The Contribution of a Bacterially Isolated Environment to the Prevention of Infection in Seriously Burned Patients

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A new system of patient protection from bacterial cross-infection called the Bacteria Controlled Nursing Unit (BCNU) is described, based on strict environmental control of a 6 × 10 foot area surrounding the patient's bed rather than the entire patient room or isolation ward, plus the ability to deliver all medical care without entering the protective environment and maintaining all monitoring, life support, and i.v. equipment outside the controlled environment. The clinical effectiveness of this system in the treatment of burn patients has been studied and compared with the effectiveness of single room isolation on a burn isolation ward and conventional isolation techniques on an open burn ward. The studies show that the BCNU is significantly more effective in preventing bacterial cross-contamination than conventional precautions (3.8% vs. 13.1%, $P < 0.001$; and 8% vs. 22.8%, $P < 0.001$) over a two and four week period. The studies also indicate that there was a significant increase in the probability of infection occurring following cross-contamination than occurring after auto-contamination (65% vs. 39%, $P < 0.005$), emphasizing the importance of preventing cross-contamination in reducing the overall infection rate in seriously burned patients. Clinical evaluation of the unit proved it to be compatible with intensive nursing and medical care without increasing the nurse to patient ratio. The unit provided sufficient control of bacterial cross-infection to allow reduction in mortality and improvement in the effectiveness of burn care through routine prompt excision of burn eschar and immediate wound closure to be carried out in severe and massively burned patients without a limiting threat of bacterial burn wound sepsis.

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DECREASED TREATMENT EFFECTIVENESS and an increase in mortality are the hallmarks of hospital acquired infection. In addition, the development of surgical treatment for diseases theoretically amenable to operative repair is retarded by the threat of bacterial infection. This is especially true in those areas where surgery is used in conjunction with therapeutic manipulation of the immunologic system (*i.e.* immunosuppression—cancer chemotherapy). In this way, the development of therapy for serious thermal injury has been retarded because logical plans for the improvement of burn care through early and extensive surgical repair cannot be realized without an effective method to prevent sepsis following surgical treatment. The work and clinical experience described here represent an attempt to design and assess the effectiveness of a system of complete bacteriologic isolation for highly susceptible or infectious patients during their acute burn illness and surgical repair. The system is based on strict environmental control of a 6 × 10 foot area immediately surrounding the patient's bed, rather than the entire patient's room or isolation ward, plus the ability to deliver all medical care without entering the protected environment and maintain all monitoring, life support, and i.v. equipment outside the controlled environment so that the bacteria carried by the staff or equipment do not contaminate the patient, nor does the patient contaminate personnel or equipment. This individual patient protective and controlled environment is called the Bacteria Controlled Nursing Unit (BCNU) and is an integral part of an overall plan to extend the surgical care of the seriously burned patient to prompt excision of the entire extent of the burn eschar and immediate wound closure, including immunosuppression and allograft closure of the most extensive burn injuries. The original engineering work was carried out at the Massachusetts General Hospital (MGH) and extensive clinical experience has been gained at the Shriners Burns Institute in Boston (SBI).

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Materials and Methods

An attempt is made to document the effectiveness of the BCNU in protecting patients from bacterial complication by recording the rate of bacterial con-

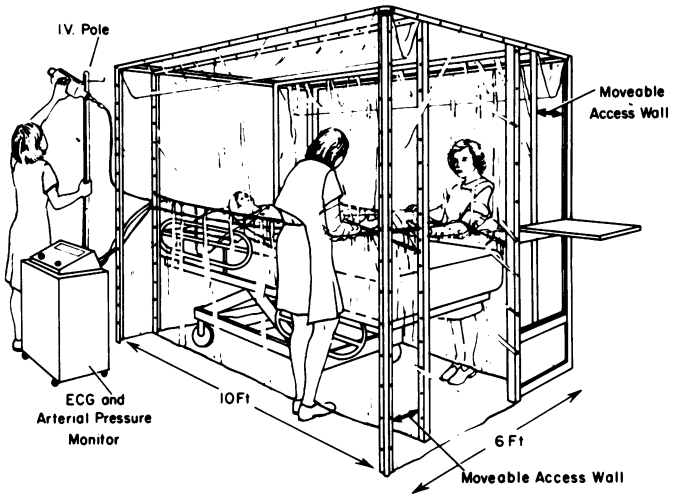

FIG. 1. Schematic drawing of a Bacteria Controlled Nursing Unit. A 6 × 10 foot area is surrounded by transparent plastic curtain walls. The entire area is continuously washed by down flow of bacteria-free air. Patient care is delivered through the two movable side access walls. All personnel, intravenous, life support and monitoring equipment function from outside the sterile environment eliminating the need for protective clothing and instrument decontamination.

tamination, its bacterial type, and its potential for invasive infection. These rates are then compared with rates of patient protection afforded by two widely used methods of conventional isolation: single room isolation precautions on a strict isolation burn unit and isolation precautions on an open ward. The study was carried out between 1970 and 1976 at the SBI and July, 1974–November, 1976 at the MGH.

Patient Groups Studied

Three groups of burned patients were studied and were segregated according to the type of bacterial isolation procedures that were used to protect them from bacterial contamination.

Group 1. Patients receiving environmental protection in the BCNU. This group consists of 264 consecutive patients admitted to the Shriners Burns Institute, Boston with burns greater than 10% of their body surface area (BSA), who were admitted directly to the BCNU, and who remained in the protective environment for at least one week (the average length of stay in the BCNU was 31 days). These patients' ages ranged from six months to 16 years, with an average age of seven years. Average burn size 42.6% BSA; average third degree component 26.7% BSA. There were 155 males and 109 females.

Group 2. This group consists of patients receiving burn care in single room isolation on a strict burn isolation ward. This group consists of 214 consecutive patients admitted to the burn service of the Massachusetts General Hospital whose burn injury exceeded ten per cent of the BSA; age range 16 to 86 years; average 45.4 years; average burn size 39.2% BSA; average third degree component 26% BSA—164 males, 50 females.

Group 3. Group 3 consists of patients receiving conventional isolation protection on an open acute burn ward. Two hundred twenty-two consecutive patients admitted to the Shriners Burns Institute, Boston with burns greater than 10% BSA who were admitted directly to the ward at a time when environmental control units were not available are included in this group. Their ages range from two months to 16 years, with average burn size 19.6% BSA, and average third degree component 6.8% BSA—145 males, 77 females.

Because of human studies considerations and hospital admitting policies, it was impossible to obtain strictly comparable groups of patients in the BCNU study group (Group 1) and the two control groups (groups 2 and 3). The study group and Group 3 are made up of children of comparable age, but the overall burn size and extent of third degree injury were considerably greater for those patients in Group 1 than in Group 3 because larger and more extensive injuries were always placed in the controlled environment of the BCNU if available rather than on the open ward. Group 2 differed from both of the above groups in that although the burn size was comparable to that seen in Group 1, it consisted of burned patients 16 years of age and older. This difference occurred because only children are admitted to the Burns Institute and only adults to the burn unit at the Massachusetts General Hospital. It was, however, felt important to compare the effectiveness of the Bacteria Controlled Unit with a strict, single room isolation burn ward in a general way.

Isolation Techniques and Facilities Described by Patient Group Treated

Each of the three groups of patients were cared for using one of the following methods of isolation protection.

Group 1 Patients; Isolation Facilities

The BCNU (Figs. 1 and 2) is a 6 × 10 foot area on an open ward requiring no more floor space than a regular bed. The unit is separated from the ward by a transparent plastic curtain wall. The entire area within the curtain walls is continuously washed with a ceiling to floor, piston-like ("laminar") flow of bacteria free air. The air temperature and relative humidity in the unit can be accurately controlled at the level most beneficial to the patients' metabolic state (usually 31.5°,

90% relative humidity) without altering the usual working temperature or humidity 22°; 50% R.H.) of the ward. The side walls (access walls) are movable to allow extension away from the bed for patient ambulation or pushing close to the bedside for delivery of care (Fig. 1). These access walls are constructed with two overlapping panels of transparent plastic, one extending down from the ceiling, the other extending up from the floor. The free edges of these panels generously overlap just above the level of the patient, forming a simple maze between the outside to inside the unit. The free edges of the panels at the overlap are supported by an elastic cord. All medical and nursing care, monitoring, and life support are carried out through the access walls so that personnel and equipment do not enter the patient's protective environment, as described in isolation techniques section below.

Isolation Techniques

Four Bacteria Controlled Units are clustered at one end of an open 12 bed, critical care ward and occupy the same space as four unprotected beds would take. No effort is made to "isolate" this critical care ward itself. Staff, visitors, and relatives are allowed on the ward without protective clothing, masks, etc. To deliver medical care to patients in the unit personnel put on a disposable apron and shoulder length plastic gauntlets and traverse the access wall maze with their hands and arms (Fig. 2). The elasticized edges of the overlapped access wall panels form a seal, preventing gross communication between inside and outside the unit. The continuous downflow of sterile air increases the effectiveness of this compromised seal around arms or entering supplies by entraining any bacterial particle entering and carrying it to the floor. The two systems (downflow and curtain wall) provide an effective and reliable barrier against cross contamination.

Sterile medical care within the unit is delivered exactly as sterile wound dressings, trachael aspiration, or Foley catheter insertions are carried out on the ward, except that the entire procedure goes on inside the unit with the sterile parts of the procedure beginning with the hands and arms of the personnel covered with plastic gauntlets rather than just being washed. Inside the unit sterile packs are open and sterile gloves are put on over the gauntlets before the procedure is carried out. Dressings and other procedures are usually carried out with teams of two to four medical personnel. No attempt is made to sterilize food, bed clothing, etc. before it enters the unit. Wounds are protected from bacteria within the unit by topical $AgNO_3$ dressings and sterile wound techniques.

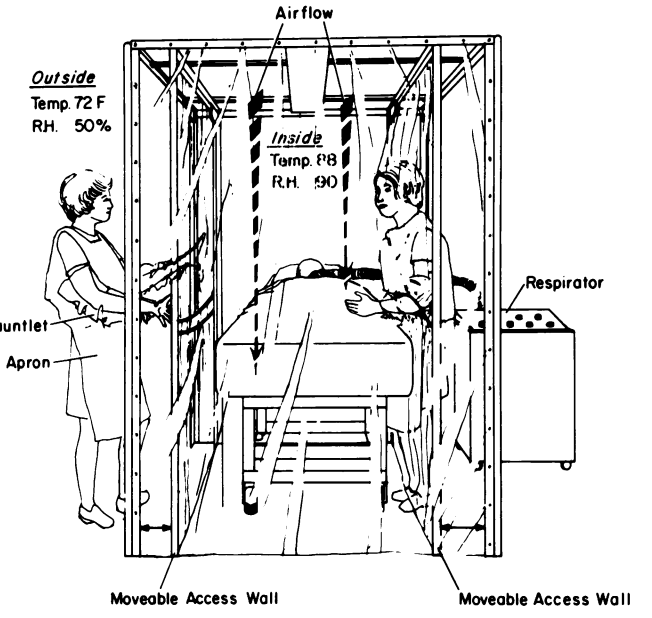

FIG. 2. Medical care being delivered to a patient housed in the Bacteria Controlled Nursing Unit. All equipment, such as the respirator shown, is maintained outside of the unit greatly reducing the probability of cross-contamination. The pattern of air flow from ceiling to floor is shown by arrows. The nurse is shown carrying out a dressing change. She dons shoulder length gauntlets outside the unit and gains access to the unit by traversing the simple maze created by the overlapped panels of the access wall.

All intravenous bottles and monitoring or life support equipment are outside the unit so that they can be adjusted or maintained without requiring personnel to don protective clothing. Intravenous tubing, arterial or Swan-Ganz lines, respirator conduit, EKG leads, etc. are led through the panel port at the head of the bed (Fig. 1) to the patient.

Group 2 Patients; Isolation Facilities

Isolation facilities consist of a dedicated, strict isolation burn unit on the top floor of the Massachusetts General Hospital. Access is limited to burn unit staff and two patient visitors at a time. All patients are housed in single rooms with hand washing facilities in the room and their own toilet facilities connecting. All were separated from the hall by a solid door plus a screen door.

Isolation Techniques

Caps and masks are required on entering the ward. Full protective clothing is worn in each patient room and changed if personnel goes from patient to patient. All dressings and procedures are caried out with sterile gloves and equipment, using sterile dressing techniques. Patients needing intensive nursing care or monitoring were nursed with a "special" nurse on each

shift who remained in the patient's room at all times and had no contect with other patients. Food was served on disposable utensils. All trash, bedding, dressings, etc. are double bagged as they leave the patient's room.

Group 3 Patients; Isolation Facilities

Isolation facilities consisted of the eight non-protected beds on the 12-bed, critical care ward of the Shriners Burns Institute. A central nursing station served both protected and non-protected beds. Hand washing and toilet facilities were located between beds and shared with neighboring patients.

Isolation Techniques

Patients are maintained on bed rest. Personnel and visitors wear protective clothing in the form of caps and gowns and/or aprons. Masks and caps and sterile gloves are worn during dressing changes. Strict sterile techniques were used for all procedures. Food is served on disposable utensils.

Burn Treatment

All three groups of patients received the same type of burn care carried out under the direction of the same professional staff.[8] 0.5% aqueous silver nitrate was used routinely as the topical agent[18] to all areas of the body except the face and perineum. Silver sulfadiazine was used on these areas. The basic mode of therapy was prompt excision of burn eschar following the injury and immediate wound closure.[6] All but a few patients were closed with autografts immediately following excision. However, in children (Group 1) and adults (Group 2) who had sustained third degree burns in excess of 35% of their BSA, initial wound closure was accomplished by a combination of skin allograft and autograft. The allografted component was replaced by autograft in two to three weeks. Nineteen children with burns over 80% BSA with third degree component over 70% BSA were treated with temporary skin transplantation and immunosuppression.[7,9] All immunosuppressed patients were nursed in the BCNU. Penicillin (300,000 U i.m.) was given to all patients acutely burned for the first three days following admission. No further antibiotic therapy was given to any patient unless there was evidence of clinical bacterial invasion, usually manifested by a positive blood culture. Preventive antibiotics were given to all patients immediately before operation and discontinued the day following operation. The antibiotic used was chosen on the basis of sensitivity studies of the predominant wound flora, if present.

Definition of Auto- and Cross-bacterial Contamination and Infection

Bacterial contamination of the patients in this study is divided into cross-contamination or auto-contamination, according to whether the bacteria came from the patient himself (auto) or from the environment (cross). Cross-contamination is defined as bacterial contamination of the burn wound, with an identified strain of a bacterial species (serotype, biotype, etc) different from those strains carried in any site by the patient on admission to the Shriners Burns Institute or Massachusetts General Hospital. Auto-infection is defined as bacterial contamination of the burn wound, with a bacterial strain carried by the patient on admission. Bacterial strains were identified by biotyping, serotyping, phage typing, and antibiogram, as noted below in the section on bacteriologic techniques. All organisms recovered from the wound or urinary tract are considered contaminating strains. Bacteria isolated from the respiratory tract, other than normal flora, are considered contaminating strains. Bacterial strains isolated from the burn wound after the first routine culture were considered cross-contaminating organisms.

Bacterial contamination is defined as the isolation of bacteria from the burn wound, respiratory or urinary tract and included those cases where there was evidence of bacterial invasion or inflammation. Burn wound infection was defined as a general clinical deterioration of the patient plus positive blood culture and/or evidence of bacterial invasion of the viable layers of the burn wound. For the most part, bacteria isolated from contaminated but not infected patients are rare to moderate in numbers. Bacterial cultures in patients with infection usually showed abundant growth.

Bacteriologic Examinations

All patients were cultured on admission and on a routine basis two times a week thereafter unless the clinical indication prompted additional culture taking. In addition to the cultures of the burn wound and nasopharynx culture, sputum, urine and stool specimens were obtained. Patients in Groups 1 and 3, treated in the Burns Institute, were cultured, with an average of 15 sites per patient. Patients treated at the Massachusetts General Hospital were cultured with an average of six culture sites per patient.

Bacteriologic Techniques

Enteric strains were only typed from patients in Groups 1 and 3 because it was not possible to type enteric strains from patients in Group 2. Therefore in

TABLE 1. *Distribution of Patients by Type of Isolation Protection Received*

	Group 1 Bacteria Controlled Environment (BCNU) 1970–1976	Group 2 Single Room (MGH) 7/74–11/76	Group 3 Open Ward (SBI) 1970–1976
Total patients	264	214	222
Flame burns	214	147	158
Scalds	50	67	64
Age	6 mos–16 yrs	16–86 yrs	2 mos–16 yrs
Sex	155 ♂, 109 ♀	164 ♂, 50 ♀	145 ♂, 77 ♀
% BSA burned	42.6	39.2	19.6
% 3° component	26.7	26.0	6.8

Group 2, the auto-contamination rate with enteric bacteria includes all instances where the same species were found on the wound and in the G.I. tract.

Gram positive cocci were isolated and identified by standard methods,[15] and gram negative bacilli were identified by varying methods, as follows. From 1970 to 1974, differentiation of enteric bacilli was accomplished by the methods of Edwards and Ewing.[11,15] Beginning in 1975 to the present all gram negative bacilli have been identified by the API 2-Enterbacteriaceae method.[13,20] Pseudomonas and unusual gram negative bacilli were identified by use of the methods of King and others.[12,15] Standard methods were used to identify anaerobes,[2,15] with the use of the Gas-Pak jar; and yeast were also identified by standard methods, plus serotyping of *C. albicans*.[2,15] The Bauer-Kirby method was used for antibiogram studies.[3,15] Sensitive or resistant patterns of bacteria obtained at different sites were studied to further differentiate strains of microorganisms.

Results

Of the 728 consecutive acute patients considered for the study who had flame or scald burns >10% BSA, 700 met the proposed criteria and are included. Four hundred eighty-six were admitted to the SBI (1970–1976) while 214 were admitted to the MGH (July 1974–November 1975). Ninety-four per cent of all patients were admitted within six days of injury. Patients were excluded because they died within seven days following admission, or were transferred from the isolation category to which they were admitted within seven days of admission. The character of the three groups of patients studied is outlined in Table 1. There were 264 who received burn care for at least one week in the BCNU (Group 1). The length of stay in the unit ranged from seven to 86 days with an average patient stay of 31 days. The outer limit of the range for all three groups indicated the time the burn wound was clinically beyond risk of invasive infection. Two hundred fourteen patients were admitted to single room isolation (Group 2) with a length of wound risk between seven and 112 days (average 38 days). Two hundred twenty-two patients received isolation precautions on an open burn ward (Group 3) with the length of wound risk between seven and 62 days (average 22 days). Table 1 shows that the population of patients in Groups 1 and 3 are comparable by age and sex, but that the average burn size is double (42.6% to 19.6%), and the 3° burn component is in excess of three times more extensive (26.7% to 6.8% in Group 1 compared with Group 3. There are no significant differences between Group 1 and Group 2 patients in regard to burn size and component of 3° burn.

The data concerning the rate of bacterial contamination of the burn wound for the first two weeks, and the cumulative contamination over the first four weeks following admission in each of the three groups of patients is presented in Table 2 and is divided into cross- and auto-contamination. In all groups contamination includes those wounds with a positive bacterial culture only, plus bacterially infected wounds. Because it was not possible to type enteric strains in Group 2 patients, the rate of auto-contamination in the sites monitored in this group may be overestimated in relation to cross-contamination since all enteric bacteria appearing on the wound were considered auto-contaminating if the bac-

TABLE 2. *Rate of Contamination of Patients*

	Group 1 Bacteria Controlled Environment (BCNU) 1970–1976		Group 2 Single Room (MGH) 7/74–11/76		Group 3 Open Ward (SBI) 1970–1976	
	2 Weeks	4 Weeks	2 Weeks	4 Weeks	2 Weeks	4 Weeks
Burn wound						
% Cross contamination	3.8*	8.0†	32	86	13.1*	22.7†
% Autocontamination	14.1	75.8	18	88	15.8	67.0

* ↔ * $p < 0.001$; † ↔ † $p < 0.001$.

TABLE 3. *Probability of Burn Wound Infection Following Contamination of Patients in BCNU*

	Total Episodes	Number of Infections	%
Cross contamination	20	13/20	65
Autocontamination	200	78/200	39

$p < 0.05$.

terial species was present in the G.I. tract. This was done in an attempt to avoid overestimating the rate of cross-contamination in this group.

Three point eight per cent (3.8%) of patients receiving burn care in the BCNU (Group 1) were cross-contaminated during the first two weeks in the unit, and eight per cent were cross-contaminated over the first four weeks. When the cross-contamination rate in Group 1 is compared to Groups 2 and 3, marked differences are seen (Table 2). The rate of cross-contamination in Group 2 at both two and four weeks following admission is very much larger (32% in two weeks and 86% in four weeks) than that seen in Group 1. However the difference in patient population between the two groups allows only broad conclusions to be drawn. When the cross-contamination rate is compared between Groups 1 and 3 where the patient population is comparable, there is a significant increase ($p < 0.001$ at both times studied) in the rate seen in Group 3 (13.1% at two weeks and 22.7% in four weeks) over that seen in Group 1 (3.8% and eight per cent).

Auto-contamination of the burn wound did not follow the same pattern as cross-contamination. The marked reduction in cross-contamination seen in Group 1 was not present in the auto-contamination rate. Auto-contamination of the burn wound during the first two weeks was present in 14.1% of patients and rose to 75.8% in four weeks. In Group 2 patients the auto-contamination rate was 18% in two weeks and 88% in four weeks. In Group 3 it was 15.8% and 67.0%, respectively. Bacteria were not grown from the wounds at any time during the four week study period in 15% of Group 1 patients, 5% of Group 2 Patients, and 13% of Group 3 patients. Uniformly these patients had relatively small burns which were located exclusively above the waist. A large proportion of these patients were scalds.

Table 3 demonstrates the probability of developing an invasive burn wound infection following autobacterial contamination of the burn wound, as opposed to cross-contamination for patients housed in the BCNU. For all organisms there is a significant increase in the infectious rate following cross-contamination (65%, $p < 0.05$) over auto-contamination (39%) of the burn wound.

The routes of auto-contamination for patients housed in the BCNU are outlined in Table 4. As the table demonstrates, the gi tract is by far the most frequent source of wound auto-contamination.

The rate at which certain bacterial species contaminate the burn wounds in a subset of patients with burns covering 25 to 90% of their body surfaces is outlined in Table 5. Fifty patients housed in single room isolation are compared to 105 patients housed in the BCNU. The overall number of episodes of clinical infection is recorded for each group. The data show that bacterial species not usually carried in the gi tract predominate in the patients housed in single rooms while those common to the gi tract predominate in patients housed in the BCNU. There is an accompanying increase in the clinical infection rate in patients housed in single rooms (28%) compared with patients in the BCNU (69%).

Discussion

That there has been an increase in the effectiveness in treating serious disease brought about through the development of the concepts of concentrated medical care which have led to the formation of the modern hospital may be stated without question. However, hand in hand with this increased therapeutic efficiency has come an increase in the problems of hospital related spread of infectious disease, of which the bacterial are the most prominent.

In the case of surgery the development of the "hospital concept" has been fundamental to advance, but

TABLE 4. *Routes of Autocontamination of Patients Housed in Bacteria Controlled Nursing Units*

Autocontamination Route	Per cent of Overall Episodes
G.I. tract → wound	72
Resp. tract → wound	16
Wound → resp. tract	8
G.I. tract → resp. tract	4

TABLE 5. *Frequency of Bacterial Strains Contaminating Burn Wounds (Subset: 25–90% BSA)*

	Bacteria Controlled Environment (BCNU) 105 Patients	Single Room 50 Patients
	(% Patients' Wound Positive)	
Pseudomonas	18	66
Klebsiella	32	68
Enterococci	28	58
Episodes of infection	6	14

the parallel development of an increased probability of producing bacterial disease, particularly in the area of open trauma or the surgical wound has, at least at one time during the development of surgery, threatened to eliminate it as a general form of treatment.[21] The improved ability to prevent bacterial infections brought about through the discovery of bacteria as the cause of sepsis, followed by the Listerian concept of antisepsis, have led to a workable, although not optimal, control of post-surgical infection through the development of aseptic techniques and sterilization technology.[5] It is important to recognize that by far the most effective methods for preventing sepsis in surgical patients are those related to infections that are generated in the operating room and not to those bacterial infections which are produced on the ward or other areas of the hospital. Although the problem of cross infection on the ward has long been recognized as a serious threat to the effectiveness of in-hospital medical care, no satisfactory solution has been evolved. The body of procedures called "Isolation Precautions"[1] which have been evolved in an attempt to control this risk, although satisfactory for the majority of patients at risk, have proven ineffective and extraordinarily inefficient for the small group of patients at high risk of acquiring bacterial disease during hospitalization. Severely burned patients are part of this group of patients at high risk.

The work reported is an attempt to assess the effectiveness of a clinical system both clinically and economically for protecting highly susceptible patients from cross-infection. This system is based on two principles: first, highly effective environmental control in the area immediately surrounding the patient's bed,[14] rather than isolating a whole room or ward; and second, the ability to deliver all medical care and maintain all monitoring, life support and intravenous equipment outside the controlled environment so that personnel or equipment do not contaminate the patient nor are personnel and equipment contaminated by the patient.

The present-day therapy of burn injury is seriously hampered by the almost inevitable bacterial cross-contamination of the burn wound.[17,19] A major portion of therapeutic effort is placed on efforts to prevent the development of infection following contamination rather than on directly closing the open wound. Improvements in burn care, therefore, would be achieved if a more effective method of prevention of burn wound contamination were available. The use of topical antibacterial therapy has decreased the rate of burn wound sepsis and decreased the mortality for moderate sized burn injury[16,18] but, and perhaps most important, it has not made burn care more effective as judged by the length of hospital stay for any size burn injury. Evaluation of the controlled environment described demonstrates that the rates of bacterial cross-contamination and infection are markedly reduced for patients in the BCNU (Group 1) as compared with patients nursed in single rooms on an isolated burn unit (Group 2), or patients protected from cross-contamination by classic isolation precautions on an open ward (Group 3). The decrease in cross-contamination seen between Group 1 and Group 3 ($p < 0.001$) is even more striking when it is recognized that patients in Group 1 have very much larger and deeper burn injuries than patients in Group 3. It is difficult to draw exact conclusions between Groups 1 and 2 because the patient population differed in age even though burn sizes are comparable. However, our experience indicates that the rate of bacterial cross-infection does not differ significantly between children and adults when both are treated on the same ward.

A further point of importance in reducing the risk of burn wound infection is the identification and protection from those bacterial strains most likely to cause infection. Table 3 demonstrates that in Group 1 patients infection was almost twice as likely to occur if the burn wound was cross-contaminated as it was if it were auto-contaminated ($p < 0.05$). It is not possible to give an exact reason for this but presumably host resistance is more effective in protecting against strains of bacteria that make up the patients' normal flora than for cross-contaminating strains to which the immunologic system of the patient has never been exposed. These data, however, indicate the importance of preventing cross-contamination, even if it is impossible to prevent auto-contamination. The importance of preventing cross-contamination is further emphasized when the pattern of bacterial strains causing cross-contamination is examined. This has been done (Table 5) in a subset of patients with burn sizes between 25 and 90% BSA. The bacterial strains seen in the BCNU are compared with those seen in patients housed in a single room on a burn isolation ward. It is evident that species, particularly pseudomonas, not part of normal G.I. tract predominate in conventionally isolated patients while they make up a minor part of contaminating species in patients housed in the BCNU. Further, these data are consistent with the concept that virulent strains of bacteria are passed from patient to patient and remain in a conventional isolation ward over long periods of time. Experience in burn units with Providencia throughout the country is typical of this problem.[10] Our experience indicates that these strains (including Providencia) appear periodically on the ward where patients are housed in the BCNU but rapidly disappear.

No special precautions against cross-contamination

are taken in moving patients to and from the OR or in the operating room itself. Patients in the three groups studied were all treated with prompt primary excision and immediate wound closure. In the case of large burns, this was done in multiple operative procedures, and in all but the patients with massive burns was usually completed within the first seven days post-injury. It is impossible to detect what portion of cross-contamination occurred when the patients were temporarily removed from the protective environment of the BCNU so that all cross-contamination is considered to occur within the unit. However, the contribution of operation may be significant.

The overall data appear consistent with the concept that a system of highly effective protection against cross-contamination of seriously burned patients, such as the BCNU, is not only a considerable, immediate benefit to the individual patient but, in addition, and equally important, that there is a long term advantage to the entire patient population of the burn unit. The effective isolation of all heavily contaminated or highly susceptible patients results in a ward bacteriology for low risk burn patients that is equivalent to a clean surgical ward, thereby considerably decreasing the overall risk of infection. Virulent strains, although periodically seen, disappear quickly and do not spread beyond one BCNU to threaten the entire ward.

The rate of auto-contamination of the burn wound, particularly from the G.I. tract (Table 4), in patients treated in the controlled environment of the BCNU is not different from that seen on the open ward. This finding is expected since no attempt was made to sterilize the patients' G.I. or respiratory tracts or skin on admission, and no attempt was made to sterilize the interiors of the unit. Although it is tempting to predict what benefits would be achieved if auto-contamination could be controlled as effectively as cross-contamination, it is not practically possible to sterilize the patient and the logistic problems of maintaining the inside of the unit sterile do not appear to be cost effective.

Although no studies concerning the effectiveness of the BCNU in preventing viral cross-infection were carried out, several inadvertent events provide some information. During the overall study there were four separate occasions where children were admitted to a BCNU with an acute burn injury, and developed clinical measles (two cases) or chicken pox (two cases) two to four days following admission. Although approximately 50% of the nursing personnel and the large majority of patients on the ward at the time were susceptible by history, in no instance was there a secondary case of the viral disease. In one instance the child in the adjacent unit (eight feet distance between beds) was being immunosuppressed with imuran with a wbc $< 2{,}000$ at the time the diagnosis of measles was evident.

This is clearly an improvement over older methods of isolation as previous studies have shown.[4] The patient and parents accepted the unit without difficulty. No psychologic problems were encountered that could be related to the unit itself, not encountered in conventional isolation. There was a considerable advantage of having the child even though in the unit on the open ward rather than in a single room, to facilitate medical observation and treatment and to allow parents to visit without mask or other protective clothing.

The ability to control both temperature and humidity within the unit at a level most advantageous to the patient, while maintaining the working temperature and humidity of the ward at comfort levels for the staff, has proven an important advantage not only for the patient's treatment, but for the efficiency of the patient care staff as well. Because the units are on the open ward, patients, even those requiring intensive care, can be nursed with the team concept, avoiding the need for a "special" nurse. Nurse to patient ratios, therefore, are kept well below one to one on the unit. The delivery of medical-nursing care or physiotherapy is a little more cumbersome with patients in the protected environment than on the ward. However, no increased personnel or specialized equipment have been required because of the BCNU. The advantages of the open ward for patient observation and team patient care, the absence of protective clothing or other restrictions on the ward itself, and the ability to adjust i.v. drips, monitors, and respirators from the ward without donning gowns, etc. between each patient more than make up for the minor inconveniences presented by the plastic access walls. The delivery of patient observation and care is not inhibited by the awkwardness of the system as it is in single room isolation—a system which requires complex changes of protective clothing between each patient encounter.

From the economic point of view, the cost of curtain wall replacement every four to six months is offset by the reduction in cost of protective clothing and in costs of decontamination, of monitoring and life support equipment if it is contaminated by the patient. However, by far the most important savings are those that accrue from the reduction of infection rates and shortening of hospital stay.

Both the clinical experience gained through extensive on-line use of the BCNU and the data concerning its effectiveness in preventing bacterial cross-contamination provide strong evidence that it is of great importance to the most effective care of the severely burned patient. In our experience it has allowed the safe application of prompt eschar excision and immedi-

ate wound closure which has been shown to reduce burn mortality and increase the effectiveness of treatment as judged by shortening the length of hospital stay.[6] It has also allowed the extension of these techniques to massively burned patients using temporary allograft transplantation and immunosuppression, to be carried out without the limiting threat of bacterial infection in the immunologically modified burn patient.

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Discussion

Dr. Stanley M. Levenson (Bronx, New York): The clear demonstration in this report of the effectiveness of a mechanical barrier system for minimizing bacterial cross-contamination and lessening clinical infection in burn patients, without sacrificing the ability to provide all aspects of the demanding medical and surgical care required by these patients, is impressive indeed.

But this should not surprise us. That the use of mechanical barriers is the most effective way to prevent microbial cross-contamination has been recognized almost from the time bacteria were discovered, and it was as long ago as 1895 that Nuttall and Tierfelder took up Pasteur's challenge to raise animals germfree, in order to determine the role of the indigenous bacteria in mammalian metabolism.

The next 45 years were spent in the development of steel isolators for this purpose, and the feasibility of accomplishing the complete prevention of cross-contamination has since been established in the raising of germfree animals for generation after generation in laboratories all over the world.

But the practicality of applying this concept to the much more complicated problems of patient care was not realized until 1957, when Trexler and Reynolds introduced the use of animal isolators made of thin, flexible plastic film. It was at this time that we began our investigations with Trexler in this field.

We thought it ought to be possible to transfer to the hospital the techniques of the germfree laboratory for the prevention of cross-contamination and cross-infection. This led to the development of an integrated isolator system for the care of patients on the ward, the transfer of patients throughout the hospital, or from hospital to hospital, and the conduct of major surgery in an environment free of all exogenous micro-organisms.

Our experience with the use of isolators for the care of burn patients on the ward, with many fewer patients than those presented by Dr. Burke, yielded similar results; namely, the high level of effectiveness of such a barrier technique for the prevention of cross-contamination and cross-infection, and the failure of conventional isolation methods, the latter most often, because of human error. We found similar results with transplant patients and patients with severe leukopenia, as have a number of other investigators with leukemics, and infants with congenital immune deficiencies.

The same sort of effectiveness for the prevention of cross-contamination by mechanical barrier techniques can be shown in the operating room as has been shown by Burke and his associates this afternoon for the care of patients on the ward.

(Slide) In the operating room the patient is outside rather than inside the isolator, and in our isolators half-suits are integrated into the walls of the isolator to provide the mobility for the surgical team required for complicated major surgery.

(Slide) In patients undergoing elective surgery, largely intra-abdominal we found a significantly lower rate of intraoperative bacterial contamination of the operative site and wound and most importantly, a substantially lower rate of postoperative wound infection when patients operated on by the isolator technique were compared with a parallel group of patients operated upon by conventional techniques.

(Slide) And just one last point. There are times when it is mandatory to deliver a pregnant woman in a way which will ensure a germfree baby, that is, when the baby is suspected of having a severe immune deficiency disease. And this is a picture of the