvement with UV Radiation Refined Clean
Hospital #4	3.0	1.2	22%
Hospital #1	4.8	2.7	44%
Hospital #2	7.0	4.8	36%
Hospital #3	11.7	8.6	15%
Hospital #5	8.8	6.1	15%

* Data taken from Postoperative Wound Infections: The influence of ultraviolet radiation of the operating room and of various other factors. Report of an Ad Hoc Committee of the Committee on Trauma NAS-NRC, Annals of Surgery 160:2, 1, 1964. Infection rates for all operations and for all clean ("refined" and "other clean" combined) operations are given for each hospital in the NRC Cooperative Study. Note that the hospitals with the lower infection rates showed the greater improvement with ultraviolet radiation.

Points of Agreement: Our past and these more recent Duke studies are in complete agreement with the NRC Cooperative Study in what we consider to be the four most important criteria in judging the value of ultraviolet irradiation. *Both studies agree* that:

(1) The air of occupied operating rooms without ultraviolet radiation is contaminated with bacteria of varying degrees of pathogenicity, particularly staphylococci, which sediment continuously on all exposed surfaces.

(2) Direct ultraviolet irradiation has a highly efficient bactericidal effect which rapidly kills all types of organisms and will markedly reduce any airborne bacterial contamination in the operating room.

(3) With suitable protection, direct ultraviolet irradiation is safe for operating room personnel and patients.

(4) With direct ultraviolet irradiation of the operating room of suitable intensity *there is a significant reduction in the number of postoperative wound infections following refined clean operations.*

Discussion

Probably the only part of the detailed 192 page NRC Cooperative Study report that has been read by most surgeons is the summary. In this is presented in three sentences the NRC Cooperative Study conclusions regarding the value of ultraviolet irradiation. These are contrary to some results given in the body of the report and are worded in such a way as to disparage the value and discourage the use of ultraviolet irradiation. We believe these concluding summary statements deserve further comment.

"The only category of wounds that benefited significantly from the use of ultraviolet irradiation was the refined clean group in which the average postoperative infection rate was reduced from 3.8% to 2.9%." An average drop of only 0.9% in the infection rate may not impress the casual reader but it represents an average improvement of 24% for the five hospitals with a range of improvement as high as 44% obtained by one of the cooperating hospitals. The NRC Cooperative Study found this decrease in infections following refined clean operations to be statistically significant. The body of the report states that "on the basis of the observed infection rate in irradiated refined clean wounds it may be concluded that about 30 of the patients would not have had wound infections if ultraviolet irradiation had been used for all of these refined clean cases." Though infection following any operation may be catastrophic, this reduction of infections is of tremendous importance in such refined clean operations as open heart surgery and transplantation procedures.

"Although ultraviolet irradiation reduced the number of airborne bacteria in the operating room, the wound infection rate in the entire series following operation was 7.4% in irradiated rooms and 7.5% in unirradiated rooms." Since ultraviolet irradiation could be used selectively for only those

operations in which it is beneficial, no logical reason is apparent to combine the results of all clean and contaminated operations, particularly when such a combination of data is used to imply the lack of value of ultraviolet irradiation after its value for refined clean operations has already been proved and so stated in the Cooperative Study report.

"Even this beneficial effect of ultraviolet irradiation which was confined to a category representing only 19.2% of all infections analyzed, was lost in the overall experience, offset by an apparent detrimental effect of irradiation in non-clean wounds." The statement that the beneficial effects observed were confined to a category representing only 19.2% of all infections analyzed does not inform the reader that this category comprised 43% of all operations analyzed in the Study including many of the large, clean operations where an infection can be most serious. The beneficial effect observed for a category comprising 43% of all operations should not be *"lost in the overall experience"* when the use of ultraviolet irradiation could be restricted to the clean cases. The concluding portion of this summary statement above regarding the beneficial effect of ultraviolet irradiation in refined clean wounds being *"offset by an apparent detrimental effect in non-clean wounds"* is not justified for it is contradicted in the text of the report where for these contaminated cases it is stated: *"The observed difference (with and without ultraviolet irradiation) is well within the limits which chance alone might reasonably produce."*

The distribution and radiant energy of ultraviolet irradiation employed in the operating rooms at Duke Hospital is such that it kills virtually all exposed bacteria that ordinarily sediment onto the sterile field or instruments from whatever source be it exhaled breath or floating lint. The viable bacteria count in the air in these irradiated rooms at almost any point at the level of the operating table and above averages a yield less than 1 colony per cubic foot of air, as compared to a yield of 30–50 colonies per cubic foot in the same occupied rooms without irradiation.

Of course, the mere elimination of the air as a vector for pathogenic organisms and the provision of more continuously sterile operating environmental surfaces through direct bactericidal irradiation does not prove by any means that all unexplained infections following clean operations originate from these sources of contamination. Because of the inability to prove the exact source and mode of infection following clean operations, the argu-

TABLE 9. *Variations in the Infection Rates for Each Category Listed for the Five Hospitals in the NRC Cooperative Study**

	With Ultraviolet Radiation		Control without Ultraviolet Radiation	
	Average %	Variations* in %	Average %	Variations* in %
Refined clean	2.9	(0.7 to 5.2)	3.8	(0.9 to 6.1)
Other clean	7.3	(2.7 to 10.0)	7.5	(1.4 to 13.6)
Clean contaminated	11.1	(2.3 to 22.0)	10.5	(4.4 to 12.6)
Contaminated	19.2	(6.1 to 33.3)	14.3	(3.7 to 26.1)
Dirty	30.9	(11.0 to 55.0)	26.3	(10.0 to 44.7)

* Based on data in charts 9–13, Postoperative Wound Infections: The influence of ultraviolet radiation of the operating room and of various other factors. Report of an Ad Hoc Committee of the Committee on Trauma NAS—NRC. Annals of Surgery, **160**:2, 1, 1964.

TABLE 10. *Cooperative Study NRC* 1959–1962—Infection Rates for Various Operative Procedures Indicating for the Five Hospitals the Average and the Wide Variations between Participating Hospitals*

	Total No. Operations	Infections		Variations between Hospitals in % of Infections
		Total No.	Average %	low high
Radical mastectomy	227	43	18.9	(6.9–40.9)
Exploratory laparotomy	321	25	7.8	(1.9–13.1)
Exploratory thoracotomy	137	8	5.8	(0.0– 9.3)
Excision bone lesion	109	6	5.5	(0.0–10.5)
Open reduction fracture	144	6	4.2	(0.0– 7.1)
Mitral valve procedure	120	5	4.2	(0.0– 5.2)
Herniorrhaphy—incisional or ventral	314	12	3.8	(1.5– 6.2)
Oophorectomy	136	5	3.7	(0.0– 7.0)
Partial mastectomy (excision lesion)	827	18	2.2	(0.0– 6.1)
Thyroidectomy	406	9	2.2	(0.0– 7.1)
Herniorrhaphy—inguinal, femoral, epigastric	1312	25	1.9	(0.8– 3.8)
Excision intervertebral disc	212	3	1.4	(0.0– 1.8)
Total Cases	4265	165	3.9	

* Data taken from Table 19—Postoperative Wound Infections: The influence of ultraviolet radiation of the operating room and of various other factors. Report of an Ad Hoc Committee of the Committee on Trauma NAS-NRC, Annals of Surgery, **160**:2, 1, 1964.

TABLE 11. *Classification of all Operations—Duke-NRC Cooperative Study**

Category	Number	Per Cent of All Operations	Per Cent of All Clean Operations
"Refined Clean"			
Duke Series	9,921	61.5	81.6
Cooperative Series	6,656	42.8	56.9
"Other Clean"			
Duke Series	2,238	13.9	18.4
Cooperative Series	5,034	32.4	43.1
Total Clean			
Duke Series	12,159	75.4	100
Cooperative Series	11,690	75.2	100
Total Contaminated			
Duke Series	3,974	24.6	
Cooperative Series	3,851	24.8	

* Data taken from Postoperative Wound Infections: The influence of ultraviolet radiation of the operating room and of various other factors. Report of an Ad Hoc Committee of the Committee on Trauma NAS-NRC Annals of Surgery, **160**:2, 1, 1964.

** For purposes of comparison we have considered here as contaminated the total of all categories other than refined clean and other clean. Thus for the NRC Cooperative Study this contaminated group includes clean-contaminated, contaminated and dirty.

ments by surgeons for and against the various possible sources and causes will obviously continue for sometime to come. Some will feel that most postoperative infections in clean wounds originate from viable organisms left on or washed up from the pores of the patient's skin; others will be sure they mainly follow breaks in sterile technic such as punctured rubber gloves, or that they are endogenous from some other infected site within the patient. Certainly, all of these sources and others that could be mentioned undoubtedly do contribute many infections. However, based upon our results from 30 years experience operating under direct ultraviolet irradiation, we feel (1) that *most* unexplained postoperative infections which occur after clean operations have their origin in the operating room while the wound is open; (2) that some of the principal sources of the offending bacteria are the mouths, throats and noses of the operating room occupants; and (3) that the organisms from these sources, along with those on lint and other floating particles, reach the sterile field, the instruments and the wound by way of continuous sedimentation through the air.

Though it may be impossible to prove these hypotheses, we and others have proven by many previously reported studies [15, 18, 19, 24, 39, 42] that ultraviolet irradiation will effectively eliminate this air route of spread of infective organisms and prevent their continuous sedimenting buildup on all exposed surfaces during operations of any duration.

It is difficult for us to escape the conviction that our use of direct ultraviolet irradiation has played a major role in keeping our postoperative infections, particularly following clean operations with large, long exposed wounds, to a very low level.

Conclusions

(1) Further data is presented regarding the use of direct ultraviolet irradiation in the operating room in the prevention of postoperative wound infections after clean operations.

(2) With direct ultraviolet irradiation the unexplained wound infection rate in over 23,000 clean operations at the Duke University Medical Center performed between 1936 and 1965 by the general surgical, thoracic, cardiac, orthopaedic and neurosurgical services has been 0.34%.

(3) In 878 consecutive cardiac operations (354 closed procedures, 524 open procedures) performed between January, 1950 and January, 1965, the wound infection rate was 0.6% and only one instance of early (5½ months) bacterial endocarditis occurred.

(4) In the evaluation of a single factor in the prevention of postoperative wound infections such as ultraviolet irradiation of the operating room, studies to be most meaningful should be confined to refined clean operations where there is the least likelihood of bacterial contamination from uncontrollable sources.

(5) Although we disagree with the wording of the summary conclusions of the NRC Cooperative Study report on ultraviolet irradiation, we are in complete agreement with their following findings:

(a) The air of occupied operating rooms without ultraviolet irradiation is contaminated with bacteria of varying degrees of pathogenicity, particularly staphylococci, which sediment continuously on all exposed surfaces.

(b) Direct ultraviolet irradiation has a highly efficient bactericidal effect which rapidly kills all types of organisms and will markedly reduce any airborne bacterial contamination in the operating room.

(c) With suitable protection, direct ultraviolet irradiation is safe for operating room personnel and patients.

(d) When surgery is performed in operating rooms directly irradiated with ultraviolet light of suitable intensity there is a significant reduction in the number of postoperative wound infections following refined clean operations.

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References

1. Amoury, R. A., Bowman, F. O., Jr. and Malm, J. R.: Endocarditis Associated with Intracardiac Prostheses. J. Thor. Cardiovas. Surg., **51**:36, 1966.
2. Attar, S., Saunders, E., McLaughlin, J. S., Scherlis, L. and Cowley, R. A.: Prosthetic Heart Valve Surgery: Evaluation of Early and Late Complications. Ann. Thor. Surg., **2**:52, 1966.
3. Barnes, B. A., Bahringer, G. E., Wheelock, F. C., Jr. and Wilkins, C. W., Jr.: Surgical Sepsis: An Analysis of Factors Associated with Sepsis in Two Operative Procedures, 1937–1957. New Eng. J. Med., **261**:351, 1959.
4. Browne, A. F., Ryan, E. A., Glassow, F. J., Martin, C. J. and Shouldice, E. E.: Staphylococcic Wound Infections. JAMA, **170**:1274, 1959.
5. Burke, J. F.: Identification of the Sources of Staphylococci Contaminating the Surgical Wound During Operation. Ann. Surg., **158**: 898, 1963.
6. Dineen, P. and Pearce, C.: A Ten Year Study on Wound Infections. Surg. Gynec. Obstet., **106**:453, 1958.
7. Firor, W. B.: Infection Followig Open Heart Surgery with Special Reference to the Role of Prophylactic Antibiotics. J. Thor. Cardiovas. Surg., **53**:371, 1967.
8. Ford, C. R. and Peterson, D. E.: The Efficiency of Surgical Face Masks. Amer. J. Surg., **106**:954, 1963.
9. Ford, C. R., Peterson, D. E. and Mitchell, C. R.: An Appraisal of the Role of Surgical Face Masks. Amer. J. Surg., **113**:787, 1967.
10. Geraci, J. E., Dale, A. and McGoon, D. C.: Bacterial Endocarditis and Endarteritis Following Cardiac Operations. Wis. Med J., **62**: 302, 1963.
11. Hart, D.: Sterilization of the Air in the Operating Room by Special Bactericidal Radiant Energy. J. Thor. Surg., **6**:45, 1936.
12. Hart, D.: Operation Room Infections. Arch. Surg., **34**:874, 1937.
13. Hart, D.: Sterilization of Air in Operating Room with Bactericidal Radiation, Comparative Analysis of 132 Individual Stages of Extrapleural Thoracoplasties Performed with Radiation and 110 Stages Performed without Radiation. J. Thor. Surg., **7**:525, 1938.
14. Hart, D.: Pathogenic Bacteria in the Air of Operating Rooms. Arch. Surg., **37**:521, 1938.
15. Hart, D.: Sterilization of the Air in the Operating Room with Bactericidal Radiation. Arch. Surg., **41**:334, 1940.
16. Hart, D.: Minimizing the Contamination of Operative Wounds. Surgical Clinics of North America, Vol. 22, p. 357, 1942.
17. Hart, D.: Bactericidal Ultraviolet Radiation in the Operating Room. Twenty-nine Year Study for Control of Infections. JAMA, **172**:1019, 1960.
18. Hart, D., Brown, I., Nicks, J., Pace, A. and Ewy, V.: Operating Facilities: Centralized Service Area-Improved, Simplified and Streamlined to Limit Bacterial Spread, Save Labor, Conserve Time, and Reduce Costs. Ann. Surg., **155**: 1962.
19. Hart, D., Devine, J. W. and Martin, D. W.: Bactericidal and Fungicidal Effect of Ultraviolet Radiation. Arch Surg., **32**:806, 1939.
20. Hart, D. and Gardner, C. E., Jr.: Sterilization of the Air in the Operative Region with Bactericidal Radiant Energy; Results of Its Use in 218 Operations. Trans. S. Surg. Assoc., **49**:376, 1937.
21. Hart, D. and Nicks, J.: Ultraviolet Radiation in the Operating Room. Arch. Surg., **82**:449, 1961.
22. Hart, D. and Sanger, P. W.: Effect on Wound Healing of Bactericidal Ultraviolet Radiation from a Special Unit. Arch. Surg., **38**:797, 1939.
23. Hart, D. and Schiebel, H. M.: Role of the Respiratory Tract in Contamination of Air. Arch. Surg., **38**:788, 1939.
24. Hart, D., Schiebel, H. M. and Sharp, D. G.: Disinfection of Air in Operating Room with Bactericidal Radiant Energy; Correlation of Intensity of Radiation with Its Bactericidal Effect. Tr. South. S. A., **54**:347, 1941.
25. Hart, D. and Upchurch, S. E.: Postoperative Temperature Reactions: Reductions Obtained by Sterilizing the Air with Bactericidal Radiant Energy. Ann. Surg., **110**:291, 1939.
26. Hart, D. and Upchurch, S. E.: "Unexplained" Infections in Clean Operative Wounds; The Importance of the Air as a Medium for the Transmission of Pathogenic Bacteria and Bactericidal Radiation as a Method of Control; Analysis of Over 5,000 Operations Covering a Period of 10½ Years. Ann. Sur., **114**:936, 1941.
27. Howe, C. W.: The Problem of Postoperative Wound Infections Caused by Staphylococcus Aureus. Ann. Surg., **146**:384, 1957.
28. Howe, C. W.: Bacterial Flora of Clean Wounds and Its Relation to Subsequent Sepsis. Amer. J. Surg., **107**:696, 1964.
29. Kittle, C. F. and Reed, W. A.: Antibiotics and Extracorporeal Circulation. J. Thor. Cardiovas. Surg., **41**:48, 1961.
30. Meleney, F. L.: Seasonal Incidence of Hemolytic Streptococcus in the Nose and Throat in Surgical Operating Personnel; Significance of Masking During Operation. JAMA, **88**: 392, 1927.

31. Meleney, F. L. and Stevens, F. A.: Postoperative Haemolytic Streptococcus Wound Infections and Their Relation to Haemolytic Streptococcus Carriers Among the Operating Personnel. Surg. Gynec. Obstet., **43**:338, 1926.
32. Nelson, R. M., Jenson, C. B., Peterson, C. A. and Sanders, B. C.: Effective Use of Prophylactic Antibiotics in Open Heart Surgery. Arch. Surg., **90**:731, 1965.
33. Nicholes, P. S.: Comparative Evaluation of a New Surgical Mask. Surg. Gynec. Obstet., **118**:579, 1964.
34. Reed, W. A.: Antibiotics in Cardiac Surgery. J. Thor. Cardiovas. Surg., **50**:888, 1965.
35. Report of an Ad Hoc Committee of the Committee on Trauma, Division Medical Sciences, NAS-NRC: Postoperative Wound Infections: The Influence of Ultraviolet Irradiation of the Operating Room and of Various Other Factors. Ann. Surg. (Suppl.), **160**:1–192, 1964.
36. Seeley, S. F.: Editorial: Influence of Ultraviolet Light on Postoperative Infections. JAMA, **189**:574, 1964.
37. Sellers, R. D., Ferlic, R. M., Sterns, L. P. and Lillehei, C. W.: Secundum Type Atrial Septal Defects: Early and Late Results of Surgical Repair Using Extracorporeal Circulation in 225 Patients. Surg., **59**:155, 1966.
38. Sharp, D. C.: A Quantitative Method of Determining the Lethal Effect of Ultraviolet Light on Bacteria Suspended in Air. J. Bact., **35**:589, 1938.
39. Sharp, D. C.: Lethal Action of Short Ultraviolet Rays on Several Common Pathogenic Bacteria. J. Bact., **37**:447, 1939.
40. Sharp, D. C.: Effect of Ultraviolet Light on Bacteria Suspended in Air. J. Bact., **39**:535, 1940.
41. Walker, I. J.: How Can We Determine the Efficiency of the Surgical Mask? Surg. Gynec. Obstet., **50**:266, 1930.
42. Wells, W. F. and Wells, N. W.: Air-borne Infections; Sanitary Control. JAMA, **107**:1698, 1805, 1936.
43. Williams, R. E. O., Jevons, M. P., Shooter, R. A., Hunter, C. J. W., Girling, J. A., Griffith, J. D. and Taylor, G. W.: Nasal Staphylococci and Sepsis in Hospital Patients. Brit. Med. J., **2**:658, 1959.
44. Yeh, T. J., Anabtawi, I. N., Cornett, V. E., White, A., Stern, W. H. and Ellison, R. G.: Bacterial Endocarditis Following Open Heart Surgery. Ann. Thor. Surg., **3**:29, 1967.

Discussion

Dr. Barnes Woodhall (Durham): It is an honor to be asked to comment on this paper, the end result of two decades and more of experience and interest in the prevention of postoperative infection.

I speak only from the point of view of our neurological service. Happily, I know nothing about major cardiac surgery or its complications. I would say, however, when I came to Duke University in 1937, I was reasonably confident of my surgical technic, and decided not to use ultraviolet radiation. Dr. Hart accepted my recalcitrance in this matter in his usual gentle manner. Four months later I quietly turned on the radiation, and since that time I have never operated on a patient in our hospital without such protection.

Since 1946, two to five staff surgeons (people like myself), five to seven graduate students with various periods of experience in the operating room, two interns (first-year people), three nurses, and two orderlies have formed both a static and a very shifting population of some size, who have been in direct contact over these years with these patients whom I shall discuss. This certainly provided a fertile source for all types of potential infections, and certainly a very strong and dangerous source of upper respiratory infections.

As Dr. Hart indicated in the body of his paper, since 1937 there were 8396 so-called clean neurosurgical cases, and according to his data these were operated upon by and with the aid of the group I just mentioned. The resulting incidence of postoperative infections was 0.333% (33/100 of 1%).

Previously my colleague Dr. Guy Odom and myself had separately made three other studies in a smaller series of cases. In one study the incidence of postoperative infection with these same people was found to be 0.6% (6/10 of 1%). As we reviewed the cases, we found there was an unusual incidence of infection in clean cases in which the extradural space had been drained by stab wounds to prevent (hopefully) postoperative hematoma. This was a technic widely used 10–15 years ago; and of course we discarded it. But it is a very good example of the values in continuing this type of postoperative infection study throughout the years.

Also, Guy Odom and I have studied the effect of ultraviolet radiation (another controversial matter) upon both the dry and wet primate brain, and there is no superimposed damage to neural tissue using customary neurosurgical technics. These studies were also reviewed by William Cone and Wilder Penfield, in Montreal, and indeed Dr. Penfield began to use ultraviolet radi-