MEDICAL GRAND ROUNDS
February 28, 1985

PREVENTING
HOSPITAL-ACQUIRED INFECTIONS
FROM SEMMELWEIS TO SENIC

Medicine's Need for the AGGREGATE VIEW

Ignaz Philipp Semmelweis (1818-1865)

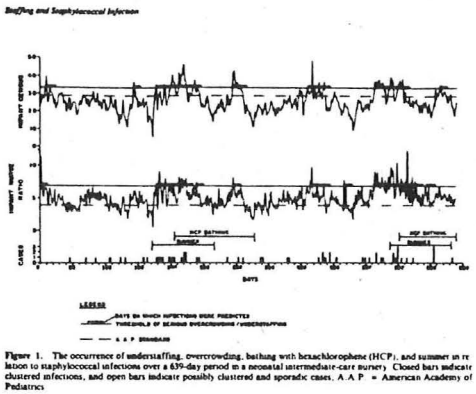
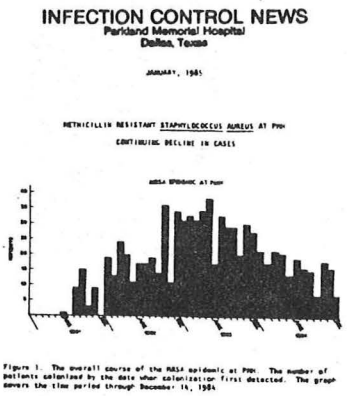


Figure 1. The occurrence of understaffing, overcrowding, bathing with hexachlorophene (HCP), and summer in re lation to staphylococcal infections over a 639-day period in a neonatal intermediate-care nursery. Closed bars indicate clustered infections, and open bars indicate possibly clustered and sporadic cases. A.A.P. = American Academy of Pediatrics



INFECTION CONTROL NEWS
Parkland Memorial Hospital
Dallas, Texas

METHICILLIN RESISTANT STAPHYLOCOCCUS AUREUS AT PMH

CONTINUING DECLINE IN CASES

Figure 1. The overall course of the MRSA epidemic at PMH. The number of patients colonized by the date when colonization or first detected. The graph covers the time period through December 14, 1984.

Study on the
Efficacy of
Nosocomial
Infection
Control

Robert W. Haley, M.D.

UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT DALLAS
SOUTHWESTERN MEDICAL SCHOOL
DEPARTMENT OF INTERNAL MEDICINE
DALLAS, TEXAS

The Aggregate View

Hospital-acquired, or nosocomial, infections constitute an increasing cause of morbidity and mortality for patients admitted to U.S. hospitals. The best single review of the subject is given in the textbook Hospital Infections edited by Bennett and Brachman, the new second edition of which will be out this September (1). This problem is not only of increasing importance in itself but also because it is perhaps the best current illustration of a more global issue, Medicine's need for the Aggregate View. My thesis is that there is an entire set of everyday medical problems of which physicians are not fully aware--a dimension that cannot be observed clinically in daily medical practice, but a dimension that nevertheless affects the outcome of every physician's therapeutic efforts and the wellbeing of his or her patients?

Generally this thesis is given little credence, because if physicians are taught anything, they are taught to be astute observers, to pick up every sign, every clue, every subtle twist that might signal malady in a patient . But notice the terminology used, in a patient--one patient. From Hippocrates through Osler to the great teachers of today, physicians have always been taught to focus on the one patient. The point is that there is a set of problems that we miss when we focus down on one. These are problems that can only be appreciated when we look at patients in the aggregate, that is, when we obtain, what I will call, the Aggregate View.

Now, this other dimension of clinical medicine has always been there, and has always been largely overlooked, and even denied by many astute clinicians even today. On rare occasions, certain medical mavericks have tried to call direct attention to its existence and to convince the scientific medical community of the need to deal with it, but at best these wild-eyed gadflies have been tolerated and then forgotten, and on occasion they've been ostracized and even persecuted. More commonly, this subject is approached obliquely or touched on lightly, as an aside or an afterthought, in the course of a clinical discussion or a case presentation, where the speaker can beat a hasty retreat back to the individual patient if challenged too directly.

More specifically, the aggregate view that allows us to observe this other dimension of clinical experience is the observation of the common experience or outcomes of a group of patients to see what they have in common or to predict the probability of occurrence of some good or bad event. It is just the opposite of what we, as physicians, have been taught to do. It is learning to look beyond our one patient; it is when we learn to count to two and beyond--to think about problems revealed by the aggregate view. The need for the aggregate view has been intuitively apparent to clinical researchers for a long time, and within the limitations of the research tools available in the past, some important observations have been made. Four epidemiologic anecdotes will illustrate this thesis.

The SEMMELWEIS story

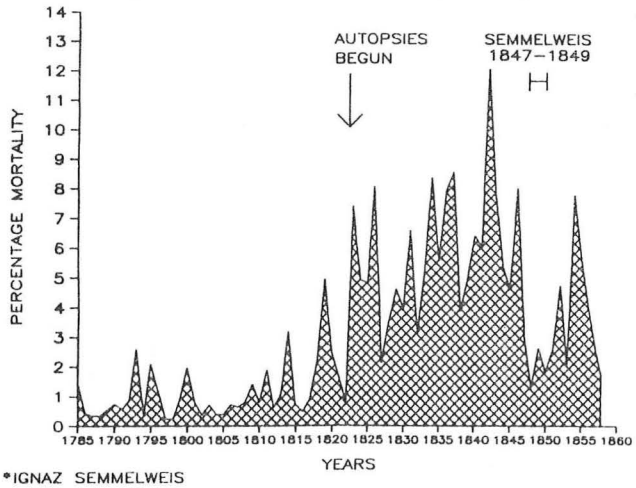
The earliest example is the Semmelweis story (2). Ignaz Semmelwiess was a young assistant professor at the Royal Lying-In Hospital of Vienna in the late 1840s. When he first assumed his position as head of the obstetrical service, he was appalled by the high rate of maternal death in the hospital. In his first several months, nearly 1 or every 10 women died in the postpartum period of overwhelming puerperal sepsis, today known as streptococcal endometritis. In later years he recalled.

> The hospital priest was wont to visit the sick in his vestments, attended and preceded by a sacristan ringing a bell, according to the Catholic rite, in order to administer the Holy Last Sacraments to them. An effort was made to see that there was only one such visit a day, but 24 hours are a long time for childbed fever, and many patients, who were indeed tolerably well during the visit of the priest and therefore did not receive the Last Sacraments, after the course of a few hours became so ill that the priest must again be summoned. One can imagine what an impression the ominous sound of the little bell, heard frequently during the day, made upon the young women in the wards. As for myself, it made me uneasy in spirit when I heard the little bell hurrying past my door; a sigh stole from my breast for the new victim, who fell before this unknown cause. This little bell was an agonizing reminder to reinvestigate this unknown cause with all zeal possible (2).

The distinguished faculty, though concerned with the high maternal mortality rates, had resigned themselves to the situation after ascribing the problem to such causes as the unavoidable overcrowding, poor ventilation, seasonal and climatic factors, and other so-called "atmospheric-cosmic-telluric conditions," as well as certain maternal factors like a preponderance of unmarried mothers, the frequency of hard working mothers of low social strata, and dietary factors. One popular theory among the medical staff held that the basic cause was really the fear of dying; that is, the young parturient women were so afraid of dying from the well known hospital contagion that they became sick to death from the fear itself.

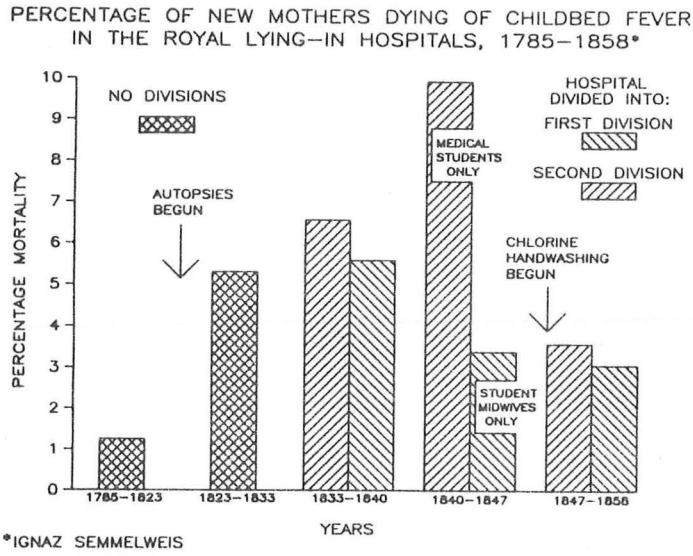
Unable to reconcile any of the prevailing theories with the facts before him, Semmelweis undertook probably the first epidemiologic study in a hospital. He began by analyzing the hospital's maternal mortality statistics that were available from the previous 60 years. With this he found that the high mortality rates had indeed not always been so high, but had risen from below 2% to the 8-10% range in the 1820s. This increase coincided with the introduction of the new Anatomical School of Pathology in which cadavers were introduced routinely into teaching medical students.

PERCENTAGE OF NEW MOTHERS DYING OF CHILDBED FEVER IN ROYAL LYING-IN HOSPITAL, 1784-1858*



*IGNAZ SEMMELWEIS

Next he analyzed the association of maternal death against all of the theories advanced by his colleagues, and disproved all of them. The only significant association he found was a strong difference in mortality between the women hospitalized in the two divisions of the hospital.



The mortality rate had been low before 1820, had increased to around 5% in the 1820s after autopsies were introduced into teaching. In 1833, the hospital was divided into two divisions, and the mortality rates were roughly the same. In 1840, however, the faculty had decided to assign the midwife students to the First Division and the medical students to the Second Division, and therafter the mortality rates increased dramatically in the Second Division and dropped in the First Division.

Shortly after noticing this strong association, Semmelweis' mentor Professor Kolletschka, a pathologist, died of sepsis after pricking his finger with a scalpel during the autopsy of a young woman who had died of puerperal sepsis. Semmelweis performed the autopsy on his mentor and was struck by the similarity of the pathological picture with that of the women who had been dying of puerperal sepsis. Putting this together with his epidemiologic findings, Semmelweis correctly concluded that the infection was being transmitted from the cadavers of the dead women to the women in labor by the medical students who had been going from morgue to labor room without washing their hands. After instituting a strict policy for washing hands in a chlorine solution before examining the women in labor, the maternal mortality rates immediately fell below 3%.

Thus, by obtaining the aggregate view of the situation from extensive statistical analysis, Semmelweis gained an important insight that led to a strategic change in clinical practice. Unfortunately, his more distinguished colleagues, unable to directly observe the effect of handwashing in any single patient, were not impressed by his statistical approach and refused to accept his explanation. After only two years on the staff, Semmelweis' academic appointment was terminated. His successor allowed the handwashing practice to deteriorate, and within another year the mortality rates resumed their epidemic levels. This situation apparently continued unchanged for another generation (3).

Brewer's Impertinence
The First Surveillance of Surgical Wound Infections

Moving forward 50 years to the turn of the century, we find another particularly illustrative story. In 1895 George Emerson Brewer, a surgeon practicing at the Roosevelt Hospital in New York City, sensing that the clean wound infection rate at his hospital might be higher than his colleagues appreciated, undertook intensive surveillance of surgical wound infections, tabulated the wound infection rates, and reported them to his colleagues as well as in the local medical journal (4). His colleagues were shocked to read that the wound infection rate among clean wounds was not the 5% or less that they had assumed but was actually 39%! He wrote,

> This report resulted in considerable unfavorable comment from many of my professional colleagues, one even going so far as to state that the report 'never should have been published as it was a disgrace to the profession and would bring it into disrepute.' I replied that to my mind the report possessed at least one merit and that was, that it was an absolutely truthful statement of the facts which had occurred during an honest effort to do clean surgery under most unfavorable conditions (5).

While this astoundingly high wound infection rate had been occurring for years without action, merely the generation of these aggregate statistics motivated the entire surgical staff and the hospital administration to re-examine their surgical techniques and the relevent environmental factors and make needed changes. Brewer subsequently published updated reports of the wound infection rates in clean surgery at the hospital and documented their steady decline from the original 39% down to 1.2% by 1915 (5). He summed up his observations like this.

> During the progress of these studies I visited many of the larger and more important hospitals in this city and also in Boston, Baltimore, and Philadelphia . . . and the question was generally asked, "How much infection do you expect in clean cases?" The answer almost invariabley was "practically none." Later conversations with members of the house staff and observations during ward visits led to the belief that while the "practically none" represented the honest opinion of the surgeon, such an opinion was not based on accurate records. Indeed I am thoroughly convinced, that if I had been asked the same question at any time during the past ten years during which no effort was made to keep accurate records of infections occurring in my service, my off-hand estimate of the percentage of infection would fall far below the actual figures. In fact I am strongly of the opinion that the only way to obtain the best technical results is to keep an accurate record of infection in every patient submitted to operation, for it is only by this means that one can be kept aware of his technical transgressions.

In recent years the strong preventive effect of reporting wound infection rates to surgeons has been repeatedly suggested by uncontrolled case studies like Brewer's (6-10) and was recently confirmed by a controlled epidemiologic evaluation study (49).

Staffing and Staph Infections

Moving forward another half-century, in the early 1970s, recurring outbreaks of Staphylococcus aureus infections plagued the large newborn nursery of a prominent teaching hospital in the country. After months of contending with the problem, opinions about the significance of the infections became seriously divided. One contingent headed by the chief of the Pedicatric service felt that infections were epidemic and the other comprising most of the neonatology staff felt that it was only the rate of infection to be expected in such high risk newborns and that no specific control measures were warranted.

After an intensive 3-week investigation, the extent of the problem was documented (11). Over the 2-year period, there had been 300 neonatal infections with Staphylococcus aureus alone, including 6 attributable deaths, 4 cases of osteomyelitis related to laboratory heal-sticks, 7 cases of meningitis, and 10 cases of septicemia. In all, 48 infants had had to be readmitted for treatment after initial discharge, resulting in approximately 200 extra days of hospitalization. In addition there were 2 related cases of maternal breast abscess and 1 of impetigo.

Table 1. Numbers of newborn infants with staphylococcal infection, attack rates, incidence density, and average length of stay, by patient-care unit and onset of infection in the hospital or after discharge over a 639-day period.

Patient-care unit	Infants with infection			Discharges	Overall attack rate*	Patient-days	Overall incidence density†	Average length of stay (days)
	In hospital	After discharge	Total					
Intensive-care unit	6	0	6	378‡	16	3,337	18	8
Premature nursery	44	2	46	612	75	14,427	32	24
Intermediate-care nursery	61	64	125	2,458	51	15,985	78	7
Term nurseries	11	111	122	14,006	9	44,010	28	3
Total	122	177	299	17,076	18	77,759	39	5

* Number of infected infants per 1,000 discharges.

† Number of infected infants per 10,000 patient-days.

‡ Because infants were not discharged from the hospital directly from the intensive-care unit, these discharges were not added into the total.

After a thorough epidemiologic analysis had ruled out all hypotheses about the cause of the epidemic held by the medical staff, several nurses conjectured that the neonatal infections seemed to increase whenever they were particularly overworked. They felt that when they had too many babies to care for they got too busy to wash their hands between babies and perhaps this was spreading the infection. by abstracting the daily infant census from the hospital's computer printouts and the daily nurse staffing census by shift from the files of the Director of Nursing, the infant-to-nurse ratio in the intermediate care nursery was calculated over the previous 21 months. A multivariate logistic regression analysis was performed to analyze the association of the infant-to-nurse ratio with the occurrence of cases of staphylococcal infection in the highest-risk nursery. In the logistic regression model, additional variables were included to represent the alternative hypotheses of the causal roles of overcrowding, hexachlorophene bathing, and seasonal increases in the summer.

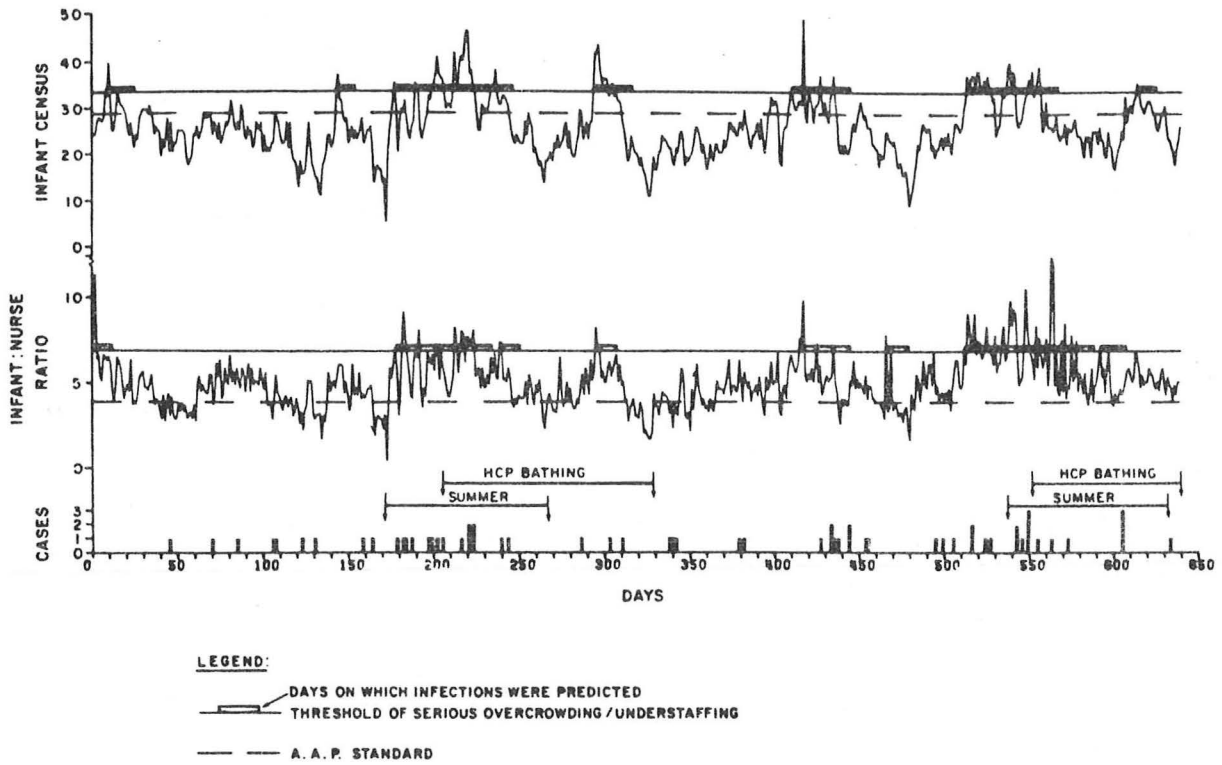


Figure 1. The occurrence of understaffing, overcrowding, bathing with hexachlorophene (HCP), and summer in relation to staphylococcal infections over a 639-day period in a neonatal intermediate-care nursery. Closed bars indicate clustered infections, and open bars indicate possibly clustered and sporadic cases; A.A.P. = American Academy of Pediatrics.

Table 2. The incidence density of clustered and sporadic cases of staphylococcal infection in a neonatal intermediate-care unit over a 639-day period, by four risk factors.

	Hexachlorophene bathing				Summer				Overcrowding				Understaffing			
Type of cases	Yes	No	RR	95% confidence interval of RR	No	Yes	RR	95% confidence interval of RR	No	Yes	RR	95% confidence interval for RR	No	Yes	RR	95% confidence interval for RR
Definitely clustered	17	27	1.6	0.8-3.4	13	44	3.4	1.8-6.3	6	47	7.3	3.5-15.4	3	53	16.4	7.0-40.0
Possibly clustered	4	10	2.6	0.6-11.2	9	4	0.4	0.1-1.8	11	3	0.3	0.1-1.2	11	3	0.3	0.1-1.2
Sporadic	11	6	0.5	0.2-1.6	9	4	0.4	0.1-1.8	10	5	0.5	0.1-1.7	10	5	0.5	0.1-1.8
All	31	42	1.3	0.8-2.4	32	52	1.6	1.0-2.7	27	54	2.0	1.2-3.4	23	60	2.6	1.6-4.3

NOTE. The incidence density was defined as the number of infected infants per 10,000 patient-days. RR = rate ratio.

Table 4. Results obtained from stepwise logistic regression analysis of the joint associations of understaffing, overcrowding, hexachlorophene bathing, and summer with the occurrence of clustered staphylococcal infections over a 639-day period in a neonatal intermediate-care unit.

		Before first step		After last step				Final estimates from linear logistic model	
Risk factor	Step at which factor entered	Approximate χ^2-to-enter	P*	Approximate χ^2-to-remove	P*	Regression coefficient	SE	RR†	95% confidence interval of RR†
Constant	0	. . .	. . .	. . .	. . .	−6.67	0.78	1.00	. . .
Understaffing	1	35.60	<0.0001	6.82	0.009	1.83	0.77	6.23	1.38-28.1
No hexachlorophene bathing	2	2.90	0.089	10.66	0.001	1.68	0.56	5.37	1.78-16.1
Summer	3	10.83	0.001	4.21	0.040	0.98	0.49	2.66	1.03-6.89
Overcrowding	4	31.76	<0.0001	3.93	0.047	1.23	0.67	3.42	0.92-12.8

NOTE. The stepwise logistic regression analysis was performed using the maximum-likelihood-ratio method of assessing the significance of each term in selecting the one to be removed or entered at each step; interaction terms were not included. The goodness-of-fit χ^2 for the model was 59.87 (df = 13; $P < 0.0001$) before any terms were entered and 6.08 (df = 9; P = 0.73) after the last step.

* For all variables, df = 1.

† RR = rate ratio.

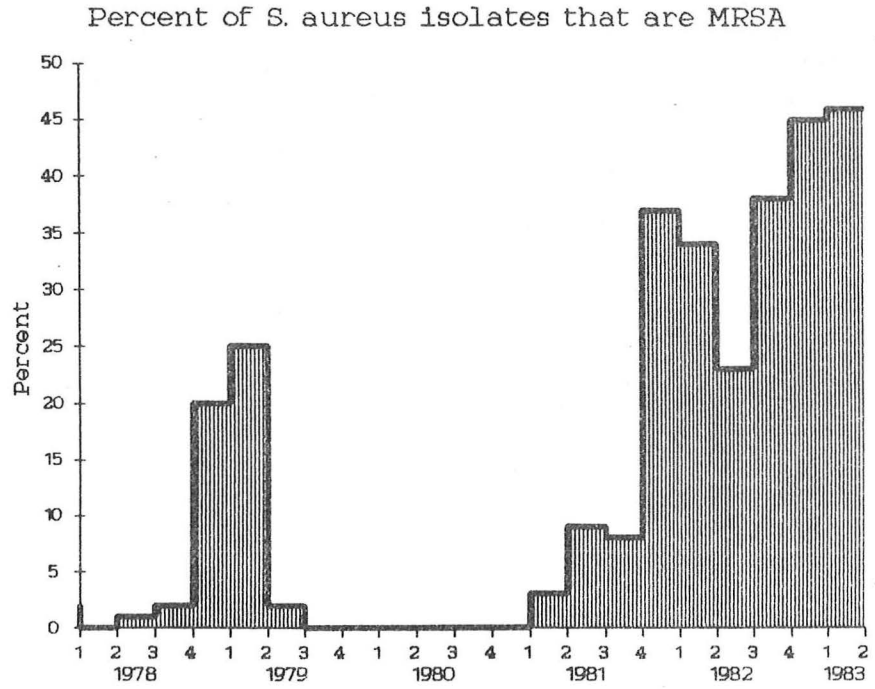
The results indicated a strong association. of the recurrent outbreaks with the infant-to-nurse staffing ratio, even after controlling for the alternative hypotheses.

After presenting these findings to the neotology staff, the nursing director, and the hospital administration, everyone finally agreed that the infection rates were excessive and that the exaggerated fluctuations in the staffing ratios had to be eliminated. Subsequently, special staffing measures were taken to stabilize the infant-to-nurse ratio and to monitor it on a routine basis. Thereafter, the rates of staphylococcal infection declined substantially. This again illustrated a persisting patient-care problem that was underrated and subconsciously suppressed by the hospital staff until brought into focus by a view of the patients in aggregate.

The Parkland MRSA Epidemic

The final illustration takes us right up to the present to the 2-year epidemic of nosocomial infections involving methicillin-resistant Staphylococcus aureus, or MRSA, at Parkland Memorial Hospital. Ever since the early 1960s, methicillin and its cousins the semisythetic penicillinase-resistant penicillins have been the mainstay of chemotherapy for infections with Staphylococcus aureus (12). In the late 1960s strains of staph resistant to methicillin became epidemic in Britain and on the continent of Europe (13), but not in the U.S. By the late 1970s, however, methicillin-resistant strains began appearing in epidemics of nosocomial infections in U.S. hospitals (14). These epidemics are now being transmitted around our country, primarily from one large, medical school-affiliated hospital to another via the transfer of infected or colonized patients or house staff (14).

The first strains of MRSA appeared at Parkland in early 1978 and by the fourth quarter had gained a strong foothold, at that time comprising one-quarter of all staph aureus isolates. This was detected by our infection control department, and in early 1979 an intensive campaign was undertaken to identify all patients colonized with the methicillin-resistant strain and isolate them to prevent secondary spread. By this and other strong measures, the organism was eradicated from the hospital by the end of 1979.

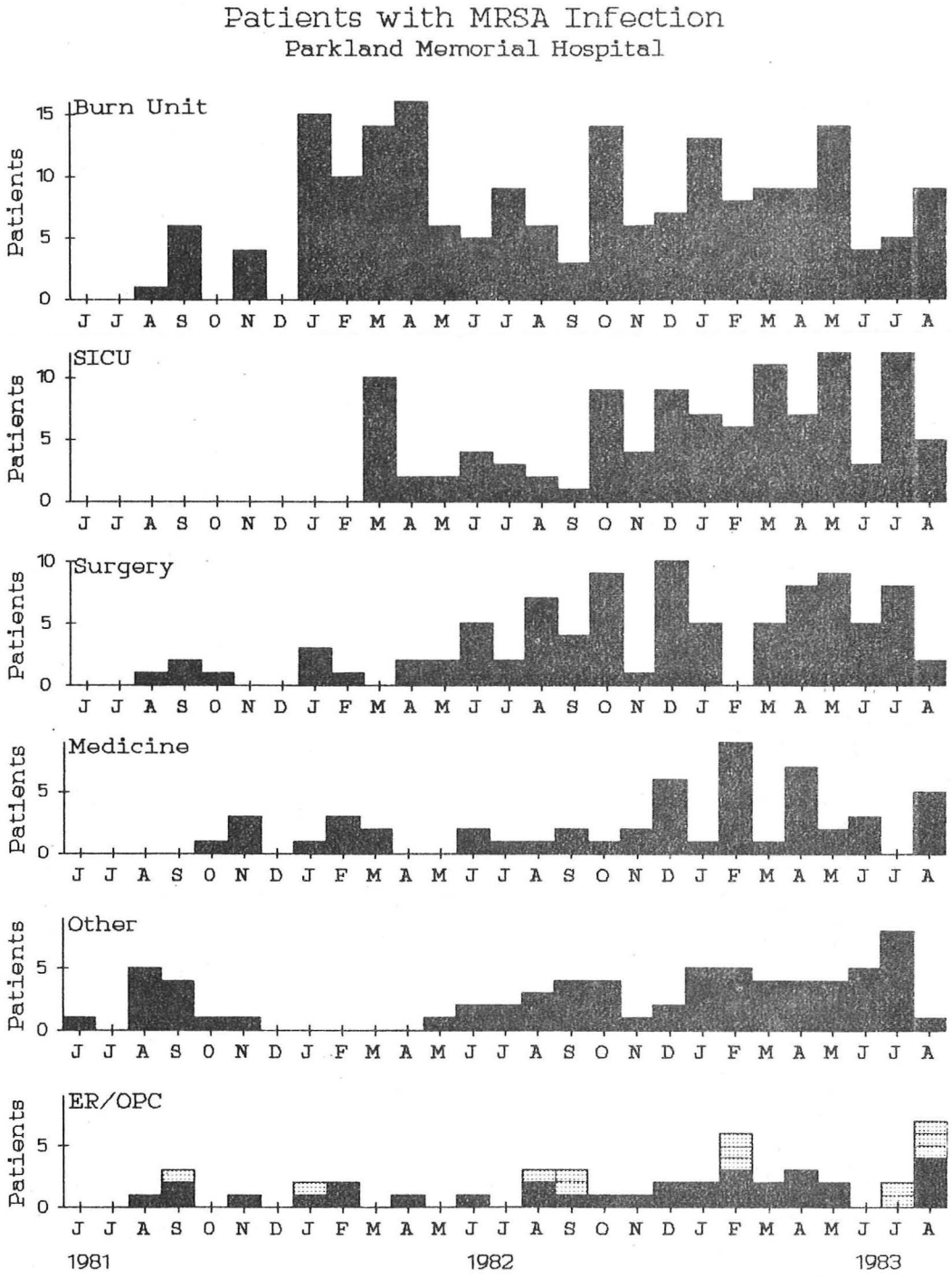


After an 18-month period free of MRSA, another strain appeared in January 1981, this one more highly resistant to methicillin and more clinically virulent. Recognized immediately, the new introduction was met with the same control measures that had been successful before, but this time without success. By the end of 1981, MRSA comprised one-third of all staph aureus isolates in the laboratory, and by early 1983, it comprised almost half.

The problem was that this new strain of MRSA seemed to be cropping up almost at random in all areas of the hospital and had soon become firmly intrenched in the burn unit and the surgical intensive care unit (the SICU), where patients infected with it would languish colonized for months. Because of the seeming ubiquity of the problem, a very strong feeling of resignation came over almost the entire hospital staff. By the summer of 1983, the feelings of the house staff and even many of our attending physicians were summed up by comments like this that were heard frequently: "It's like penicillin resistance; it's here to stay." "It's only a saprophyte like the gram negatives; why all the concern?" "All we ever see is colonization; it doesn't cause real infection." "If they don't get MRSA, it will just be Pseudomonas or some other opportunistic organism." "Nothing will stop it from spreading, so these heroic isolation and handwashing measures are futile." "We just have to learn to live with it."

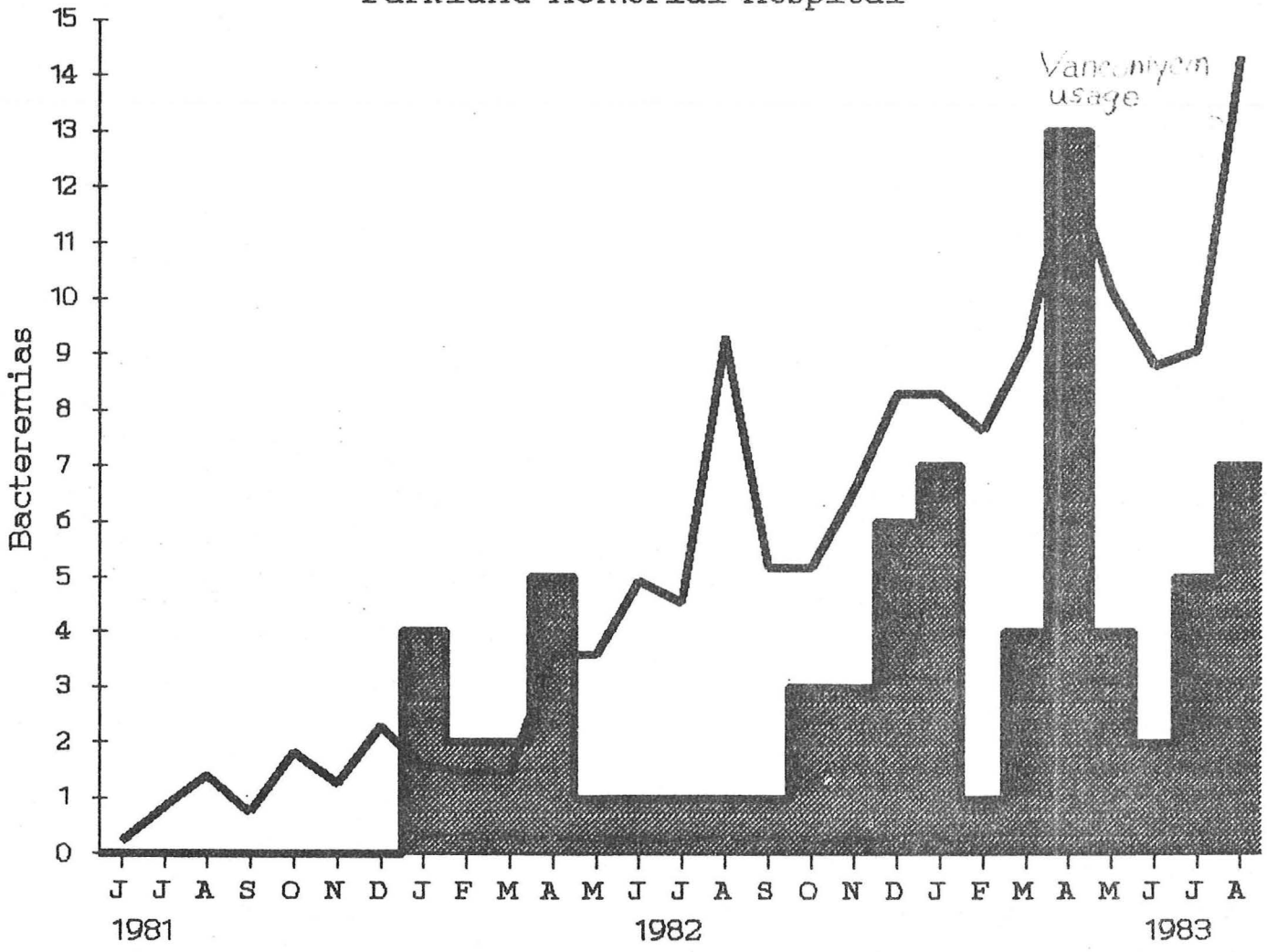
As a result, many house staff and a few attending physicians alike began ignoring the isolation precautions posted on the infected patients' doors, and the problem went completely out of control. By the summer of 1983, we were having between 30 and 40 new cases including 5 to 6 cases of MRSA bacteremia per month. From a review of the literature and a quick telephone survey of other major teaching hospitals known to have indigenous MRSA problems, it became clear that Parkland's MRSA epidemic was by far the largest on record anywhere in the world. In fairness, this also reflected the extraordinary efforts that were being made by our infection control department to detect and document MRSA infections.

As a result, through the summer of 1983 a thorough investigation was conducted. We began by screening the surveillance files of the infection control department and all of the microbiology records for the previous 2 years in order to construct a computerized file of all patients known to have been infected or colonized by MRSA. Next we obtained a huge computer file of all patient room assignments and transfers covering the same 2-year period from the Parkland billing computer. In a large computer operation we merged the infection data into the room assignment file and thereby identified all the precise days on which MRSA patients occupied each room. We also obtained data on antibiotic use from the Pharmacy. Statistical analysis of these data yielded the following results.


Patients with MRSA Infection
Parkland Memorial Hospital
Burn Unit
SICU
Surgery
Medicine
Other
ER/OPC
Patients
J J A S O N D J F M A M J J A S O N D J F M A M J J A
1981
1982
1983

Inpatient Vancomycin Usage vs. MRSA Bacteremias

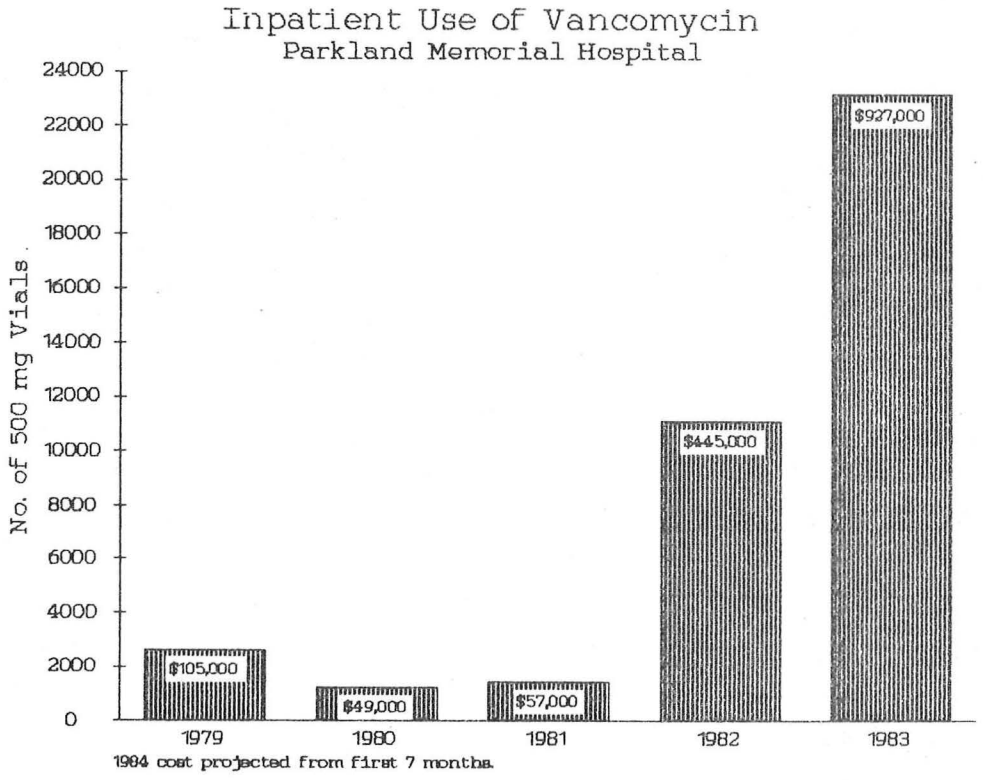
Parkland Memorial Hospital



Over the 21 months outbreak, 508 patients were found to have been colonized or infected. Of these 66 (13%) had MRSA bacteremia; 28 (6%) had infection complicating orthopedic procedures, causing an extraordinarily high amputation rate; and 84 (17%) of these patients died. Two of us reviewed the death charts and estimated that 25 patients with nonfatal underlying illnesses had died as a direct result of MRSA infection.

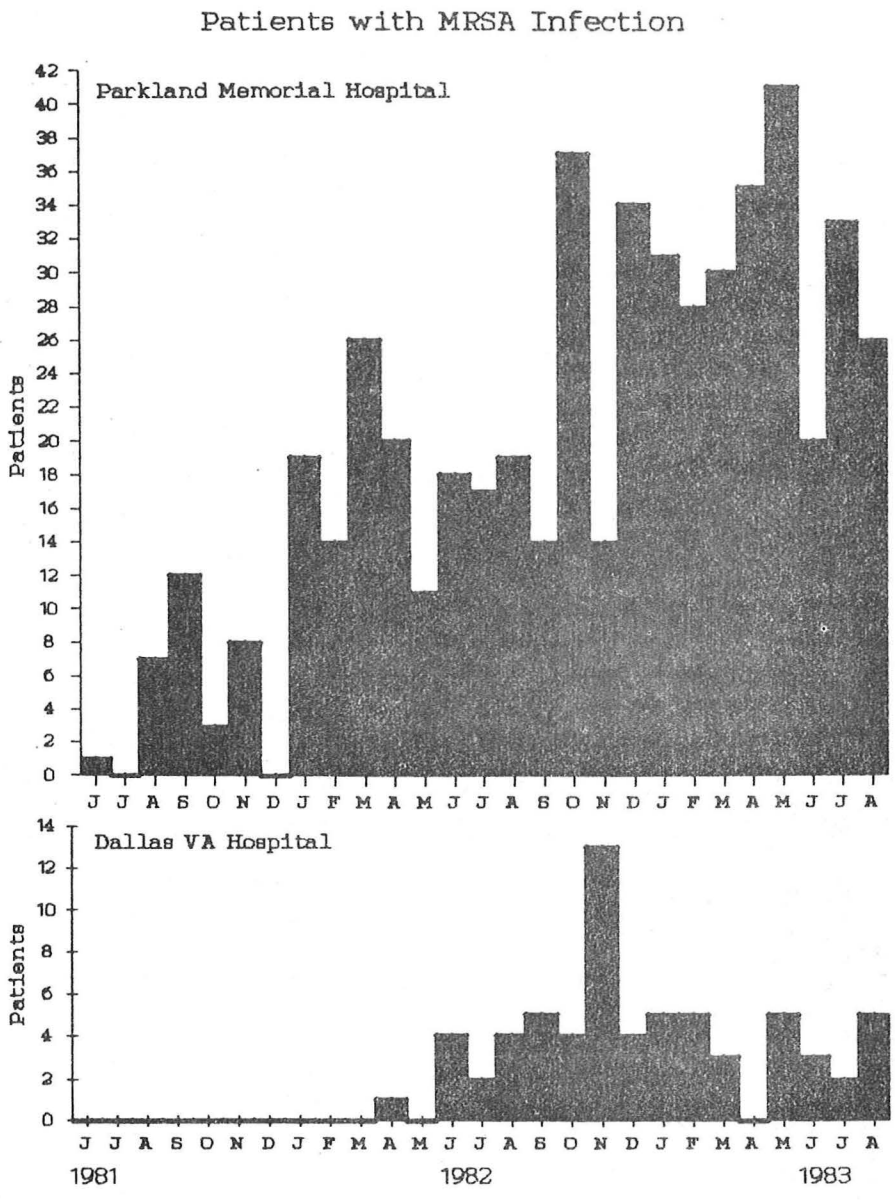
> Mrs. G, a 58 year old white woman, was admitted to the surgery service for treatment of serious gastrointestinal bleeding. She was initially admitted for 2 days of careful monitoring to the surgical intensive care unit, where incidentally the most intensive spread of the epidemic organism was occurring. After the 2 days her condition improved and she was transferred back to the floor. Twenty-four hours later she developed a high spiking fever with no other apparent focus of infection. After 36 hours of standard antibiotic therapy, she suffered a cardiac arrest and died. The clinicians suspected recurrent bleeding or gram negative sepsis from the subclavian line. An autopsy revealed sepsis from the epidemic strain of methicillin-resistant Staph that was resistant to the antibiotics that the patient had been given. By the time the results of the autopsy were available, the resident physicians who had cared for the patient had rotated to another hospital in the system and thus never learned that the death was directly attributable to the epidemic.

Another serious cost of the epidemic involved a dramatic change in antimicrobial usage. Before the MRSA epidemic registered in the clinical consciousness of the medical staff, Vancomycin was a very uncommonly used antibiotic, being reserved primarily for patients with penicillin allergy and



other miscellaneous circumstances, and total pharmacy charges for Vancomycin ranged annually in the $50,000-$100,000 range. As the awareness of MRSA spread, Vancomycin use skyrocketed. As you may know Vancomycin is just about the most expensive antibiotic marketed in this country, the charge from our pharmacy running in the range of $1,500 for an average 10-day course. In 1982 pharmacy charges for Vancomycin amounted to almost a half million dollars, and in 1983 to almost a million dollars--very little of which is paid for under the current DRG prospective payment system. Since the actual cost to the hospital is about 10% of the pharmacy's listed charge, the epidemic was costing Parkland approximately $100,000 per year in unanticipated antibiotic costs alone, not to mention the other extra patient-care costs of the infectious complications that are also not included in prospective payment.

As we might have predicted from the epidemiology of MRSA across the country, it wasn't long before the Parkland strain of MRSA was introduced by the transfer of several colonized patients to the Dallas VA where a separate outbreak began. It also appeared at Children's Medical Center, most likely transmitted via a surgical resident who was later found to have inapparent nasal colonization with the epidemic strain.



The analysis of the large computer file gave a new insight into the mechanism of transmission of the epidemic strain. By tracing the previous hospital roommates of all of the cases, we were able to show that the most intense source of transmission of the epidemic strain around the hospital was the SICU, although it was by no means the only source. Because of the seriously overcrowded conditions, the chronic malfunctioning of the air conditioning which prevented gowning and gloving, and inability to get surgical house staff to wash hands between patient contacts, transmission of infective organisms from patient to patient in the SICU was intense. To make matters worse, patients discharged from the SICU went to rooms on all different services in all parts of the hospital, thus serving as an efficient vehicle for spreading the epidemic strain to all quarters. The following tables show the relative risk of acquiring MRSA. Patients who shared a room with a patient who had been discharged from the SICU had a 9-fold greater chance of subsequently contracting MRSA infection than patients who did not share a room with an SICU patient. And this difference was highly statistically significant.

EXPOSURE TO A ROOMMATE PREVIOUSLY IN THE SICU

	SICU Roommate	
	No	Yes
Patients	15,838	1,462
Cases	38	32
Risk (%)	.24	2.19
Relative Risk	9.1	
p value	<.0001	

Moreover, there was evidence of a strong "dose-response effect." The more days a general ward patient spent as the roommate of a former SICU patient, the higher the risk of subsequently acquiring MRSA infection.

MRSA RISK BY DURATION OF EXPOSURE TO MRSA-INFECTED ROOMMATES

	Roommate-Days of Exposure					
	0	1-7	8-14	15-21	>21	Overall
Patients	14,671	499	40	5	4	15,219
Cases	28	14	3	1	1	47
Risk (%)	.19	2.81	7.5	22.2		0.31
Relative Risk	1	15	39	117		-

An important potential confounding variable in this analysis is the degree of illness of a patient. More seriously ill patients are known to be more susceptible to all types of nosocomial infections, particularly MRSA. Although the degee of underlying illness is difficult to measure, the patient's length of stay is generally a reasonably good indicator of it (37). This was found to be true of MRSA at Parkland.

MRSA RISK BY LENGTH OF HOSPITALIZATION

		Length of Stay (days)				
		1-7	8-14	15-21	>21	Overall
Burn Unit	Patients	67	56	32	49	204
	Cases	4	18	6	28	56
	Risk (%)	6	32	19	57	27
	Relative Risk	1	5	3	10	-
SICU	Patients	38	56	65	209	368
	Cases	0	1	7	53	61
	Risk (%)	α	2	11	25	17
	Relative Risk	1	2/α	11/α	25/α	-
Wards	Patients	11,699	3,255	973	1,373	17,300
	Cases	2	12	3	53	70
	Risk (%)	.02	.37	.31	3.86	.40
	Relative Risk	1	19	16	193	-

If we controlled for ward patients' length of stay in order to control for their degree of underlying susceptibility to MRSA, we find that sharing a room with a former SICU patient is still a strong risk factor.

EFFECT OF EXPOSURE TO AN SICU ROMMATE
CONTROLLING FOR LENGTH OF STAY

Stay	1-7 Days		8-14 Days		15-21 Days		>21 Days	
Exposure	No	Yes	No	Yes	No	Yes	No	Yes
Patients	11,251	448	2905	350	779	194	903	470
Cases	2	0	8	4	3	0	25	28
Risk (%)	.02	0	.28	1.14	.39	0	2.8	6.0
Relative Risk	0		4.1		0		2.1	

Mantel-Haenzel common relative risk = 2.2 (95% C.I. 1.4-3.6)
Breslow-Day test of homogeneity of the relative risk - p = 0.40

Additional analyses were carried out to study the importance of spread from infected or colonized patients to their patient roommates. The following table illustrates this line of analysis by demonstrating a "dose-response effect" of sharing a room the the former roommate of a patient with MRSA. Even though the former roommate of the MRSA patient was not known to have been

infected, enough of them had contracted inapparent infection to cause a substantial risk to their future roommates.

MRSA RISK BY DURATION OF EXPOSURE TO A POTENTIAL CARRIER*

		Roommate-Days of Exposure					
		0	1-7	8-14	15-21	>21	Overall
Wards	Patients	14,671	1,700	276	60	45	16,752
	Cases	28	13	7	3	0	51
	Risk (%)	.19	.76	2.54	5.0	0	3.0
	Relative Risk	1	4	13	26	-	-

*The former roommate of an MRSA-infected patient

By calculating the attributable risks, we found that that 30% of the cases occurred in the Burn Unit, but there was no evidence of spread from these patients to any others outside the Burn Unit. Another 33% of the cases were acquired in the SICU by patients who were in the SICU while other infected patients were there also. Another 17% were never in the SICU but shared a room with an SICU patient who had earlier become infected or colonized with MRSA in the SICU. Another 6% became infected from infected or colonized roommates who had not been in the SICU, and whose original source we could not determine. And that left only 15% of the cases whose exposure we could not pinpoint. These perhaps shared a room with a roommate whose infection was not detected or were exposed by hands of hospital staff or environmental factors.

MRSA CASES BY LOCATION OF EXPOSURE

	No. Cases	%	Cum. Cases	Cum. %
Burn Unit	56	30	56	30
SICU	61	33	117	63
Ward				
from SICU case	13	7	130	70
from SICU carrier	18	9	148	79
Ward				
from other case	6	3	154	82
from other carrier	5	3	159	85
None identified	28	15	187	100

Based on these findings, we developed a new strategy for controlling the epidemic. Instead of trying to tighten isolation procedures throughout the hospital, we decided to focus on the SICU since transmission within the unit and secondary spread from former SICU patients accounted for the largest part of the hospitalwide problem, although in fairnes I should emphasize that this was not the only source of the problem.

Thus, in September 1983, on the basis of these findings the SICU surgical and nursing staff and the Surgery administration in consultation with the Chairman of the Infection Control Committee worked out a new set of measures to interrupt transmission in the Unit and prevent spread from SICU patients who were being transferred out to all areas of the hospital. The control measures were as follows:

1. Restrict entry into the SICU
2. Everyone gown and glove upon entry
3. Enforce handwashing
4. Repair SICU air conditioner
5. Intensive environmental disinfection
6. ICNs monitor SICU techniques daily
7. Reroute "elective" SICU admissions to recovery room
8. All SICU discharges "quarantined" on 2E
9. Dedicated X-ray machine and technician
10. Nasal cultures of all SICU personnel
11. Continued surveillance of MRSA cases
12. New SICU in 1 year

Once this aggregate view of the overall MRSA problem was available and the hospital staff members were able to perceive its true magnitude and the significance of breakdowns in isolation procedures in the SICU, the hospital staff became genuinely concerned and determined to carry out the necessary isolation and handwashing protocol, and the SICU air conditioner that had been malfunctioning for 2 years was quickly fixed.

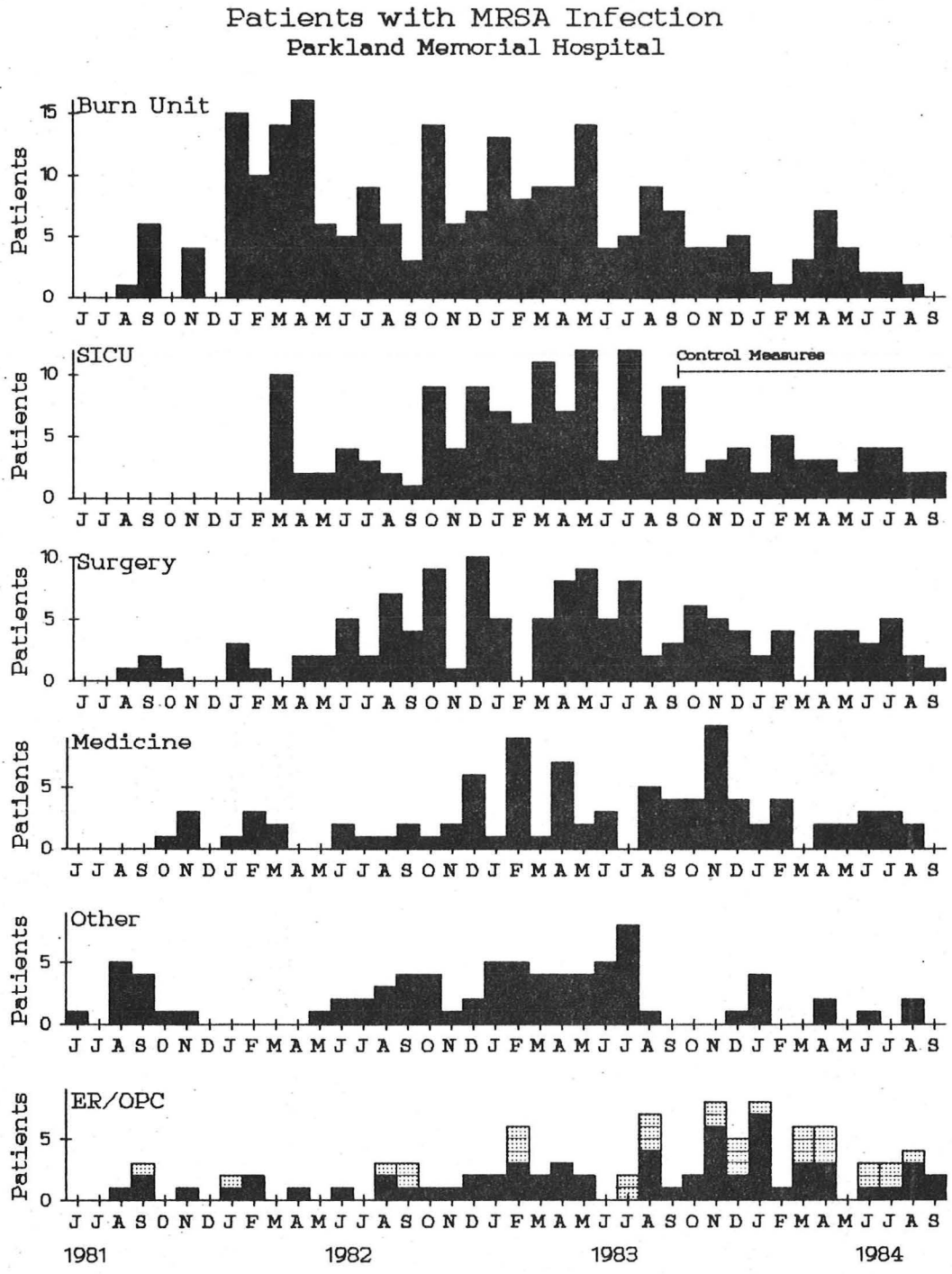
The result was an immediate reduction in the number of cases of MRSA bacteremia in the SICU, as well as a significant reduction in the cases on all other services. Where we were averaging 5 to 6 cases of MRSA bacteremia per month before the September control measures, the number fell to an average of 1-2 cases per month and has since remained at that low level.

NUMBER OF MRSA BACTEREMIAS PER MONTH IN THE YEAR BEFORE AND AFTER CONTROL MEASURES INSITUTED*

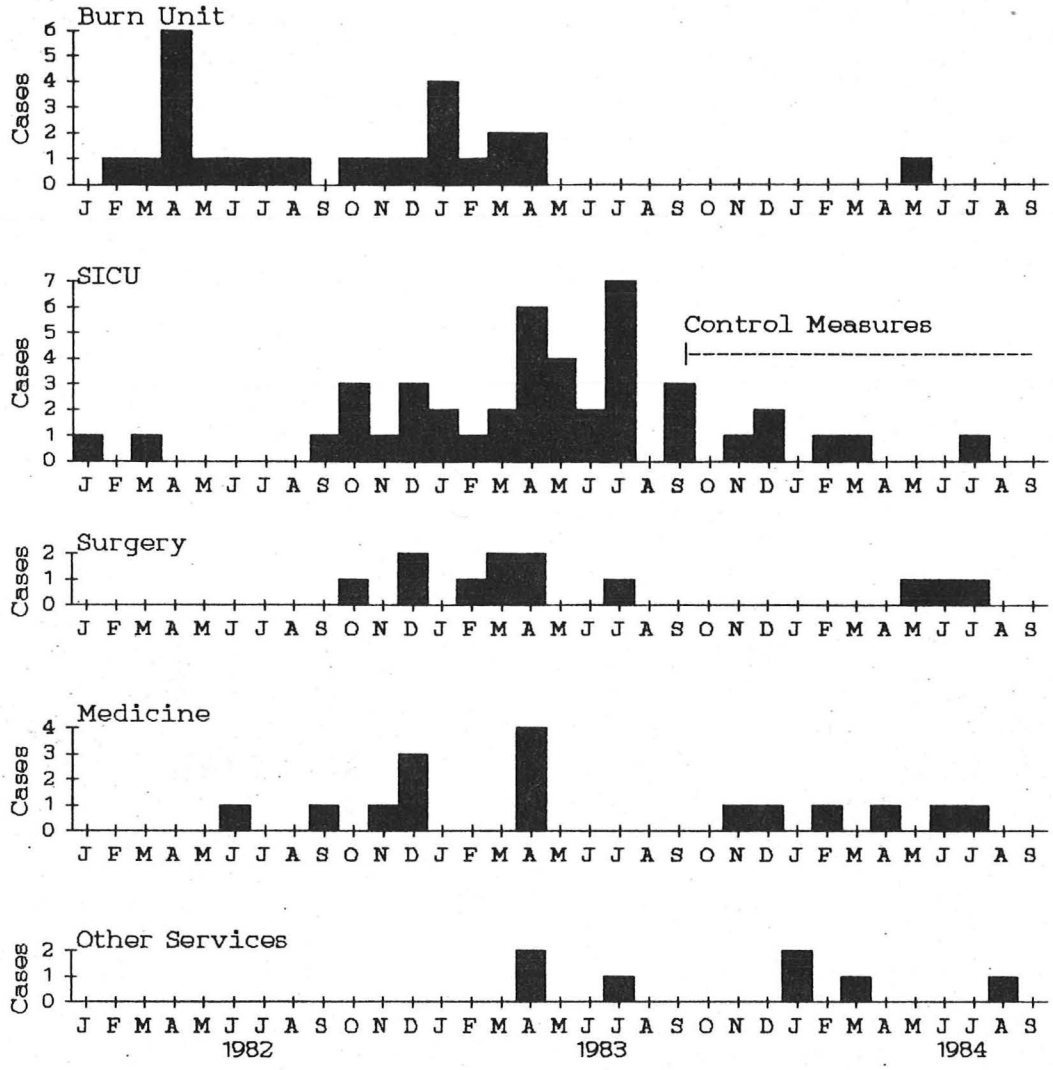
	Median No. Cases		
	Before	After	p value†
SICU	2.5	0	0.001
All Hospital	5	2	0.008

*Oct.-Sept. 1983 versus Oct.-Sept. 1984
†By the Mann-Whitney U test (2-tailed)

Thus, although strains of MRSA are still around the hospital, the rampant spread of the epidemic strain was effectively curtailed by the intensive efforts of the SICU staff after they had seen the aggregate view. These reductions have been sustained for almost 6 months.


Patients with MRSA Infection
Parkland Memorial Hospital
Burn Unit
SICU
Control Measures
Surgery
Medicine
Other
ER/OPC
Patients
0
5
10
15
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
1981
1982
1983
1984

MRSA Bacteremias by Date of First Positive Blood Culture
For Selected Hospital Areas



The Common Thread

An important common thread runs through these four anecdotes. In all four cases, the practicing physicians and house staff had been relatively unconcerned about the need for preventive measures to reduce serious complications in their patients, and generally did not want to be reminded. But after epidemiologic investigations gave them a new view -the aggregate view -they became genuinely concerned and acted decisively to adopt the necessary preventive practices. Here it is important to realize that the physicians were not willfully acting against the interests of their patients. Given what they could observe from their individual-patient perspective, they were acting appropriately. But, except for the Semmelweis story, in the last three examples, once they had seen the aggregate view, they recognized serious problems in another dimension of experience that they had not even suspected was there. And as a result, they took the lead, altered their practices and reduced their patients' risks.

What seems routine and satisfactory from the viewpoint of the individual, sometimes appears entirely different when viewed in the aggregate.

This type of epidemiologic investigation, intended to develop an aggregate view for physicians to use in improving patient care, should be differentiated from the types of activities performed in peer-review programs. Generally, PSRO reviews and similar audits, make no effort to gain a new perspective on this aggregate dimension. Instead, they involve no more than a single auditor's viewing the record of a single patient to judge whether certain "standard" practices were performed. Although peer review is often confused with epidemiology, it is merely an extension of the traditional individual-patient perspective. It is my opinion that the new perspective afforded by the aggregate view--rather than an auditor's case review--is the way to allow physicians to improve the quality of their own patient care.

The SENIC Project

Background

In the late 1960s, a new Hospital Infections Branch was formed at the Centers for Disease (CDC) to begin looking at the emerging problem of hospital-acquired, or nosocomial, infections. At that time a major new epidemic of infections caused by a highly virulent and multiply resistant strain of Staphylococcus aureus, the so-called phage-type 80/81 or 52/52A strain, had been sweeping the country, causing large outbreaks in newborn nurseries and maternity units as well as on adult medical and surgical services (56).

After being called to assist numerous hospitals to control their staphylococal outbreaks, the young physicians of CDC's Epidemic Intelligence Service (EIS Officers as they are called) in the Hospital Infections Branch made several observations that seemed to tie most of these outbreaks together. First, they noticed that whenever they would first go into a hospital at the request of the local health department or a concerned chief of staff, they would almost invariably be met by a reaction of either indifference or even hostility by the medical staff and the hospital

administration. When asked about the epidemic, the practicing physicians and the administrator would usually reply that they were not having any problems, that the infections that had been reported were nothing out of the ordinary, the hospital's usual experience that was to be expected. Believe me, this reaction is real and it is common. I know because I've experienced it more than once. In fact, it is so common that every EIS Officer soon learns to step carefully when going into a hospital, because at first the individual physicians and administrators almost always feel that there are no problems and your visit is not necessary.

The second major observation was that, as soon as the visiting EIS officer would establish a surveillance system to simply count the number of infections from before the presumed epidemic to the present, he would present the observational data to the hospital staff, and immediately--at least in most instances -there would be a dramatic turnaround in the attitudes and concerns of the physicians and the administrators. Suddenly, everyone would become cooperative, physicians who had been aloof or hostile would strike up collegial conversations, and the administrator would invite you over to his house for dinner. When the surveillance system turned up a risk factor that could be modified to control the outbreak, it would become the talk of the hospital, and months later you would hear that one of the most hostile physicians had given a noon conference on the mechanism by which the risk factor had caused the outbreak.

From these experiences, CDC gradually evolved a nationwide recommendation that all hospitals should establish what is called an Infection Surveillance and Control Program, to maintain surveillance over nosocomial infections and give the hospital staff the information they need to recognize outbreaks and ongoing problems when they begin (57). More specifically, on the basis of pilot studies to work out the logistics of these programs, CDC recommended that every hospital have a physician trained in infection control to supervise an infection control nurse and to conduct intensive epidemiologic surveillance and, on the basis of information gleaned from surveillance, formulate infection control strategies and policies to reduce infection risks (57). Thus, these four components--an infection control physician, an infection control nurse, intensive surveillance, and control policies--formed the basis of a program for obtaining the aggregate view in every hospital.

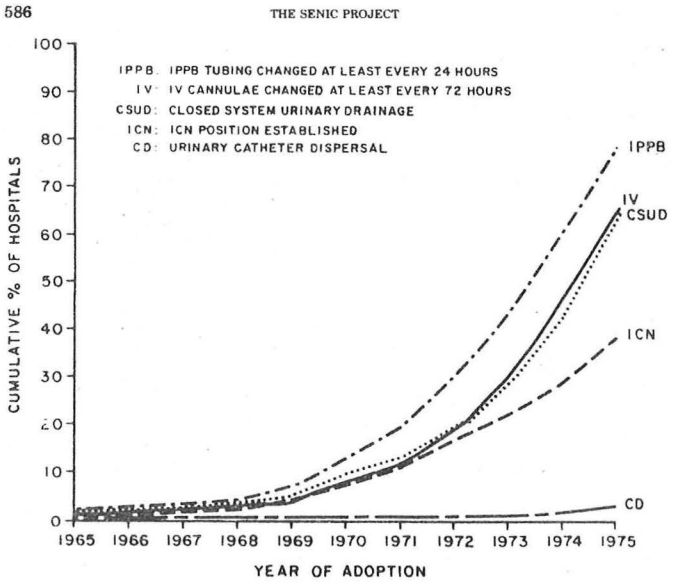


FIGURE 3. Cumulative percentage of hospitals in SENIC target population adopting five infection control policies advocated by CDC and other authorities, 1965–1975.

Between 1970, when these recommendations were begun, and 1975 when we first surveyed U.S. hospitals' practices, the majority of hospitals established some form of infection surveillance and control program. For example, in 1970 fewer than 10% had an infection control nurse, or an active surveillance system, or policies to maintain aseptic, closed urinary catheter drainage systems or schedules for routinely changing IV catheters, and the like, and that by 1975 over half had such positions, surveillance systems, and policies (19-32).

In early 1974, with the new infection control movement just beginning to take hold in hospitals across the country, the CDC undertook a study to evaluate the efficacy of this approach in actually reducing the risks of nosocomial infections in the nation's hospitals (15). At the time we were simply asking whether this nationwide recommendation was an effective and prudent national policy; did it work? In retrospect, what we were really evaluating was the impact of a mechanism for giving clinicians the aggregate view to supplement their daily clinical viewpoints. That is, to what degree, if any, does this aggregate view improve the outcome of patient's hospital course?

Design and Methods

The study is known by the acronym of the SENIC Project (Study on the Efficacy of Nosocomial Infection Control). A complete review of the methods and preliminary results was published in a special issue of the American Journal of Epidemiology devoted to the project in May 1980 (15-18, 33-36), and the final report has just come out this month in four articles in the February 1985 issue of the same journal (45, 47-49).

After determining that a randomized clinical trial and similar traditional approaches were infeasible (15), we developed the design for a controlled observational study, of what is called the quasi-experimental type (58). The design called for data representative of all U.S. general hospitals to be collected in three phases.

Phase I. Preliminary Screening Questionnaire
Phase II. Hospital Interview Survey
Phase III. Medical Records Survey

The first two phases would measure the intensity of surveillance and control activities in the hospitals, and the third stage would estimate the changes that had occurred in the nationwide nosocomial infection rates in relation to the establishment of these programs. Inferences regarding the causal effect of these surveillance and control programs on infection rates would then be made studying the statistical associations of the types and intensities of the programs in each hospital with the changes in its infection rates over time. Since it was infeasible to randomly assign hospitals to groups that would adopt different types of programs, several years were consumed in developing a study design that would strategically avoid the types of potential biases --Selection Bias, Information Bias, and Confounding--that can occur in such epidemiologic studies (58), and a 4-year statistical analysis was carried out at the end to test for all of the potential biases and to make appropriate adjustments for those that were found.

Phase I. The first phase involved measuring the intensity of hospitals' surveillance and control programs with a questionnaire designed to give two mathematical indexes: a surveillance index and a control index. Conducted in early 1976, this phase of the study involved the voluntary participation of 85% of the over 6,000 U.S. hospitals, thus giving us a quantitative measure of these programs throughout the country.

From these data, we calculated a value for each hospital on the surveillance index by summing the weights of specific practices that contributed to detecting nosocomial infections, analyzing for trends in the hospital, and disseminating the findings to the medical staff. A hospital's score on this index was then multiplied by separate adjustment factors that measured the qualifications and duties of the infection control physician and the infection control nurse to give the final value.

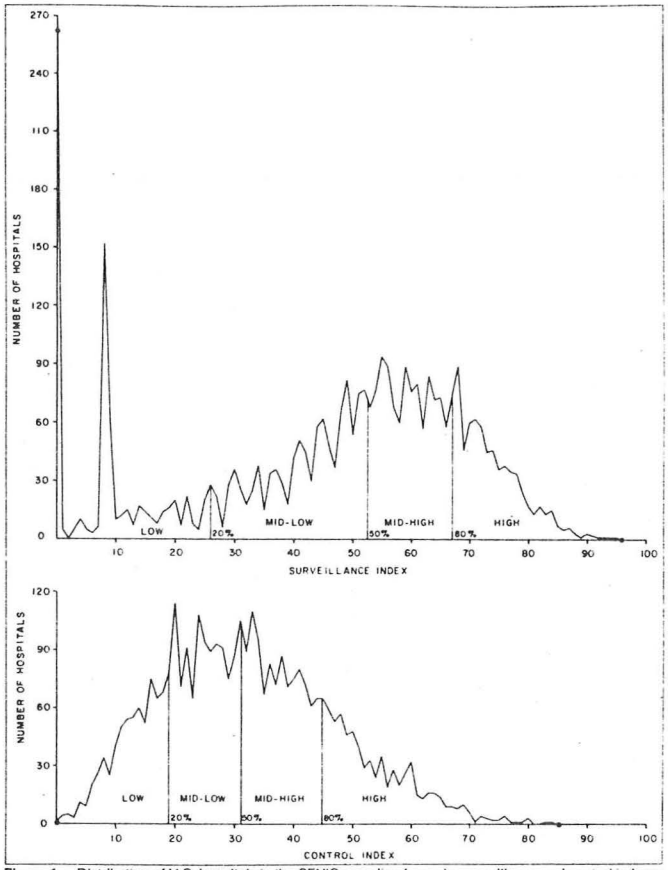


Figure 1. Distribution of U.S. hospitals in the SENIC sampling frame by surveillance and control indexes and categories. The 20th, 50th and 80th percentiles, indicated by vertical lines, determine the low, mid-low, mid-high and high categories.

The top graph shows the distribution of the scores of the 5,000+ U.S. hospitals from which we received the data in 1976. Along the horizontal axis is the value of the surveillance index. Notice a spike of hospitals at zero on the index, indicating those hospitals that had established none of the surveillance practices hypothesized to be effective in reducing nosocomial infection risks, a slightly skewed curve for the majority of U.S. hospitals, and very few hospitals scoring near the top on the scale, having established most of the surveillance activities hypothesized to be effective. For conducting subsequent phases of the project, we divided all of the hospitals into four categories, or strata, on the surveillance index, indicating hospitals that had established "Low" intensity or no surveillance practices, "mid-low," "mid-high," and "high" intensity surveillance practices by 1976.

Likewise, from these data, we calculated a value for each hospital on the control index by summing the weights of specific practices that contributed to the sources of information used for program direction, the authorities of the infection control staff to act, organized programs to teach and train the hospital staff in infection control practices, and patient-care policies for infection control formulated by the program staff. This index was likewise adjusted by the qualifications and duties of the infection control physician and nurse. Here is the distribution of the 5,000+ U.S. hospitals on the control index, slightly skewed to the right, and also subdivided into four categories for later phases of the project.

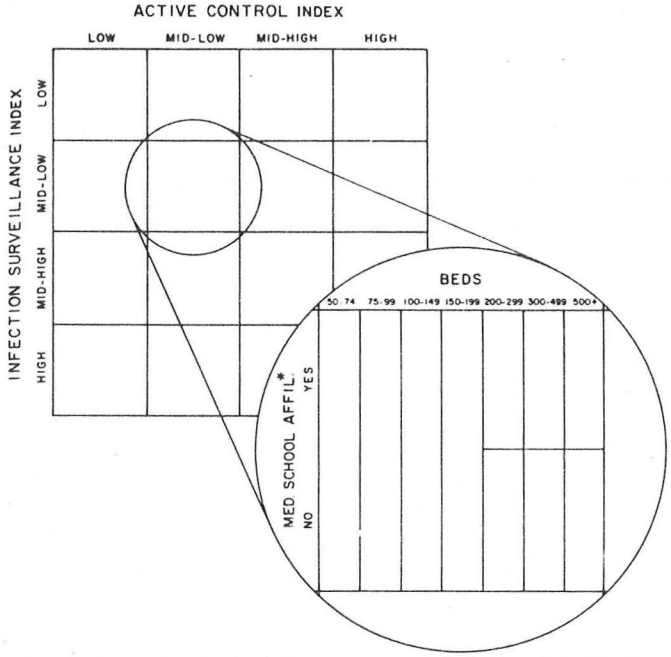


FIGURE 4. Stratification matrix for selecting representative sample of US hospitals for SENIC Project
*Since, in reality, few hospitals with ≤200 beds are affiliated with a medical school, we did not stratify those groups of hospitals by this parameter.

Since we could not afford to study all 5,000+ U.S. hospitals with the intensive methods required in Phases 2 and 3, we planned to select a smaller sample. To minize the chances for serious selection bias, we used a system for randomly selecting hospitals from strata. To do this, we stratified all 5,000+ participating hospitals into boxes determined by the cross-classification of the categorized surveillance and control indexes, as shown here. We also substratified each box by categories of hospital size, indicated by categories of the number of hospital beds, and medical school affiliation. From this large sampling matrix, we selected by a computerized random sampling technique enough hospitals from each box to give a representative sample of 338 U.S. hospitals for study in Phases II and III. I will refer to these 338 hospitals as the sample hospitals. Notice that by using this selection technique, we would minimize or eliminate any selection biases that were related to hospital size or medical school affiliation, and the final results could be validly projected to the population of U.S. Hospitals.

Phase II. In Phase II of the Project, we developed a structured interview protocol, with standardized booklets and interviewing techniques, for conducting personal interviews with the people in the 12 key positions that interact with infection control in each of the 338 sample hospitals.

Number of hospital personnel interviewed and average duration of their interviews among the 433 hospitals in the Hospital Interview Survey (Phase II) of the SENIC Project

Hospital personnel	No. of persons interviewed	Average (±SD) interview time (minutes)
1. Chairperson of the infection control committee and/or HE*	488	86 (±26)
2. ICN† (if none, the nursing representative on the infection control committee or other most knowledgeable infection control person)	465	176 (±49)‡
3. Hospital Administrator (or Assistant Administrator more directly in charge of infection control)	437	20 (±7)
4. Director of the Microbiology Laboratory	435	24 (±9)
5. Technicians in the Microbiology Laboratory	432	17 (±6)
6. Director of the Nursing Service	447	15 (±5)
7. Operating Room Supervisor	437	25 (±8)
8. Head of Pharmacy	435	7 (±4)
9. Head of Inhalation Therapy	430	15 (±5)
10. Head of Intravenous Team (if IV team present)	121	15 (±5)
11. Head of Housekeeping	439	13 (±5)
12. Person in charge of cleaning anesthesia equipment	434	10 (±5)
13. Sample of the nursing staff	7188	50¶
TOTAL	12,969	

* HE = hospital epidemiologist.
† ICN = infection control nurse.
‡ This interview had a scheduled break at approximately the midpoint to reduce the adverse effects of fatigue.
¶ Estimated

These included the infection control physician, infection control nurse, the hospital administrator, the director of nursing, the head of the microbiology laboratory and several technicians, etc., as well as a random sample of the regular staff nurses who were on duty on the day of the interviews. The main purpose of these interviews was to gather information with which to verify the data that had been gathered in phase I to calculate the surveillance and control indexes.

Phase III. The purpose of Phase III, the Medical Records Survey, was to measure the change of the nosocomial infection rates from 1970 to 1976. Within each of the 338 sample hospitals we selected randomly 1,000 admissions: 500 admissions were selected randomly from all of their admissions in 1970, a year before any of the sample hospitals had established any organized infection surveillance or control activities, and 500 more from all of their admissions in 1976, the year in which we had measured the intensity of their infection surveillance and control programs in phase I. In all, this gave us approximately 169,000 patients in 1970 and 169,000 patients in 1976.

BASIC UNITS OF OBSERVATION IN SENIC

	1970	1975-6	Total
Hospitals	338	338	338
Patients	169,518	169,526	339,044
Patient-days	1,782,172	1,603,307	3,385,479

We then visited each hospital with a team of specially trained CDC medical records analysts who reviewed the medical records of the randomly selected admissions to detect all nosocomial infections by using a system we had developed to avoid the information bias that has been found in many types of hospital surveys. Specifically, for each case our staff studied all clinical information in the admission workups, the progress notes and nurses notes, the graphics records, the laboratory and X-ray reports, and the discharge summaries. To this basic clinical data they applied standardized diagnostic algorithms, which had been developed and tested in pilot studies on over 6,000 patients' records, to make clinical diagnoses of nosocomial infections. As a result, we could estimate the infection rates in 1970 -a year before any of the sample hospitals had established their infection control programs --and in 1976--the year in which our first survey had documented active programs in about half the hospitals. From this in each hospital we could calculate the change in the infection rate from before to after the establishment of the infection surveillance and control programs, and since about half of the sample hospitals had not established programs, we had a controlled comparison from which to infer whether the programs had had any effects on the infection rates.

To do the analysis right required 4 years of intensive effort. This was due to three factors. First was the fact that the huge database had to be entirely managed and analyzed by computer. The file structure of the database included large files of data at the hospital level, describing the hospital characteristics from phases I and II and additional descriptive data on the hospitals supplied by the American Hospital Association (59); as well as complex files of data at the individual patient level including the data on each patient's infections, discharge diagnoses, X-rays, urinalyses, daily fever and antibiotic data, surgical procedures, and microbiologic cultures.

The second complicating factor was the need to develop and analyze numerous measures of alternative factors about the hospitals and their patients that could reasonably be suspected to be confounding variables, that is, factors that could change a hospital's infection rate and account for an apparent association of infection control programs with changes in infection rates. In the analysis, we developed and analyzed several hundred measures of hospital characteristics such as hospital size, medical school affiliation, type of ownership, region of the country, occupancy rates, patient-nurse ratios, hospital financial data, size of house staff, and medical staff characteristics. And third, we developed an index of patients' risk factors for nosocomial infection to measure the potential confounding influence of changes in hospitals' patient mix (37, 43-45).

The Results

The result of these analyses was a series of statistical models that would estimate the association of starting an infection surveillance and control program, with the change in the hospitals' infection rate after controlling for all of the potential confounding variables (49). Separate statistical models were developed for each of the main types of nosocomial infections: surgical wound infections, urinary tract infections, bacteremia, and pneumonia. For each of these types of infections, patients were first stratified in those with high and low intrinsic risk, based on the multivariate risk indexes.

TABLE 1

*Multiple regression models explaining the change in hospitals' surgical wound infection (SWI) rates from 1970 to 1975–1976**

Model for high-risk patients† (R^2 = 0.52)				Model for low-risk patients‡ (R^2 = 0.42)			
Predictor variable§	Coefficient	*F* value	*p* value	Predictor variable§	Coefficient	*F* value	*p* value
Intercept	−5.627			Intercept	−2.242		
logit(1970 SWI rate)	−1.476	41.94	<0.0001	logit(1970 SWI rate)	−0.627	155.38	<0.0001
sqrt(1970 SWI rate)	0.709	13.69	0.0002				
Δsqrt(ratio of FTE nurses to beds)	0.626	5.36	0.0114	Δlog(average length of stay)	0.453	5.63	0.0092
Δlogit(average patient risk for SWI†) in regions outside the Northeast	0.788	26.02	<0.0001				
Δlog(% patients undergoing surgery)	−0.791	14.17	0.0001	Δlog(% patients undergoing surgery)	−0.462	12.66	0.0002
Δ(% patients undergoing surgery)^2	0.206×10^{-2}	6.52	0.0058	Δsqrt(ratio of house staff to beds)	0.941	7.27	0.0047
If (hospital in the Northeast)	0.175	7.44	0.0041	If (large hospital in the South not affiliated with a medical school)	−0.319	9.69	0.0010
If (small hospital in the West)	−0.287	9.11	0.0013	If (nonprofit hospital in the West)	−0.251	6.72	0.0050
If [EITHER {( or Hospital epidemiologist is a physician) + Feedback SWI rates to surgeons} OR (Hospital epidemiologist with course + Reduced environmental culturing)] ‖	−0.225	17.17	<0.0001	If [ + Feedback SWI rates to surgeons] ‖	−0.210	11.76	0.0003
If [BOTH {( or Hospital epidemiologist is a physician) + Feedback SWI rates to surgeons} AND (Hospital epidemiologist with course + Reduced environmental culturing)] ¶	−0.429	14.05	<0.0001	If [BOTH ( + Feedback SWI rates to surgeons) AND (Hospital epidemiologist with course + Reduced environmental culturing)] ¶	−0.519	15.16	<0.0001

* Dependent variable: logit(1975–1976 SWI rate) − logit(1970 SWI rate).
† Risk for SWI, estimated for each patient from his or her risk factors (33), >2%; mean risk for all patients in the analysis = 7.3%.
‡ Risk for SWI, estimated for each patient from his or her risk factors (33), <2%; mean risk for all patients in the analysis = 0.9%.
§ Δ signifies the change from 1970 to 1975–1976; "if" signifies an indicator variable coded 1 when the simple condition within parentheses was true or when the complex condition within the braces was established between 1970 and 1975–1976, and coded 0 otherwise. s, surveillance; c, control; FTE, full-time-equivalent.
‖ Will be referred to as a "moderately effective" program.
¶ Will be referred to as a "very effective" program.

TABLE 2

*Multiple regression models explaining the change in hospitals' nosocomial urinary tract infection (UTI) rates from 1970 to 1975–1976**

Model for high-risk patients† (R^2 = 0.66)				Model for low-risk patients‡ (R^2 = 0.50)			
Predictor variable§	Coefficient	*F* value	*p* value	Predictor variable§	Coefficient	*F* value	*p* value
Intercept	−6.460			Intercept	−3.859		
logit(1970 UTI rate)	−1.549	108.23	<0.0001	logit(1970 UTI rate)	−0.791	169.08	<0.0001
sqrt(1970 UTI rate)	0.853	39.84	<0.0001	(1970 UTI rate)^2	0.081	10.26	0.0080
Δurine culturing rate in asymptomatic patients	0.058	39.07	<0.0001	Δ(urine culturing rate in asymptomatic patients)^2	0.271×10^{-3}	16.14	<0.0001
Δ(urine culturing rate in asymptomatic patients)^2	-0.533×10^{-3}	16.32	<0.0001	Δ(worked up fever rate)^2	0.540×10^{-4}	4.95	0.0134
Δlog(urine culturing rate in asymptomatic patients)	−0.165	13.89	0.0001				
Δ(worked up fever rate)^2	0.576×10^{-4}	8.23	0.0022				
If (colony count rate was 0 in 1970)	−0.472	33.56	<0.0001				
Δ(colony count rate)^2	0.681×10^{-4}	36.40	<0.0001				
Δ(colony count rate)^2 in nonprofit hospitals	-0.569×10^{-4}	16.50	<0.0001				
If (hospital epidemiologist with training course)	0.151	7.26	0.0037				
Δlog(ratio of FTE nurses to patients)	−0.241	9.78	0.0009	Δlog(ratio of FTE physicians to patients)	-0.451×10^{-1}	8.27	0.0022
If (hospital was nonprofit)	0.164	5.40	0.0104	If (affiliated with a medical school and in the Northeast)	0.362	7.19	0.0039
If (municipal hospital in the South)	−0.215	6.36	0.0060	If (municipal hospital in the South)	−0.259	7.93	0.0026
If [ AND (≥1 FTE infection control nurse per 250 beds OR Hospital with <200 beds and equivalent staffing level to do surveillance)] ¶	−0.364	20.78	<0.0001	If [ AND (≥1 FTE infection control nurse per 250 beds OR Hospital with <200 beds and equivalent staffing level to do surveillance)] ¶	−0.531	16.78	<0.0001

* Dependent variable: logit(1975–1976 UTI rate) − logit(1970 UTI rate).
† Risk for UTI, estimated for each patient from his or her risk factors (33), >2%; mean risk for all patients in the analysis = 8.2%.
‡ Risk for UTI, estimated for each patient from his or her risk factors (33), <2%; mean risk for all patients in the analysis = 0.8%.
§ Δ signifies the change from 1970 to 1975–1976; "if" signifies an indicator variable coded 1 when the simple condition within parentheses was true or when the complex condition within the braces was established between 1970 and 1975–1976, and coded 0 otherwise. s, surveillance; c, control; FTE, full-time-equivalent.
¶ Will be referred to as a "very effective" program.

TABLE 3

*Multiple regression models explaining the change in hospitals' nosocomial pneumonia rates from 1970 to 1975–1976**

Model for surgical patients† (R^2 = 0.48)				Model for medical patients‡ (R^2 = 0.38)			
Predictor variable§	Coefficient	*F* value	*p* value	Predictor variable§	Coefficient	*F* value	*p* value
Intercept	−2.861			Intercept	1.179		
logit(1970 pneumonia rate)	−0.663	198.82	<0.0001	sqrt(1970 pneumonia rate)	−1.687	151.73	<0.0001
Δ(chest x-ray rate in symptomatic patients)²	0.392×10^{-4}	8.88	0.0015	Δ(worked-up fever rate)²	0.351×10^{-4}	12.41	0.0003
Δchest x-ray rate in asymptomatic patients	0.347×10^{-2}	6.07	0.0071				
If (had at least one FTE infection control nurse per 250 hospital beds)	0.172	3.66	0.0282	If (at least a medium-low surveillance program)	0.195	7.47	0.0033
Δlogit(average patient risk for pneumonia†)	0.237	6.64	0.0052	Δ(average patient risk for pneumonia‡)² in the South	0.221×10^{-1}	6.10	0.0070
				Δ(% patients on medical service)²	-0.928×10^{-4}	9.79	0.0009
If (affiliated with a medical school)	0.210	6.49	0.0056	If (affiliated with a medical school)	0.329	18.24	<0.0001
If (municipal hospital affiliated with a medical school)	0.431	6.65	0.0052	If (hospital in the West)	0.312	16.16	<0.0001
				If (small hospital in the South)	−0.253	11.80	0.0004
If { s c } AND ≥1 FTE infection control nurse per 250 beds‖ ¶	−0.320	7.00	0.0043	If { s c } ‖	−0.137	4.60	0.0164

* Dependent variable: logit(1975–1976 pneumonia rate) − logit(1970 pneumonia rate).
† Mean risk for all surgical patients, estimated for each patient from his or her risk factors (33), 1.3%.
‡ Mean risk for all medical patients, estimated for each patient from his or her risk factors (33), 0.3%.
§ Δ signifies the change from 1970 to 1975–1976; "if" signifies an indicator variable coded 1 when the simple condition within parentheses was true or when the complex condition within the braces was established between 1970 and 1975–1976, and coded 0 otherwise. s, surveillance; c, control; FTE, full-time equivalent.
‖ Will be referred to as a "moderately effective" program.
¶ Will be referred to as a "very effective" program.

TABLE 4

*Multiple regression model explaining the change in hospitals' nosocomial bacteremia rates from 1970 to 1975–1976**

Model for all patients† (R^2 = 0.47)			
Predictor variable‡	Coefficient	*F* value	*p* value
Intercept	−11.207		
logit(1970 bacteremia rate)	−1.645	61.11	<0.0001
sqrt(1970 bacteremia rate)	3.172	28.87	<0.0001
Δ(overall culturing rate in symptomatic patients)²	0.162×10^{-3}	15.14	0.0001
Δ(average patient risk for bacteremia§)²	2.124	19.42	<0.0001
Δlog(% patients undergoing surgery)	0.228	7.08	0.0041
Δ(ratio of total emergency visits to total admissions)²	0.829×10^{-3}	7.84	0.0027
Δsqrt(ratio of house staff to beds)	−0.747	5.07	0.0125
If (affiliated with a medical school and located in North Central or Northeast)	0.552	35.15	<0.0001
If (hospital in the West)	0.235	10.04	0.0008
If (small hospital)	−0.278	22.35	<0.0001
If (municipal hospital in the South)	−0.212	7.06	0.0041
If { s c } ‖	−0.163	6.46	0.0057
If { s c } AND ≥1 FTE infection control nurse per 250 beds AND a hospital epidemiologist‖¶	−0.433	15.82	<0.0001

* Dependent variable: logit(1975–1976 bacteremia rate) − logit(1970 bacteremia rate).
† The comparatively low rates of bacteremia precluded stratifying the analysis on patient risk.
‡ Δ signifies the change from 1970 to 1975–1976; "if" signifies an indicator variable coded 1 when the simple condition within parentheses was true or when the complex condition within the braces was established between 1970 and 1975–1976, and coded 0 otherwise. s, surveillance; c, control; FTE, full-time-equivalent.
§ Estimated for each patient from his or her risk factors (33).
‖ Will be referred to as a "moderately effective" program.
¶ Will be referred to as a "very effective" program.

Overall, we found that an intensive surveillance program in which surgical wound infection rates were regularly reported to the staff surgeons resulted in a 35% reduction of the wound infection rate. Similar programs resulted in a 38% reduction in nosocomial urinary tract infections, a 35% reduction in nosocomial bacteremia, and 27% reduction in postoperative pneumonia, with only a modest 13% reduction in pneumonia in medical patients. Overall, in hospitals that established the most intensive surveillance and control programs, the nosocomial infection rates dropped by 32% over 5 years. In contrast, in hospitals that did not establish these programs, the infection rates did not remain constant but in fact increased by 18% over the same 5 year period. All of these results were highly statistically significant (49).

Table 9-1. Percentage of nosocomial infections prevented by the most effective infection surveillance and control programs

Type of Infection	Components of most effective programs	Percent Prevented
Surgical Wound Infection (SWI)	An organized hospitalwide program with: • Intensive surveillance and control • Reporting SWI rates to surgeons	20
	Plus: • An effectual physician with special interest and knowledge in infection control	35
Urinary Tract Infection	An organized hospitalwide program with: • Intensive surveillance in operation for at least a year • An ICN per 250 beds	38
Nosocomial Bacteremia	An organized hospitalwide program with: • Intensive control alone	15
	Plus: • Moderately intensive surveillance in operation for at least a year • An ICN per 250 beds • An infection control physician or microbiologist	35
Post-operative pneumonia in surgical patients	An organized hospitalwide program with: • Intensive surveillance • An ICN per 250 beds	27
Pneumonia in medical patients	An organized hospitalwide program with: • Intensive surveillance and control	13
All types	An organized hospitalwide program with: • All of the above components	32

Remember, now, that in SENIC we had a random sample of patients in a random sample of U.S. hospitals. From this we could estimate with reasonable precision the magnitude of the nosocomial infection problem in U.S. hospitals and the cost-benefit of establishing infection surveillance and control programs in all of them. Overall, we estimate that on an annual basis in the mid-1970s there were just over 2.1 million nosocomial infections per year in all short-term general medical and surgical hospitals in this country (47). To give you an idea of the magnitude of this number, in 1976 there were approximately 4 times more nosocomial infections than there were hospital admissions for acute myocardial infarction, and slightly more than admissions for all cancers and for all types of accidents.

Table 24-4. Estimated extra days, extra charges, and deaths attributable to nosocomial infections annually in U.S. hospitals

	Extra days		Extra Charges			Deaths			
						Infections directly causing death		Infections contributing to death	
	Avg. per infection*	Est. U.S. total†	Avg. extra charges per infection in 1975 dollars*	Avg. extra charges per infection in 1985 dollars‡	Est. U.S. total in 1985 dollars†	Percent§	Est. U.S. total†	Percent§	Est. U.S. total†
Surgical Wound Infection	7.8	3,980,240	$897	$2,937	$1,499,000,000	0.64	3,251	1.91	9,726
Pneumonia	4.9	1,119,709	$1,270	$4,158	$944,000,000	3.12	7,087	10.13	22,983
Bacteremia	7.4	759,256	$935	$3,061	$315,000,000	4.37	4,496	8.59	8,844
Urinary Tract Infection	1.0	892,532	$181	$593	$535,000,000	0.10	947	0.72	6,503
Other site	3.1	1,271,585	$395	$1,293	$524,000,000	0.80	3,246	2.48	10,036
All sites	3.7‖	8,023,332	$542‖	$1,777‖	$3,817,000,000	0.90‖	19,026	2.70‖	58,092

*Adapted from Haley et al.(50) by pooling data from the 3 SENIC pilot study hospitals.
†Estimated by multiplying the total number of nosocomial infections estimated in the SENIC Project (49) by the average extra days, average extra charges, or the percentage of infections causing or contributing to death, respectively.
‡1985 dollars estimated from Haley et al. (50) by pooling data from the 3 hospitals and adjusting for the annual rate of inflation of hospital expenses from 1976 to 1985 (range 10.4 to 19.1 percent) obtained from the American Hospital Association's National Panel Survey.
§Unpublished analyses of data reported to the National Nosocomial Infections Study (NNIS) in 1980-1982
‖Nationwide estimate obtained by summing the products of the site-specific estimate of the average extra days, average extra charges, or the percentage of infections causing or contributing to death, respectively, from the SENIC pilot studies (50) and the nationwide estimate of the proportion of nosocomial infections affecting the site from the main SENIC analysis (49).

Taking the most conservative estimates of the hospitals costs due to nosocomial infections--which hospitals do not recover under prospective payment by DRGs -the average nosocomial infection will cost approximately $1,800 in 1985 (38-42, 53). By multiplying by the expected number of infections, this will cost the average 250-bed community hospital over a quarter of a million dollars per year, and the nationwide cost is over 3.8 billion dollars (53). From the SENIC findings, we estimate that approximately one-third of this can be avoided by the establishment of intensive surveillance programs (49).

As for mortality, on a nationwide basis an estimated 20,000 inhospital deaths were directly attributable to nosocomial infections in patients with no other cause, and in an additional 60,000 deaths nosocomial infections contributed to death but were not the only cause (53). Unfortunately, since nosocomial infections are usually not recorded on the face sheet of patients' medical records and are almost never recorded as a cause of death on a death certificate, these deaths are not counted in our nationwide systems of vital statistics. If they were, nosocomial infections that directly cause death would rank just below the tenth leading cause of death in the U.S. population (53). If some portion of those that just contribute to death were also counted, it would rank as high as fourth, just after heart disease, cancer and stroke.

THE TEN LEADING CAUSES OF DEATH
IN THE U.S. POPULATION (60)

Cause of Death	Estimated deaths, 1982
1. Heart disease	756,000
2. Cancer	434,000
3. Stroke	158,000
Nosocomial infections*	**80,000**
4. Chronic lung disease	59,000
5. Pneumonia and influenza	49,000
6. Motor vehicle accidents	49,000
7. Other other accidents	46,000
8. Diabetes mellitus	36,000
9. Suicide	28,000
10. Chronic liver disease	28,000
Nosocomial infections†	**20,000**

*Includes infections that were the main cause of death as well as those that only contributed to death.
†Includes only those that were the main cause of death.

By applying the SENIC estimates of efficacy to these measures of the nationwide morbidity and mortality of nosocomial infections, we estimate that the establishment of the most effective infection surveillance and control programs in all U.S. hospitals would result in the prevention of approximately 732,000 nosocomial infections and at least 5,000 premature deaths annually (49, 53).

Given these findings, it would now seem prudent for every U.S. hospital to establish an epidemiologic surveillance unit to generate an ongoing aggregate view of infection risks and regularly report this information to the private physicians on the staff. This in turn would allow the physicians to take measures to reduce their patients' infection risks that they would not have taken in the absence of such a program.

Notice that the strategy that has been validated here is diametrically opposite that which underlies the PSRO movement and related peer-review strategies. These assume that some physicians either cannot or will not act responsibly and therefore a colleague with presumably greater insight or skill must review his or her cases to detect errors and take corrective or punitive

measures to reduce such problems in the future. The view that I have described and that I think is validated by the results of the SENIC Project is that, because of the increasing complexity of modern technological medicine, there is a dimension of clinical problems with which the physician cannot deal effectively without supplementary information obtained from aggregate analysis of his or her patients, but that given this aggregate view, physicians will act earnestly and skillfully in the interests of their patients. An infection control program, with an infection control nurse to collect and analyze surveillance data, is merely an example of a team employed by the hospital to generate this aggregate view as it relates to one particularly serious and costly medical problem. The model could and should be generalized to other problems as well.

The Future

To conclude, let me predict what is going to happen in the next few years as a result of these and other related developments. First, I think that the release of the findings of the SENIC project, appearing now just at the height of the financial squeeze on hospitals by the new DRG-based prospective payment system, is going to substantially increase the commitments of hospitals to their infection surveillance and control programs. Infection control constitutes one of the rare double-win measures--reducing hospital costs while at the same time improving patient care--and hospital administrators are going to recognize this.

Second, I think the new epidemiologic methods and findings are going to have an even broader impact in hospitals than just the control of infectious complications. Presently, there is an increasing emphasis on quality assurance programs and risk management programs to improve the quality of hospital care. Unfortunately, most of these efforts are being run on the old PSRO/peer-review audit concept that will never have any real impact. Hopefully, the more scientifically based technologies that have grown up and have now been validated in infection control will be applied to these other activities as well, to move them into a more productive direction.

More specifically, I can foresee the day when all of these offices - infection control, risk management, quality assurance, utilization review, and others--will be replaced wholesale by a new department of clinical epidemiology. Its responsibility will be to generate an ongoing and comprehensive analysis--the aggregate view--of diverse problems for the entire hospital staff. As a result, current ineffective methods of medical audit will be reduced or phased out entirely. Given the rapid advances in the sophistication and usefulness of computers and the new statistical methods from epidemiology, I think that the technology to do this in a comprehensive way is available today.

And finally, in view of the computing power that I have on my desk today, I think it is not too unrealistic to picture the practicing physician of tomorrow--perhaps our present medical students who took "computer literacy" back in elementary school--eventually to generate the aggregate view of their own private practices. Today many physicians are managing their entire medical records and billing systems with an integrated office computer system. Why not add some carefully thought out patient-care parameters and a standard monthly or yearly epidemiologic analysis program--the aggregate view almost at the bedside--for predicting the most effective antibiotic to use in certain situations, for a surgeon to monitor his operating technique, for the

hematologist to assess his own patients enrolled in treatment protocols, for more precisely guaging doses of nephrotoxic drugs? These are but a few examples of complex clinical problems that will eventually be managed far more skillfully by physicians with computerized access to the aggregate view of their own clincial practice, combined with aggregate databases from their hospitals, the community or the country.

Regardless of exactly what shape these developments take, it is clear that clinical epidemiology, coupled with new generations of computers that are right around the corner, will become an important force to give us the aggregate view in clinical medicine, certainly before the end of this century, and possibly even by the end of this decade.

REFERENCES

General

1. Bennett JV, Brachman PS, eds. Hospital infections. Boston: Little, Brown and Co., 1980 (second edition in press, 1985)

Epidemiologic Anecdotes

2. Semmelweis, I. P. The etiology, the concept and the prophylaxis of childbed fever. Pest, Wien, u. Leipzig. C.A. Hartleben, 1861 (reprinted in translation by F.P. Murphy. Med Classics 5:334-773).
3. Iffy L, Kaminetzky H, Veramenta Z. Infection control in obstetrics. In: Principles and practice of obstetrics. Iffy L, Kaminetzky eds. John Wiley & Sons, Inc. 1981.
4. Brewer GE. Operative surgery at the City Hospital with a preliminary report on the study of wound infection. New York Med J May 2, 1896.
5. Brewer GE. Studies in aseptic technic, with a report of some recent observations at the Roosevelt Hospital. JAMA 1915; 64:1369-1372.
6. Cruse PJE, Foord R. The epidemiology of wound infection: a 10-year prospective study of 62,939 wounds. Surg Clin North Am 1980; 60:27-40.
7. Altemeir WA. Surgical infections: Incisional wound. In: Bennett JV, Brachman PS, eds. Hospital infections. First edition. Boston: Little, Brown and Co., 1979: 287-306.
8. Kaiser AB. Effective and creative surveillance and reporting of surgical wound infections. Infect Control 1982; 3:41-43.
9. Condon RE, Schulte WJ, Malangoni MA, Anderson-Teschendorf MJ. Effectiveness of a surgical wound surveillance program. Arch Surg 1983; 118:303-307.
10. Olson M, O'Conner M, Schwartz ML. Surgical wound infections: A 5-year prospective study of 20,193 wounds at the Minneapolis VA Medical Center. Ann Surg 1984; 199:253-259.
11. Haley RW, Bregman DA. The role of understaffing and overcrowding in recurrent outbreaks of staphylococcal infection in a neonatal special care unit. J Infect Dis 1982; 145:875-885.
12. Jevons MP. "Celbenin"-resistant staphylococci [Letter]. Br Med J. 1961; 1:124-5.
13. Parker MT, Hewitt JH. Methicillin resistance in Staphyloccus aureus. Lancet 1970; 1:800-4.
14. Haley RW, Hightower AW, Khabbaz RF, Thornsberry C, Martone WJ, Allen JR, Hughes JM. The emergence of methicillin-resistant Staphylococcus aureus infections in U.S. hospitals: Possible role of the house staff-patient transfer circuit. Ann Internal Med 1982; 97:297-308.

REFERENCES FROM THE SENIC PROJECT

General Project Descriptions and Commentaries

15. Haley RW, Quade D, Freeman HE, Bennett JV, et al. Study on the Efficacy of Nosocomial Infection Control (SENIC Project): Summary of study design. Am J Epidemiol 1980;111:472-485.
16. Quade D, Culver DH, Haley RW, et al. The SENIC sampling process: Design for choosing hospitals and patients and results of sample selection. Am J Epidemiol 1980;111:486-502.

17. Eickhoff TC. General comments on the Study on the Efficacy of Nosocomial Infection Control (SENIC Project). Am J Epidemiol 1980;111:465-469.
18. Deming WE. The statistical procedure in the SENIC Project. Am J Epidemiol 1980;111:470-471.

Descriptions of Surveillance and Control Programs

19. Haley RW, Shachtman RH. The emergence of infection surveillance and control programs in U.S. hospitals: An assessment, 1976. Am J Epidemiol 1980;111:574-591.
20. Haley RW. Identification of infection surveillance and control interventions that have been effective in reducing nosocomial infection risks: The usefulness of a conceptual model. Rev Infect Dis 1981;3:775-780.
21. Emori TG, Haley RW, Stanley RC. The infection control nurse in U.S. hospitals, 1976-1977: Characteristics of the position and its occupant. Am J Epidemiol 1980;111:592-607.
22. Haley RW. The "hospital epidemiologist" in U.S. hospitals, 1976-1977: A description of the head of the infection surveillance and control program. Infect Control 1980;1(1):21-32.
23. Raven BH, Haley RW. Social influence in a medical context. In: Bickman L, editor. Applied Social Psychology Annual, Volume 1. Beverly Hills, CA: Sage Publications, January, 1980;10:255-277.
24. Raven BH, Haley RW. Social influence and compliance of hospital nurses with infection control policies. Eiser JR, editor. In: Social Psychology & Behavioral Medicine. New York: Wiley & Sons, 1980;17:413-438.
25. Raven BH, Freeman HE, Haley RW. Social science perspectives in hospital infection control. In: Contemporary Health Services -- Social Science Perspectives, Eds. AW Johnson, O Grusky, BH Raven. Auburn House Publishing Company, Boston. 1981; 137-176.
26. Haley RW, Emori TG. The employee health service and infection control in U.S. Hospitals, 1976-1977: I. Screening procedures. JAMA 1981; 246(8):844-847.
27. Haley RW, Emori TG. The employee health service and infection control in U.S. Hospitals, 1976-1977: II. Managing employee illness. JAMA 1981; 246(9):962-967.
28. Brachman PS, Haley RW. Nosocomial infection control: Role of the hospital administrator. Rev Infect Dis 1981;3:783-784.
29. Mallison GF, Haley RW. Microbiologic sampling of the inanimate environment in U.S. hospitals, 1976-77. Am J Med 1981;70:941-946.
30. Emori TG, Haley RW, Garner JS. Techniques and uses of nosocomial infection surveillance in U.S. hospitals, 1976-77. Am J Med 1981; 70:933-940.
31. Garner JS, Emori TG, Haley RW. Operating room practices for the control of infection in U.S. hospitals, October 1976 to July 1977. Surg Gynecol Obstet 1982;155:873-880.
32. Emori TG, Haley RW, Garner JS, et al. Comparison of surveillance and control activities of infection control nurses and infection control laboratorians in the United States hospitals, 1976-1977. Am J Infect Control 1982;10:1:3-16.

Development of the Retrospective Chart Review Method

33. Haley RW, Schaberg DR, McClish DK, et al. The accuracy of retrospective chart review in measuring nosocomial infection rates: Results of validation studies in pilot hospitals. Am J Epidemiol 1980;111:516-533.
34. Quade D, Lachenbruch PA, Whaley FS, McClish DK, Haley RW. Effects of misclassifications on statistical inferences in epidemiology. Am J Epidemiol 1980;111:503-515.
35. Whaley FS, Quade D, Haley RW. Effects of method error on the power of a statistical test: Implications of imperfect sensitivity and specificity in retrospective chart review. Am J Epidemiol 1980;111:534-542.
36. Haley RW, Hooton TM, Schoenfelder JR, Crossley KB, Quade D. Effect of an infection surveillance and control program on the accuracy of retrospective chart review. Am J Epidemiol 1980;111:543-555.

Estimating the Frequency and Costs of Nosocomial Infections

37. Haley RW, Hooton TM, Culver DH, et al. Nosocomial infections in U.S. hospitals, 1975-76: Estimated nationwide frequency by selected characteristics of patients. Am J Med 1981;70:947-959.
38. Haley RW. Preliminary Cost-Benefit Analysis of Hospital Infection Control Programs (The SENIC Project), Proven and Unproven Methods in Hospital Infection Control. In: Proceedings of an International Workshop at Baiersbronn, West Germany, September 24-25, 1977, Gustav Fischer Verlag, Stuttgart, New York, 1978;93-94.
39. Haley RW, Schaberg DR, Von Allmen SD, and McGowan JE. Estimating the extra charges and prolongation of hospitalization due to nosocomial infections: A comparison of methods. J Infect Dis 1980;141:248-257.
40. Haley RW, Schaberg DR, Crossley KB, et al. Extra charges and prolongation of stay attributable to nosocomial infections: A prospective interhospital comparison. Am J Med 1981;70:51-58.
41. Pinner RW, Haley RW, Blumenstein BA, et al. High cost nosocomial infections. Infect Control 1982;3:143-149.
42. Haley RW. Cost-benefit aspects of surveillance of hospital infections. In: Evaluation and management of hospital infections. Ed. Van Furth R. Boston: Martinus Nijhoff Publishers. 1982, pp. 230-43.

Development of a Multivariate Patient-Risk Index

43. Hooton, TM, Haley RW, and Culver DH. A method for classifying patients according to their nosocomial infection risks. Am J Epidemiol 1980;111:556-573.
44. Hooton TM, Haley RW, Culver DH, et al. The joint associations of multiple risk factors with the occurrence of nosocomial infection. Am J Med 1981;70:960-969.
45. Haley RW, Culver DH, White JW, Morgan WM, Emori TG. Identifying patients at high risk of surgical wound infection: A simple multivariate index of patient susceptibility and wound contamination. Am J Epidemiol 1985;121:206-15.

Assessing the Efficacy of Infection Surveillance and Control Programs

46. Haley RW, Culver DH, Hooton TM et al. Progress report on the Evaluation of the efficacy of infection surveillance and control programs. Am J Med 1981;70:971-975.
47. Haley RW, Culver DH, White JW, Morgan WM, Emori TG. The nationwide nosocomial infection rate: A new need for vital statistics. Am J Epidemiol 1985;121:159-67
48. Haley RW, Culver DH, Morgan WM, White JW, Emori TG, Hooton TM. Increased recognition of infectious diseases in U.S. hospitals through the increased use of diagnostic tests, 1970-1976. Am J Epidemiol 1985;121:168-81.
49. Haley RW, Culver DH, White JW, Morgan WM, Emori TG. The efficacy of infection surveillance and control programs in preventing nosocomial infections in U.S. Hospitals. Am J Epidemiol 1985;121:183-205.
50. Haley RW, Morgan WM, Culver DH, White JW, Emori TG, Mosser J, Hughes JM. Hospital infection control: Recent progress and opportunities under prospective payment. Am J Infect Control 1985 (in press).

Project Applications and Implications

51. Haley RW. The epidemiology and prevention of nosocomial infections. In: S.S. Block, ed. Disinfection, Sterilization, and Preservation. 3rd ed. Philadelphia: Lea & Febiger, 1983.
52. Haley RW. Surveillance by objective: A new priority-oriented system for the surveillance and control of nosocomial infections. Am J Infect Control 1985 (in press)
53. Haley RW. Incidence and nature of endemic and epidemic nosocomial infections. In: Hospital Infections. Ed. Bennett JV and Brachman PS. Little, Brown & Co. 2nd edition. 1985 (in press).
54. Haley RW, Garner JS. Infection surveillance and control programs. In: Hospital Infections. Ed. Bennett JV and Brachman PS. Little, Brown & Co. 2nd edition. 1985 (in press).
55. Haley RW, Aber RC, Bennett JV. Surveillance of nosocomial infections. In: Hospital Infections. Ed. Bennett JV and Brachman PS. Little, Brown & Co. 2nd edition. 1985 (in press).

Other References

56. Nahmias AJ, Eickhoff TC. Staphylococcal infections in hospitals: Recent developments in epidemiologic and laboratory investigation. N Engl J Med 1957; 265:74-81.
57. Bennett JV, Scheckler WE, Maki DG, Brachman PS. Current national patterns: United States. In: Proceedings of the International Conference on Nosocomial Infections, August 3-6, 1970. Chicago: Am. Hosp. Assoc. pp. 42-9, 1971.
58. Kleinbaum DG, Kupper LL, Morgenstern H. Epidemiologic Research. Belmont, California: Lifetime Learning Publications. 1982.
59. American Hospital Association. Guide to the Health Care Field. Chicago: Am Hosp Assoc, 1977.
60. United States National Center for Health Statistics. Advanced report of final mortality statistics, 1982. NCHS Monthly Vital Statistics Report. Hyattsville, Md.: National Center for Health Statistics, 1984; 33:1-3.
61. Finkler SA. The distinction between costs and charges. Ann Int Med 1982; 96:102-9.