Surgical wound sepsis

Summary: With the help of a surgical nurse and using data-processing techniques, a prospective clinical study was conducted to determine the wound infection rate in two hospitals in Calgary. The overall sepsis rate was 5.2% and the clean wound rate 3.5%. The latter is the more meaningful figure as it allows for comparison between hospitals, specialties and individuals and is a good guide for hospital morbidity reviews. The groundwork for succeeding wound infection is laid in the operating theatre, and it is believed that wound infection would be reduced more by attention to Halsted's principles than by more rigid aseptic techniques. It is estimated that wound sepsis costs the Province of Alberta 1.5 million dollars per year for hospitalization alone. This amounts to roughly $1 per person per year. The annual cost of a prospective study such as the present one is approximately $7000. This is equivalent to the cost of hospitalizing 24 patients with infected wounds for one week (at $300 per week). One dividend of a prospective study is an associated reduction in infection rate. This reduction more than pays for the cost of the program.

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In 1867 Joseph Lister published the first of his articles on the Antiseptic Principle of the Practice of Surgery.[1] This morbidly shy, stubborn and yet gentle Quaker[2] was responsible for one of the great milestones, if not the greatest, in the history of surgery. It is difficult to visualize the misery and mortality caused by "hospital gangrene" following surgical operations in the pre-Listerian era. As late as 1874 Von Nussbaum deplored that wound sepsis "gnawing like a wild beast, slew or permanently crippled 80 out of every hundred" of his surgical patients.[3] In the Franco-Prussian War of 1870, 13,173 amputations of all types, including amputations of the digits, were done in French hospitals. These resulted in 10,006 deaths.[4] Von Nussbaum, on the Prussian side, had 100% mortality with 34 consecutive through-the-knee amputations. At that time, Erichsen gave the mortality for thigh amputations at the University College Hospital, London as 85% for injury and 20% for disease. The problem of wound sepsis appeared so hopeless that in 1874 he stated, "The abdomen, the chest, and the brain would be forever closed to the intrusion of a wise and humane surgeon."[5] Lister, who was Erichsen's intern in 1852, is primarily responsible for proving this prophecy false and making elective surgery possible.

Wound infection is still responsible for much morbidity, significant mortality and failure of an operation to achieve its purpose as, for example, from a hernia repair breaking down or in a wound dehiscence. However, the most common result of wound sepsis is an increase in the patient's hospital stay and the attending economic loss. Loewenthal[6] found that 40 patients with sepsis required 290 additional bed days, or 7.3 days per patient. Clarke[7] found that postoperative staphylococcal sepsis delayed the discharge of patients by an extra eight days. The Public Health Laboratory Service Survey[8] also calculated this figure as 7.3 days, and in the present study in Calgary it was found that wound sepsis delayed the patient's discharge from the hospital by 7.7 days.

An estimate was made of the cost of wound infection in Alberta. In 1966,[9] 84,171 operations were performed wherein sepsis would be a hazard. Postulating a very conservative 6% infection rate and a seven-day prolongation of stay owing to sepsis, 34,351 bed days at $40 per bed day were utilized. This amounted to $1,414,040 in hospitalization alone. To this figure should be added the sums representing wages lost, decreased productivity and payments from Medical Insurance Plans; the expense of wound sepsis begins to look prohibitive.

The purpose and method of the study

The main purpose was to determine the incidence of wound sepsis in two Calgary hospitals. It was believed that this figure would be one of the best indicators of the quality of surgical care and would also show whether more stringent precautions against infection were necessary. The second purpose was to try to assess the influence of various factors and procedures in the hospitals on the wound sepsis rate.

A registered nurse, whose sole responsibility was to the present study, examined all surgical incisions with the exception of cases of burns, oral,

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rectal and vaginal surgery, circumcisions, and incision and drainage of abscesses. She observed and recorded the states of these incisions for a total period of 28 days after operation.

Using the criteria of the National Research Council study,[10] a wound was defined as infected if pus discharged from it. The wound was categorized as "possibly infected" if it developed the signs of inflammation or a serous discharge. The wound was then inspected daily until it either discharged pus, when it was classified as infected, or resolved, when it was classified as not infected.

Two forms on (1) type of surgery (Fig. 1) and (2) the postoperative course (Fig. 2) were completed.

A clinical estimate of the extent of bacterial contamination was made by classifying all wounds as clean, clean contaminated, contaminated, or dirty, as defined by the National Research Council.[10]

Clean wounds by definition included those in which the gastrointestinal tract or respiratory tract was not entered, where no apparent inflammation was encountered, and with which no break in aseptic technique occurred. Appendectomy, cholecystectomy, hysterectomy and genitourinary operations were included in this category if no acute inflammation was present.

Clean contaminated. These were clean wounds that entered the gastrointestinal tract or the respiratory tract but without significant spillage.

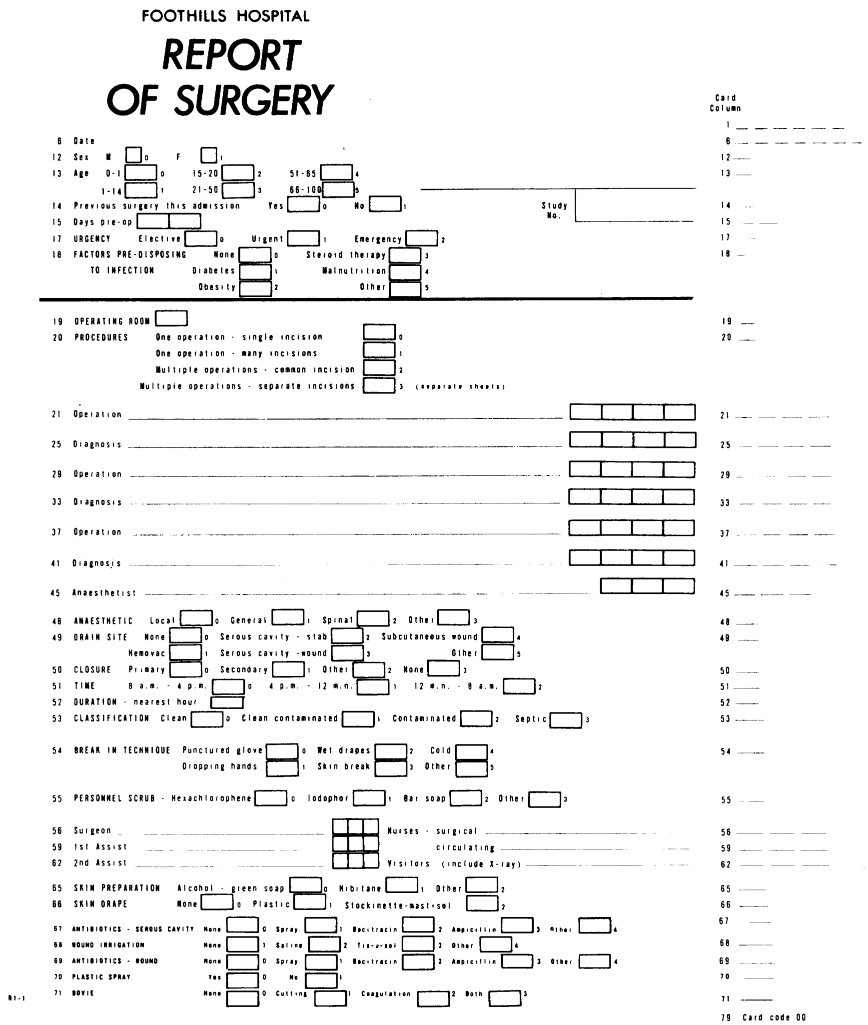
In *contaminated wounds* acute inflammation without pus formation was encountered or gross spillage from a hollow viscus occurred during the operation. Fresh traumatic wounds and operations during which a major break in aseptic technique occurred were included in this category.

Dirty wounds were defined as those in which pus was encountered at operation or a perforated viscus was found. Old traumatic wounds also were included in this group.

This information was then transferred to punch cards and thereafter the information was extracted by the University of Calgary Data Processing Centre.

The study at Hospital A, Calgary, lasted from May 1966 to May 1967. Since September 1967 the same study has been undertaken at Hospital B and the figures for the first year are presented.

Infection data for the first and second six-month periods as well as a monthly infection rate and individual surgeons' infection rates were extracted.


FOOTHILLS HOSPITAL

REPORT OF SURGERY

Card Column

1
6 Date
12 Sex M 0 F 1
13 Age 0-1 0 1-14 1 15-20 2 21-50 3 51-65 4 66-100 5
14 Previous surgery this admission Yes 0 No 1
Study No.
15 Days pre-op
17 URGENCY Elective 0 Urgent 1 Emergency 2
18 FACTORS PRE-DISPOSING TO INFECTION None 0 Diabetes 1 Obesity 2 Steroid therapy 3 Malnutrition 4 Other 5
19 OPERATING ROOM
20 PROCEDURES One operation - single incision 0; One operation - many incisions 1; Multiple operations - common incision 2; Multiple operations - separate incisions 3 (separate sheets)
21 Operation
25 Diagnosis
29 Operation
33 Diagnosis
37 Operation
41 Diagnosis
45 Anaesthetist
48 ANAESTHETIC Local 0 General 1 Spinal 2 Other 3
49 DRAIN SITE None 0 Hemovac 1 Serous cavity - stab 2 Serous cavity - wound 3 Subcutaneous wound 4 Other 5
50 CLOSURE Primary 0 Secondary 1 Other 2 None 3
51 TIME 8 a.m. - 4 p.m. 0 4 p.m. - 12 m.n. 1 12 m.n. - 8 a.m. 2
52 DURATION - nearest hour
53 CLASSIFICATION Clean 0 Clean contaminated 1 Contaminated 2 Septic 3
54 BREAK IN TECHNIQUE Punctured glove 0 Dropping hands 1 Wet drapes 2 Skin break 3 Cold 4 Other 5
55 PERSONNEL SCRUB - Hexachlorophene 0 Iodophor 1 Bar soap 2 Other 3
56 Surgeon; Nurses - surgical
59 1st Assist; circulating
62 2nd Assist; Visitors (include X-ray)
65 SKIN PREPARATION Alcohol - green soap 0 Hibitane 1 Other 2
66 SKIN DRAPE None 0 Plastic 1 Stockinette-mastisol 2
67 ANTIBIOTICS - SEROUS CAVITY None 0 Spray 1 Bacitracin 2 Ampicillin 3 Other 4
68 WOUND IRRIGATION None 1 Saline 2 Tis-u-sol 3 Other 4
69 ANTIBIOTICS - WOUND None 0 Spray 1 Bacitracin 2 Ampicillin 3 Other 4
70 PLASTIC SPRAY Yes 0 No 1
71 BOVIE None 0 Cutting 1 Coagulation 2 Both 3
R1-1
79 Card code 00

FIG. 1—Report of Surgery.

Results and discussion

1. *Overall infection rate*

The overall infection rate in the two hospitals with 6629 patients was 5.2% (Table I).

TABLE I
The overall wound infection rate

Hospital	*Number of Wounds*	*Number Infected*	%
A	2947	179	6.1
B	3682	164	4.5
Combined	6629	343	5.2

The infection rate at Hospital A was significantly higher than at Hospital B (testing at the 99% significance level).

The sepsis rates in various hospitals in the Western world are shown in Table II. The criteria for wound sepsis in all these studies were clinical.

The one aspect of wound sepsis which is usually ignored in surveys is the number of wounds that are recognized as septic after the patient is discharged from hospital; 21.6%

TABLE II
Comparison with present-day figures in wound sepsis

Author	*Country*	*No. of Operations*	*Sepsis Rate %*
Clarke[7]	England	382	13.6
Robertson[11]	Canada	1,917	9.3
Williams *et al.*[12]	England	722	4.7
P.H.L.S.[8]	England	3,276	9.4
Rountree *et al.*[13]	Australia	198	14
Myburgh[14]	South Africa	Not noted	17
N.R.C.[10]	U.S.A.	15,613	7.5

of the infections became evident only after the patient had left the hospital. This high rate is explained in part by the short hospital stay of one to three days of patients on whom minor surgery had been performed, e.g., herniorrhaphies, varicose vein operations, etc.

In both hospitals a significant reduction occurred in the overall infection rates during the second six-month period of the study (Table III).

TABLE III
Overall infection rate in six-month periods

	Hospital A First 6 months	Hospital A Second 6 months	Hospital B First 6 months	Hospital B Second 6 months
No. of wounds	1500	1447	1743	1939
No. infected	126	53	100	64
%	8.4	3.7	5.7	3.3

One explanation for this improvement is that, because of the project, surgical personnel were more "consciously aware" of the problem of wound sepsis and therefore became more careful in observing all aspects of technique. The staffing pattern and work load in both operating suites did not change during these six-month periods. The probability that a reduction of this magnitude would occur by chance is negligible. At Hospital A the operating room and the wards were transferred to a new wing at the end of the first six-month period. Hospital B was a new hospital when the study commenced. It is of interest that there is no significant difference in the infection rates of the two hospitals when their second six-month periods are compared. It is suggested that a new hospital environment plays a role in reducing wound infection rate. The difference in infection rates in old and new theatres and wards was also noted by May *et al.*[15] and by Sonneland.[16] Kippax and Thomas[17] noted the same reduction in sepsis rate in association with a transfer to a new theatre. They suggested that the work load in the operating theatre might be an important factor. However, there was no change in the staffing or number of patients undergoing operation in the old and new theatres of Hospital A.

2. *Bacterial contamination of the wound at operation*

In every surgical wound a struggle takes place between the forces of the bacterial invaders and the patient's defences. Altemeier and Culbertson[18] have stated that wound infection is the unfavourable result of the equation:

$$\frac{\text{Dose of bacteria x virulence}}{\text{Resistance of patient}}$$

Previous studies[10,19-21] have shown that the dose of bacterial contamination at operation is the chief determinant of succeeding wound infection.

Table IV shows the importance of wound contamination. The incidence of sepsis in dirty wounds is seven times higher than in clean wounds in the overall results. Hospital A had a significantly higher infection rate in clean, clean-contaminated, and dirty wounds and this may be because the first half-year of the study in Hospital A was conducted in the old hospital building.

In Table V the figures for the infection rates in the various categories are compared with those from the National Research Council study.

The clean wound infection rate

The wound classification used in this study has the advantage that statistics are available on all clean wounds. In these wounds, wherein the bacterial contamination has been minimized, the influence of other procedures, for instance, hand scrub preparations, skin preparations, etc., can be more accurately assessed. Further, it allows for a comparison between various surgeons and surgical departments. For instance, the overall sepsis rate of a general surgeon performing bowel surgery (contaminated) will be higher than that of an orthopedic surgeon, and a comparison of their clean wound infection rates would therefore be more meaningful; although even here, where appendectomies and cholecystecto-

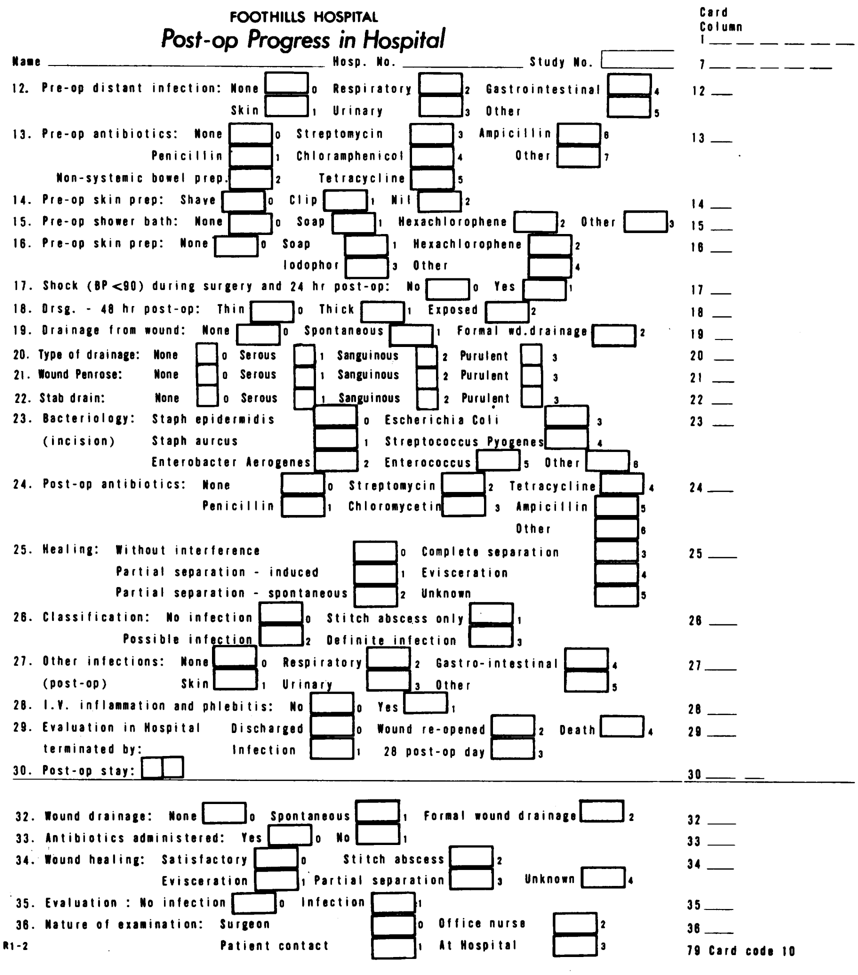

FOOTHILLS HOSPITAL
Post-op Progress in Hospital
Card Column 1
Name Hosp. No. Study No. 7
12. Pre-op distant infection: None 0 Respiratory 2 Gastrointestinal 4 Skin 1 Urinary 3 Other 5 — 12
13. Pre-op antibiotics: None 0 Streptomycin 3 Ampicillin 6 Penicillin 1 Chloramphenicol 4 Other 7 Non-systemic bowel prep. 2 Tetracycline 5 — 13
14. Pre-op skin prep: Shave 0 Clip 1 Nil 2 — 14
15. Pre-op shower bath: None 0 Soap 1 Hexachlorophene 2 Other 3 — 15
16. Pre-op skin prep: None 0 Soap 1 Hexachlorophene 2 Iodophor 3 Other 4 — 16
17. Shock (BP <90) during surgery and 24 hr post-op: No 0 Yes 1 — 17
18. Drsg. - 48 hr post-op: Thin 0 Thick 1 Exposed 2 — 18
19. Drainage from wound: None 0 Spontaneous 1 Formal wd.drainage 2 — 19
20. Type of drainage: None 0 Serous 1 Sanguinous 2 Purulent 3 — 20
21. Wound Penrose: None 0 Serous 1 Sanguinous 2 Purulent 3 — 21
22. Stab drain: None 0 Serous 1 Sanguinous 2 Purulent 3 — 22
23. Bacteriology: (incision) Staph epidermidis 0 Escherichia Coli 3 Staph aurcus 1 Streptococcus Pyogenes 4 Enterobacter Aerogenes 2 Enterococcus 5 Other 6 — 23
24. Post-op antibiotics: None 0 Streptomycin 2 Tetracycline 4 Penicillin 1 Chloromycetin 3 Ampicillin 5 Other 6 — 24
25. Healing: Without interference 0 Complete separation 3 Partial separation - induced 1 Evisceration 4 Partial separation - spontaneous 2 Unknown 5 — 25
26. Classification: No infection 0 Stitch abscess only 1 Possible infection 2 Definite infection 3 — 26
27. Other infections: (post-op) None 0 Respiratory 2 Gastro-intestinal 4 Skin 1 Urinary 3 Other 5 — 27
28. I.V. inflammation and phlebitis: No 0 Yes 1 — 28
29. Evaluation in Hospital terminated by: Discharged 0 Wound re-opened 2 Death 4 Infection 1 28 post-op day 3 — 29
30. Post-op stay: — 30
32. Wound drainage: None 0 Spontaneous 1 Formal wound drainage 2 — 32
33. Antibiotics administered: Yes 0 No 1 — 33
34. Wound healing: Satisfactory 0 Stitch abscess 2 Evisceration 1 Partial separation 3 Unknown 4 — 34
35. Evaluation : No infection 0 Infection 1 — 35
36. Nature of examination: Surgeon 0 Office nurse 2 Patient contact 1 At Hospital 3 — 36
R1-2
79 Card code 10

FIG. 2—Postoperative progress sheet.

TABLE IV
Analysis of infection rates related to wound types

	Hospital A No. of wounds	Hospital A No. of infections	Hospital A %	Hospital B No. of wounds	Hospital B No. of infections	Hospital B %	Combined No. of wounds	Combined No. of infections	Combined %
Clean	2463	105	4.2	2609	71	2.7	5072	176	3.5
Clean-contaminated	350	36	10.3	850	57	6.7	1200	93	7.8
Contaminated	64	10	15.6	143	22	15.4	207	32	15.5
Dirty	70	28	40.0	80	14	17.5	150	42	28.0

TABLE V
Comparison of infection rates of Calgary and from N.R.C. studies

	Calgary No. of wounds	Calgary No. of infections	Calgary %	N.R.C. No. of wounds	N.R.C. No. of infections	N.R.C. %
Clean	5072	176	3.5	11690	594	5.1
Clean-contaminated	1200	93	7.8	2589	280	10.8
Contaminated	207	32	15.5	681	111	16.2
Dirty	150	42	28.0	581	166	28.5

mies with drains are included, the statistics would perhaps be biased against the general surgeon.

The clean wound infection rates of the various departments of Hospital B do not differ significantly (Table VI).

Using the same wound criteria, Altemeier's General Surgical Service of Cincinnati General Hospital achieved a clean wound infection rate of 0.7% over a 14-month period.[22]

The clean wound infection rate is a good guide to the quality of a surgeon's operating technique and is a more meaningful figure than the overall sepsis rate in infection control. The "irreducible minimum" incidence of clean wound infections should be set at less than 1%. When the clean wound infection rate exceeds 2% it has become the practice at Hospital B to review wound infections at the departmental morbidity rounds.

Wound irrigation and topical antibiotics

Neuber of Kiel[23] in 1882 was the first to break away from Lister's antiseptic wound irrigation. He substituted saline irrigations, adopted the cap and gown, developed theatre furniture and instruments that could be sterilized, and introduced aseptic surgery.

Lister did not accept the aseptic method and stated, "... asepsis in this imperfect world is not to be trusted. Human carelessness and fallibility are common and it is safer to have an antiseptic."[24] Lister used carbolic acid to prevent access of bacteria to the wound and also to destroy those already present.

TABLE VI
Clean wound infection rates by department—Hospital B

	No. of surgeons	No. of operations	No. of infections	%
General surgery	7	1007	21	2.1
Gynecology	9	466	16	3.4
Orthopedics	9	620	18	2.9
Neurosurgery	3	138	2	1.4
Plastic surgery	3	88	3	3.4

Although most workers feel that prophylactic systemic chemotherapy has no beneficial effect in preventing wound sepsis,[10,25,26] there has recently been a resurgence of interest in the reduction of bacterial contamination at surgery with topical antiseptics and antibiotics. Meleney[27] states, "These contaminating organisms are on the surface of the wound during and at the end of the operation. They are in relatively small numbers. The area of the wound is blocked off from the circulation by ligatures and firmly closed blood vessels. Antibiotics given systemically, prophylactically, never reach this area. The time to use antibiotics is at the time of operation, applying them in bactericidal concentrations to the surface of the wound, where the organisms are, thus surrounding the bacteria with lethal effect before they have invaded the body."

Garrod[28] advocated that antiseptics, e.g. chlorhexidine, should be re-evaluated because bacteria do not become resistant to them and because they do not cause sensitization.

Experimental topical techniques

Mendelson[29] described how the use of topical penicillin spray to massive wounds in the thighs of goats prolonged survival time, whereas a bacitracin-neomycin spray resulted in only minimal increase. Gingrass, Close and Ellison[30] used standard incisions on the dorsum of guinea pigs, and these were inoculated with a measured quantity of *Staphylococcus aureus*. The wounds were then treated in various ways by topical and/or parenteral methods. They found that saline irrigation, saline scrubbing, hexachlorophene detergent cream (pHisoHex) scrubbing, and neomycin instillation proved worthless in preventing infection. Irrigation with topical neomycin solution was of limited value. When it was utilized in conjunction with gentle scrubbing of the wound a significant reduction in the infection rates occurred. They concluded that bacteria are in tissue niches or covered in clots of serum or blood and are not reached by antibiotics unless the wound surfaces are adequately roughened by gentle scrubbing. They also found that parenteral neomycin failed to prevent infection in a single one of their experimental animals.

Matsumoto *et al.*[31] showed the value of local oxytetracycline in experimental wounds in the rabbit. The mortality figures after local and systemic use of this drug were respectively 1% and 1%.

Hopson *et al.*[32] irrigated experimentally contaminated wounds in guinea pigs with normal saline, 1% cephalothin or 1% kanamycin solution. They found a decrease in the infection rate in the animals treated with topical antibiotics as compared to the rate in those with wounds irrigated with saline alone.

Clinical topical applications

Taylor[33] has shown that saline irrigation of wounds is highly inefficient in removing bacteria from the wound surface. The benefit of irrigation comes from removal of gross foreign material such as fat and blood clots which act as a nidus for bacterial multiplication.

Casten, Nach and Spinzia[34] found that their clean wound infection rate with saline irrigation was 3.5%. In a subsequent comparable series of patients the addition of penicillin reduced the rate to 0.27%.

Ryan[35] described the local use of a penicillin solution in clean wounds and noted a 10-fold reduction in his clean wound sepsis rate. He described 1492 herniorrhaphies with two infections, i.e. a rate of 0.14%.

Nash and Hugh[36] compared two series of patients undergoing colonic surgery, which is always associated with high infection rate (24.1% in Hospital B). These workers applied powdered ampicillin in the wound after closure of the peritoneum in half the cases, and in these patients only one postoperative wound infection occurred. In the control group of 36 patients 14 infections occurred. Thus the infection rates were 3% and 41% respectively.

Heusinkveld[37] used either topical penicillin or bacitracin after saline irrigation of 389 clean and 336 dirty surgical wounds. One wound infection occurred (0.14%).

At Hospital B three surgeons used topical antibiotics. One of two methods was used. One was to irrigate the wound with saline and then one gram of powdered ampicillin was sprinkled into the wound after the peritoneum was closed. The other method was to mix 500 mg. of bacitracin in one litre of saline and to irrigate the wound thoroughly with this solution after the peritoneum had been closed. Other surgeons used saline irrigation alone. The majority used neither irrigation nor topical antibiotics. The results of these different techniques are set forth in Table VII.

The only significant difference is in the clean wounds, where saline irrigation in combination with antibiotics produced the best results.

According to these admittedly small numbers, the chief advantage of a topical antibiotic appears to be in the clean cases. A further analysis of the results of those wounds treated with a combination of irrigation and antibiotics compared irrigation and ampicillin with irrigation and bacitracin. There was no statistically significant difference between the results of these two methods.

In view of these findings the influence of topical antibiotics and irrigation is now being investigated on a larger scale at Hospital B. Lister's method of reducing wound sepsis by means of an antiseptic was brought to an end by the concept of asepsis. It may be that we shall have to revert to a chemotherapeutic agent or an antibiotic to reduce the inevitable wound contamination that occurs at operation. As Fowler[38] states, "It is now evident that we must use the weapon of attack (antisepsis) to supplement our main defence (asepsis)."

No untoward reactions occurred with topical bacitracin solution. In spite of pre-operative questioning about penicillin allergy, four patients who were treated with topical ampicillin developed a pruritic eruption around the wound seven to ten days after the operation. These rashes responded rapidly to antihistamines. Topical ampicillin has the further disadvantage that it may produce sensitization of the patient to the penicillin molecule and thus interfere with future systemic use of this valuable drug.

The role of the surgeon's hands in introducing wound infection

Semmelweiss, in 1847, identified the hands of doctors and students as the carriers of infection in puerperal sepsis. He reduced the mortality of puerperal sepsis by insisting on handwashing in hypochlorite solution. It is ironical that Semmelweiss died of a wound infection the day after Lister applied carbolic acid to the compound fracture of little James Greenlees at the Glasgow Royal Infirmary (August 13, 1865).[56]

Lister cleansed his hands before an operation by soaking them in a 1-in-20 carbolic lotion and suffered severe cracks in his skin and nails. He said that he could always recognize a fellow-Listerian on first shaking hands because the skin was hard and cracked and the nails were brittle.[2]

Halsted developed the surgical glove because his operating-room nurse developed sensitivity to the bichloride of mercury which he used.

TABLE VII

A comparison of sepsis rates in wounds irrigated with saline, or saline and antibiotics, and in wounds untreated with irrigation or antibiotics

	Irrigation Alone			*Irrigation and Antibiotic*			*No Antibiotic*		
	No. of wounds	*No. of infections*	%	*No. of wounds*	*No. of infections*	%	*No. of wounds*	*No. of infections*	%
Clean	275	9	3.3	187	1	0.5	2119	60	2.8
Clean-contaminated	149	7	4.7	125	7	5.6	561	43	7.7
Contaminated	19	3	15.8	33	5	15.2	72	11	15.3
Dirty	14	2	14.3	20	3	15.	30	4	13.3
Overall	457	21	4.6	365	16	4.4	2782	118	4.2

Rubber gloves are not always impermeable to bacteria; Devonish and Miles[39] in 1939 originally observed that some 30% of gloves develop perforations during the course of an operation. Various studies since then have confirmed the finding that about a third of gloves are perforated by the end of each operation.[33] Penikett and Gorrill[40] described a method of testing the integrity of gloves during use. To prevent bacteria-laden sweat from leaking through the glove into the wound various preparations have been tried to reduce the bacterial count inside the glove.

Price[41] showed that scrubbing with soap and water for six minutes reduced the skin flora by only half.

Lowbury and Lilly[42] found that several skin disinfectants were effective in reducing resident organisms on hands. Hexachlorophene has the disadvantage of acting slowly but, because a residue stays on the skin, the skin flora is much reduced after an hour. A further reduction occurs if hexachlorophene is used for all ablutions. Hexachlorophene 3% in liquid soap (pHisoHex) proved the best; 2% in solid soap was considerably less efficacious. To achieve its greatest efficacy hexachlorophene should be used repeatedly and consistently.

Povidone iodine surgical scrub (Betadine) has a greater immediate effect than a single application of hexachlorophene. However, unlike hexachlorophene, this preparation has no prolonged further action inside the glove.[43]

Rinsing the hands in aqueous or alcoholic solution of chlorhexidine is also very efficacious in reducing the bacterial counts. The counts are further decreased with repeated use of this rinse. Lowbury, Lilly and Bull[43] found that the addition of alcoholic chlorhexidine rinse after repeated usage of hexachlorophene reduced the bacterial count in hand washings to zero in four out of nine subjects.

During the present study we compared the incidence of wound sepsis in clean wounds when the surgeon used an iodophor preparation (Betadine), hexachlorophene (pHisoHex), or simply soap and water. None of the surgeons used pHisoHex for all ablutions (Table VIII). The majority preferred iodophor, and their clean wound infection rate in the combined hospital statistics was 3.5%. The rate with the use of hexachlorophene was 3.1%. Those who used soap and water had an infection rate in clean cases of 4.8%. These differences are not statistically significant.

Preparation of the patient's skin

Lister prepared the site of the operation by washing with a 1-in-20 carbolic solution. He never used soap or water.

Lowbury, Lilly and Bull[44] found 1% iodine in 70% alcohol and 0.5% chlorhexidine in 70% alcohol to be the most effective skin antiseptics and significantly better than povidone iodine in reducing the resident skin flora. Because of this work the subcommittee on aseptic methods in the operating suite advocates the use of either 1% iodine in 70% alcohol or 0.5% chlorhexidine in 70% alcohol applied with friction for two minutes as a preoperative skin preparation.[45] A greater reduction in bacterial flora may be obtained if the patient has repeatedly been washed with hexachlorophene detergent cream or povidone iodine.

In this study at Hospital A the preoperative preparation of the patient's skin consisted of an application either of iodophor or a 0.5% solution of chlorhexidine in 70% alcohol.

At Hospital B the preoperative skin preparation consisted of a thorough manual scrubbing of the patient's skin with green soap, which was then washed off with 70% alcohol solution. The infection rate for clean wounds in the two hospitals is outlined in Tables IX and X. Statistically we were unable to detect any significant advantage attributable to any of the three methods.

Plastic skin drapes

Three towelling techniques were used during this study at the two hospitals. After the skin was cleansed and the operative area draped, some surgeons covered the skin with an adhesive plastic drape (Steridrape or Vidrape) while others left the skin exposed. Some orthopedic surgeons applied stockinette with Mastisol adhesive and then incised through this material.

The lowest infection rates were found when the stockinette covered the skin (2.2%). Contrary to the findings of Shepherd and Kinmonth,[46] plastic skin drapes were not associated with a reduction in the wound infection rate. However, in abdominal surgery these drapes would have the advantage that bowel delivered through the wound would not be irritated by contact with skin towels or with antiseptics used to prepare the skin. Because living skin cannot be rendered completely sterile, most surgeons believe that it should be covered while the wound is open.

The resistance of the patient

Certain general factors make the patient more susceptible to wound infection.

Age. It has been shown by the Public Health Laboratory Service in England[8] and by Barnes *et al.*[47] as well as by the N.R.C. study[10] that there is an increase in wound infection rate with advancing years. Fig. 3 indicates the increase in wound infection rate in clean wounds in both hospitals, with advancing age.

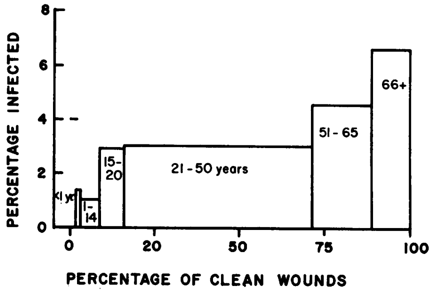


FIG 3.—Clean wound infection rate in relation to age of patient.

In comparison with the total clean wound infection rate a higher infection rate is encountered in patients with diabetes (clean wound infection rate 7.8%) and in patients with extreme obesity (clean wound infection rate 6.9%). The wound sepsis rate was equal in the two sexes, the clean wound rate being 3.5% for males and 3.4% for females.

Resistance of the wound to infection

Kocher and Von Bergman first showed that meticulous hemostasis and gentle handling of wounds were associated with a lower wound sepsis rate. Halsted adopted these views and stressed meticulous attention to operative detail with his principles of complete hemostasis, adequate blood supply, removal of devitalized tissue, obliteration of dead space, use of fine non-absorbable suture material, and wound closure without tension. Elek and Conen[48] have shown that one million staphylococci were needed to produce a pustule after intradermal infection in medical students. They found that the number of bacteria needed to establish infection is reduced 1000-fold if the bacteria are

TABLE VIII
Incidence of infection with different hand-scrub techniques (clean wounds only)

	Hexachlorophene			*Betadine*			*Soap and Water*		
	No. of wounds	*No. of infections*	%	*No. of wounds*	*No. of infections*	%	*No. of wounds*	*No. of infections*	%
Hospital B	333	6	1.8	2,260	65	2.8	16	0	0
Hospital A	689	26	3.8	1,472	65	4.4	218	11	5
Combined	1,022	32	3.1	3,732	130	3.5	234	11	4.8

TABLE IX
Patients' skin preparation (clean cases) Hospital A

Povidone iodine			*0.5% Chlorhexidine in 70% alcohol*			*Other*		
No. of wounds	*No. of infections*	%	*No. of wounds*	*No. of infections*	%	*No. of wounds*	*No. of infections*	%
1,853	79	4.3	483	18	3.7	40	4	10

TABLE X
Patients' skin preparation (clean cases) Hospital B

Soap and alcohol			*Chlorhexidine tincture*			*Other*		
No. of wounds	*No. of infections*	%	*No. of wounds*	*No. of infections*	%	*No. of wounds*	*No. of infections*	%
2,480	60	2.6	112	2	1.7	17	3	17.6

introduced on a silk suture, and they concluded that this was because bacteria could multiply while being protected from the tissue defences in the wound. Howe and Marsden[49] showed that the infective dose could be even further reduced if the tied silk suture contained tissue.

Miles and Niven[50] showed that the non-specific tissue defences are of great importance during the first few hours after inoculation. They showed in experimental animals that the induction of shock to the point of impaired skin perfusion reduced the minimal dose of bacteria necessary to initiate infection up to 10,000-fold. Conolly *et al.*[51] in an experimental study showed that distant trauma increased the susceptibility of the wound to infection and this is probably due to a decrease in the nutritive blood flow to the wound. Sonneland[16] showed that in a series of gastric and colic operations the patients who developed sepsis had lost more blood and received more transfusions than non-septic patients. At Hospital B, 36 patients with clean wounds developed a systolic blood pressure of less than 90 mm. Hg during operation or within the next 24-hour period. Four of these wounds became infected (an infection rate of 11.1%). In the remaining 2573 patients the infection rate was 2.3%.

Drains

Meleney[19] and Lidwell[52] have noted a higher infection rate in drained than in undrained wounds. The N.R.C. study found an infection rate of 11.1% for drained and 5% for undrained wounds. In the present series the infection rate for undrained clean wounds was half that of drained clean wounds. In the N.R.C. study no difference was noted whether the drain was brought through the primary wound or through a separate stab wound. The present study confirms this conclusion (Table XI).

TABLE XI
Drains and clean wound infection rate

	No. of wounds	No. of infections	%
No drain	3963	105	2.6
Stab drain	390	21	5.4
Through wound	473	31	6.6

TABLE XII
Clean wounds

Duration in hours	No. of wounds	No. of infections	%
0-1	3340	86	2.6
2	1313	57	4.3
3	243	25	10.3
4	83	3	3.6
5+	43	3	7.

Duration of the operation

Previous studies have shown that the wound infection rate is increased with prolongation in the operating time.[8,10,52] This may be because the dosage of bacterial contamination of an incision increases with time; because cells are increasingly damaged by exposure to air or to trauma from sponges and retractors; because increased amounts of suture may reduce the local resistance to infection; or because longer procedures are more liable to be associated with blood loss and shock, thereby reducing the patient's general resistance. The apparent decrease in infection rate in operations lasting longer than three hours cannot be explained, but in view of the small numbers involved, no valid statistical conclusions can be drawn.

Preoperative length of stay

There is an increase in infection rate with increasing preoperative stay in hospital (Table XIII and Fig. 4). This observation was also made by the N.R.C. study[10] and the Public Health Laboratory Service study[8]. The two possible explanations are a lowering of the resistance of the patient and an increase in the bacterial contamination.

(*a*) *Decrease in the resistance of the patient.* It might be postulated that those patients who require a long preoperative stay in hospital have a lowered general resistance because of age and other diseases. However, it has been shown[10] that if the statistics are adjusted for age, obesity, diabetes, steroid therapy and contamination at operation, the relationship of an increased infection rate to preoperative hospitalization is not significantly altered.

(*b*) *Bacterial contamination and virulence.* During his preoperative hospital stay the patient becomes increasingly contaminated by bacteria to which he has not developed an immunity, and these bacteria may be antibiotic-resistant. Williams *et al.*[12] showed that an increase in hospital stay is associated with a greater proportion of nasal carriers of coagulase-positive staphylococci. Ketcham and his associates[53,54] showed that these carriers have a higher wound infection rate.

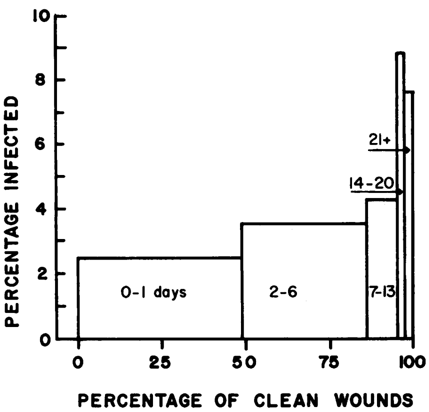


FIG. 4—Clean case infection rate in relation to days spent in hospital before operation (combined hospitals).

TABLE XIII
Clean case infection rate in relation to days spent in hospital before operation (Combined hospitals)

Pre-operative stay (days)	No. of wounds	No. of infections	%
0-1	2468	65	2.6
2-6	1864	68	3.6
7-13	450	19	4.2
14-20	160	14	8.8
21+	130	10	7.7

Conclusions

Certain conclusions and impressions have been gathered from this study:

1. A prospective study is the only accurate means of determining wound infection rate. A method is described which employs a surgical nurse and data-processing techniques. Wounds should be followed up for 28 days postoperatively because 21% of wound infections became evident after the patient had left hospital.

2. The cost of this study amounted to $7000 per year. Although this seems expensive, it is in fact equivalent to the cost of hospitalizing 24 patients with infected wounds for one week (at $300 per week). One dividend of a prospective study is an associated reduction in infection rate. This reduction more than pays for the cost of the program.

3. The clean wound infection rate is more meaningful than the overall infection rate usually quoted in reviews. It is a good guide to the operating techniques of individuals and departments. All clean wounds

that become infected should be reviewed at departmental morbidity rounds.

4. The groundwork for succeeding wound infection is laid in the operating theatre, either by introducing a large dose of bacteria or by reducing the local resistance of the wound. Wound infection would be reduced more by attention to Halsted's principles than by more rigid aseptic techniques. The avoidance of hematomas and dead space is more important, for instance, than prolonged hand and skin scrubbing, additional drapes and gowns, etc. The use of topical antibiotics and chemotherapy deserves more study.

5. Although most organisms cultured from infected wounds can be traced bacteriologically to the wards rather than to the operating room[55] we believe that only a minority of septic wounds are due to ward cross-infection. This conclusion is based on the observation that different surgeons doing the same operation using the same wards have consistently different infection rates. Wounds with a low resistance will tend to become infected by available pathogens.

Résumé

L'infection des plaies chirurgicales

Avec l'aide d'une infirmière spécialiste en chirurgie et l'emploi d'ordinateurs, nous avons entrepris une étude clinique de prospection, destinée à établir la proportion des plaies infectées observées dans deux hôpitaux de Calgary. Le pourcentage global de plaies infectées a été de 5.2%, celui des plaies non infectées de 3.5%. Ce dernier chiffre est le plus significatif, car il permet de comparer la situation entre hôpitaux, spécialités et individus et peut représenter un critère d'évaluation de la morbidité dans les hôpitaux. C'est dans la salle .d'opération que sont créées les conditions conduisant aux infections de plaies et nous estimons qu'on réduirait ce risque bien plus par l'observance des principes de Halsted que par l'application d'une asepsie plus rigoureuse. On évalue à 1.5 million de dollars par année le coût du traitement des plaies infectées pour la province d'Alberta et en frais d'hospitalisation uniquement. Ce qui représente, grosso modo, $1.00 par personne et par année. Or le coût annuel de la présente étude est d'environ $7,000. C'est donc l'équivalent des frais d'hospitalisation de 24 cas de plaies infectées pendant une semaine (à raison de $300. par semaine). Un des avantages qu'offre une étude de prospection est la diminution du pourcentage des infections. A elle seule, cette réduction justifie amplement pareille entreprise.

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