Acta Orthop. Scand. *58*, 4–13, 1987

Ultraclean air and antibiotics for prevention of postoperative infection

A multicenter study of 8,052 joint replacement operations

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To determine the value of ultraclean air in operating rooms, 8,052 operations for total hip- or knee-joint replacement were followed up for 1–4 years. For operations done in ultraclean air, bacterial contamination of the wound, deep joint sepsis, and major wound sepsis were substantially less than for operations done in conventionally ventilated rooms. Sepsis was also less frequent when prophylactic antibiotics had been given. The two precautions acted independently so that the incidence of sepsis after operation in ultraclean air and with antibiotics was much less than that when either was used alone. Wound sepsis was associated with an enhanced risk of joint sepsis. *Staphylococcus aureus* was the commonest joint pathogen, but infections with other organisms, often considered to be of low pathogenicity, were almost as numerous. Most *S. aureus* infections were traced to sources in the operating room.

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This paper summarizes seven papers on the Medical Research Council's prospective trial of ultraclean operating-room air for the control of infection during joint-replacement operations (Lowbury & Lidwell 1978, Lidwell et al. 1982, 1983a, 1983b, 1984, 1985, Whyte et al. 1983b) which give more detail of the methods and more justification for the conclusions that are reviewed here.

Operations for joint replacement call for exceptional aseptic measures to counter the enhanced risks of bacterial contamination of the wound from the large exposure during the operation, and the influence of a massive implant (Charnley 1964a), especially when cemented (Petty et al. 1985). Ultraclean-air techniques to minimize contamination were developed by Charnley (1964a, 1979, 1980). He specified a rapid downflow of filtered air over the operating area and containment of bacteria from the surgical team by exhaust-ventilated whole-body suits. His results, showing reduction in the incidence of joint sepsis from more than 10 per cent to less than 1 per cent during 1959–70 (Charnley 1964b, 1979, Charnley & Eftekhar 1969), appeared to support his claims for the value of the system, but other improvements in technique might have contributed to the results (Charnley 1972). Charnley did not use prophylactic antibiotics in the belief, widely held in the 1960s, that they might increase the incidence of sepsis (Committee on Trauma 1964). However, other groups used them systemically (Fitzgerald et al. 1977) and as an addition to the cement (Bucholtz et al. 1979) and, working in conventionally ventilated operating rooms, claimed sepsis rates as low as those reported by Charnley. There was, therefore, in the early 1970s, no consensus on the value of

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ultraclean air nor on the prophylactic use of antibiotics. But a deep joint sepsis rate of more than 1 per cent was unacceptable because of the serious consequences for the patient and the high cost of treating a septic joint (Howorth 1984). After discussions between the Department of Health & Social Security and the Medical Research Council in 1973, a prospective controlled trial was set up.

Patients and methods

It was decided that the trial should, at least, be able to demonstrate a reduction in the sepsis rate from 2 per cent to 1 per cent. To have a 90 per cent chance of doing this at the 95 per cent level of significance for comparisons between conventional and ultraclean-air operating rooms where (a) the staff wore conventional clothing or (b) the staff wore body-exhaust suits or plastic patient-isolators (Trexler 1973) were used, about 7,500 operations would have to be monitored. To do this in a reasonable time, a multi-hospital trial was necessary (Lowbury & Lidwell 1978, Lidwell et al. 1982).

General plan

The operations in each group were performed in otherwise identical circumstances; each surgeon operated on patients randomly allocated to rooms with conventional (control) or ultraclean-air ventilation. The "conventional" systems were not all identical, but all were positive-pressure systems delivering 15–25 air changes per hour (Medical Research Council, 1972). To ensure that the ventilation systems were functioning correctly and to determine the performance of the several systems in use, air samples were taken during some 10 per cent of operations, by a Casella slit sampler or Sartorius gelatine-membrane filter about 30 cm from the wound. All the samples were incubated at 37° C aerobically and, at two hospitals, anaerobically. To allow for plate contamination, which could be significant in relation to the very low bacterial content of air from the most effective ultraclean systems, dummy samples were taken without airflow through the sampler.

Four Swedish and fifteen British hospitals took part in the trial. Each hospital recorded operations for total hip- or knee-joint replacement for 3 years and followed up each patient until the end of the fourth year. The first operation was recorded in 1975 and the last one at the end of July 1979, and follow-up records ceased at the end of July 1980. The number of operations recorded was 8,316, of which 8,052 complied with the protocol. Of these, 6,782 were hip-joint and 1,270 were knee-joint operations. A selected group of patients was followed up until the end of 1984, a maximum time of 10 years (Lidwell et al. 1985).

Clinical and bacteriological records

At each hospital a research nurse entered, on standardized forms, details of each patient: diagnosis, operation, and subsequent inpatient and outpatient history. At 14 of the hospitals the exposed tissues were examined bacteriologically, after insertion of the prosthesis, by a washout technique (Lidwell et al. 1983b). At 13 of these hospitals, nose swabs were taken, at or about the time of operation, from the patient and operating-room staff; strains of *Staphylococcus aureus* isolated from them were compared, by phage typing, with strains later isolated from septic wounds or joints (Lidwell et al. 1983a, 1984).

Postoperative wound sepsis, without involvement of the joint, was recorded as major, minor, or "possible," according to the clinical picture. The form also provided for recording specified clinical signs during the postoperative period. Bacterial cultures were made from wounds possibly or manifestly septic (Lidwell et al. 1984).

Joint sepsis. Reoperation, for any reason, was recorded; each such record was scrutinized and, on the basis of clinical, bacteriological, and histological findings, was classified as indicating strong evidence of joint sepsis, evidence of possible sepsis, or no evidence of sepsis. "Suspected" joint sepsis was recorded when, usually on grounds of abnormal pain, the surgeon considered that the joint was probably septic, but this could not be confirmed because reoperation had not been done; an extended follow-up of these patients was made (Lidwell et al. 1985).

Analysis of results

For the principal comparison between operations done in control and in ultraclean conditions randomization ensured that the ratio of the incidence of joint sepsis between them was a valid measure. But there were many other comparisons that could be made on which the possible effect of other variables could not be ignored. In some cases, for which only one or two such variables were involved, a simple standardization procedure was sufficient. In others, more complex statistical procedures were needed. All the data were, therefore, analyzed by a logistic sequential multiple-regression program by which these other effects could be evaluated and a check obtained on the validity of results from the simpler methods (Lidwell et al. 1984).

Results and discussion

Bacterial content of the air

For all ventilations systems and for the dummy samples, there was much variation between the hospitals (Figure 1). The wide variation between conventionally ventilated rooms – tenfold between the highest and lowest values – was probably the result of differences in operating- room procedures, including the number and activity of persons in the room and in bacterial dispersal from different individuals (Lidwell et al. 1983b). The same factors probably accounted for much of the variation between the results from ultraclean-air rooms with similar ventilation systems. Blowers (1963) has pointed out the extent to which operating-room practice and discipline can contribute to reduction of airborne contamination.

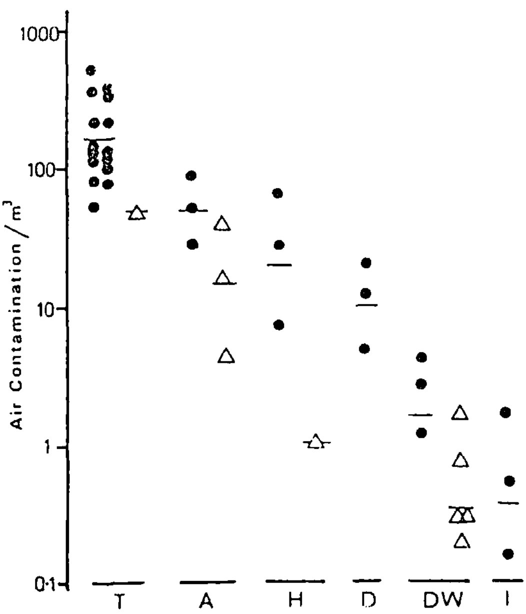

Figure 1. Bacterial contamination of operating-room air in relation to ventilation system. T = good positive-pressure turbulent ventilation (the control rooms); A = Allander system, which includes an air curtain around the working area (Able & Allander 1966); H = horizontal ("laminar") airflow; D = unidirectional downflow *without* walls around the operating zone below 2 m from the floor; DW = as D, but *with* walls down to near floor level; I = operations within a plastic patient-isolator (Trexler 1973). ● = the median value in one operating room when conventional clothing was worn and △ when body-exhaust suits were worn. The short horizontal lines indicate the median value for each system. The distribution of counts for each system was generally log normal; the medians were therefore approximated by calculating the log means.

Vertical-flow ventilation was more effective than horizontal ventilation, especially when combined with walls around the operating area down to 30 cm from the floor. The wearing of body-exhaust suits led to further substantial reduction in the number of airborne bacteria. Whyte et al. (1983a) have reported comparable reduction from the wearing of suitably designed operating-room clothing, without exhaust ventilation from them, and made from appropriate fabrics.

On the basis of these results and the incidence of joint sepsis in relation to them, recommendations have been made for standards of air contamination and methods of testing to ensure that they are attained (Whyte et al. 1983b).

Wound contamination during operation

The isolation of bacteria from the wounds by washout differed considerably between hospitals (Lidwell et al. 1982, 1983b), but at every hospital was less for operations done in ultraclean air than for those done in conventionally ventilated rooms. The median bacterial count in samples from wounds in the control rooms was 4.5 and for those from the ultraclean rooms was 1.5 if conventional clothing was worn, but only 0.6 when body-exhaust suits were worn – not significantly different from the value of 0.7 recorded as procedural contamination of dummy samples. The actual contamination in these conditions must therefore have been very small. More detailed analysis (Lidwell et al. 1983b) suggested that in conventionally ventilated rooms around 95 per cent of the bacteria reaching the wound had been airborne, some entering by direct sedimentation and some via instruments, gloves, etc. contaminated from the air (Whyte et al. 1982). Only in the cleanest air, with fewer than 5 bacteria-carrying particles/cu.m, did sources of contamination other than the air begin to predominate (Lidwell et al. 1983b).

Confirmed deep joint sepsis

In the main study the longest follow-up time was 4 years and the median follow-up time was about 2.5 years. During this time, joint sepsis was confirmed in 86 patients. Another 41 patients were reckoned to be possibly septic. There were 241 reoperations for various reasons without any evidence of infection (Table 1). Of the 86 cases of confirmed sepsis, only 11 (13%) were recorded within 3 months of operation. This is similar to the experience of Charnley (1979) with operations done after 1968; he records the complete disappearance of the early fulminating infections seen before that date.

The effect of operating in ultraclean air. The incidence of joint sepsis was much less when the prosthesis had been inserted in ultraclean air. In strictly randomized comparisons (Lidwell et al. 1982), the overall incidence ratio, control:ultraclean, was 2.6:1 (with a confidence range of 1.6–4.2 per cent). The ratio was markedly greater (4.5:1) when air contamination was minimized by the wearing of a patient isolator than when conventional clothing was worn in ultraclean air, the ratio then being 2.0:1. There was, however, no difference between the frequency of reoperation after arthroplasties done in ultraclean air and of those done in the control rooms when there was no, or only inconclusive, evidence of joint sepsis at reoperation.

If the operating rooms are grouped according to the level of air contamination within them, with 6–9 hospitals in each group, the incidence of joint sepsis shows a progressive fall with reduction of air contamination (Lidwell et al. 1983b) (Figure 2).

Assessing the effect of prophylactic antibiotics was not a primary object of the study, and operations were not randomized with respect to it. The comparisons are therefore confounded by interhospital differences in the risk of sepsis and the preferences of individual surgeons on the use of antibiotics. However, the apparent effect of antibiotics was substantial,

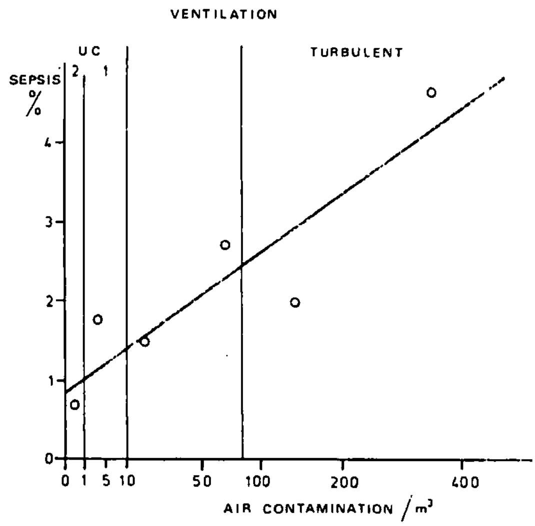

Figure 2. The incidence of confirmed joint sepsis, computed for operations without antibiotic prophylaxis, in the six groups of hospitals into which the data were divided according to the level of air contamination. The incidence for operations with antibiotics will be about a quarter of these values. Each group includes data from 6–9 hospitals. The vertical lines divide the figure into four ranges of air contamination. From right to left: (a), that resulting from conventional (TURBULENT) ventilation and clothing; (b), with relatively ineffective special ventilation; (c), with effective ultraclean (UC) ventilation; this range is further divided into (1) air contamination > 1/m³, when conventional clothing was worn and (2) air contamination < 1/m³, when body-exhaust suits or other equally effective clothing was used.

with a simple incidence ratio, not-used:used, of 4.0:1 (Table 2). At 14 hospitals, prophylactic antibiotics were given routinely either to the great majority of patients or to only a small minority (Lidwell et al. 1984). At the five other hospitals, prophylactic antibiotics were given by almost every surgeon to 38–58 per cent of the patients; for these, it was possible to compare the incidence of sepsis in the patients not receiving antibiotics with that among patients in the same hospital who were given them. The ratio in favor of antibiotics in these hospitals was 2.5:1, somewhat less than that for all the

Table 1. Number of reoperations (per cent) in relation to operating-room ventilation and joint sepsis. (Lidwell et al. 1982).

	Conventional 4.133 operations	Ultraclean 3.922 operations	Ratio control ultraclean
No evidence of sepsis	119 (2.9)	122 (3.1)	0.9
Some evidence of sepsis	20 (0.5)	21 (0.5)	0.9
Confirmed sepsis	63 (1.5)	23 (0.6)	2.6

Table 2. Joint sepsis in relation to combined use of ultraclean air and prophylactic antibiotics. (Lidwell et al. 1984).

Operating-room conditions	Without antibiotics		With antibiotics		Ratio with/without antibiotics
	Number of operations	Number (per cent) septic	Number of operations	Number (per cent) septic	
Control	1,161	39 (3.4)	2,968	24 (0.8)	4.2
Ultraclean air with					
conventional clothing	516	8 (1.6)	1,279	9 (0.7)	2.2
body-exhaust suit or plastic patient-isolator	544	5 (0.9)	1,584	1 (0.1)	14.6
Total	2,221	52 (2.3)	5,831	34 (0.6)	4.0

hospitals together; but at these five hospitals, the patients given antibiotics were probably chosen because they were considered to be more at risk of contracting infection. If this was so, the apparent benefit from antibiotics would be less than for all the hospitals together. A fully randomized study in France has compared placebo with cefazolin in hip-replacement operations and recorded a sepsis incidence ratio of 3.5:1 in favor of antibiotics (Hill et al. 1981), very similar to the value from our study.

Table 2 shows not only that ultraclean air and prophylactic antibiotics substantially reduced the incidence of joint sepsis, but also that they acted independently and combined in a multiplicative fashion. The observed rates were almost exactly those that can be calculated on the assumption that, compared with the control conditions, the use of ultraclean air halved the sepsis rate, the use of body-exhaust suits or a plastic patient-isolator approximately halved it again (together to 1/4.5), and that prophylactic antibiotics further reduced it to a quarter of that without their use (Lidwell et al. 1984).

As would be expected, benzyl and other penicillins inactive against intestinal-type organisms had no effect on infection with these species, but these were controlled by ampicillin, gentamicin, or the cephalosporins. There were nine infections with organisms of this type among 2,655 patients receiving cloxacillin or flucloxacillin alone, whereas there were no infections among 2,528 patients who had received systemic ampicillin + flucloxacillin or a cephalosporin, or gentamicin in the cement (Lidwell et al. 1983a). The very low incidence of joint sepsis, 1 case after 1,584 operations when prophylactic antibiotics, ultraclean air, and body-exhaust suits were all used, is very striking.

Bacterial contamination of the wound at operation in relation to joint sepsis. Wound-washout counts and joint sepsis were less for operations done in ultraclean air than for those done in the control rooms. Regression analysis showed that lower rates of joint sepsis were experienced by patients from whose tissues the washout during operation had yielded fewer bacteria.

Bacterial species found in septic joints. Of the instances of sepsis, 31 per cent were associated with *S. aureus*. There was a similar proportion with common skin commensals, such as *S. epidermidis* or *Propionibacterium* (Kamme & Lindberg 1981, Whyte et al. 1981), often considered harmless; failure to isolate or report these may have been responsible for the "sterile sepsis" reported in much early work. Intestinal species were found in 15 per cent of septic joints and 21 per cent yielded no growth.

S. aureus from 14 of the septic joints could be compared by phage typing with strains from the operating-room staff. A possible source of infection was traced for 12 of them (Table 3).

From 19 patients who later developed joint sepsis due to *S. aureus*, a wound washout was obtained during the operation, but the organism was isolated from only 4 of them, though it probably entered the wound a that time. It therefore seems that the washout technique was only 20–25 per cent effective in detecting bacteria in the wound, similar to the 24 per

Table 3. Possible sources of infection with Staphylococcus aureus *indicated by phage-type similarity after operation at which nose swabs had been obtained from patient and staff. (Lidwell et al. 1983a, 1984).*

Possible source	Number of *S. aureus* isolations from	
	Wound not followed by joint sepsis (103 operations)	Septic joint (14 operations)
In operating room		
Surgeon	9 + 1/2[a]	2
Other staff	12 + 1/2[a]	8
Patient	28	2
None found	53	2

[a]Identical phage type a possible source from surgeon or another member of staff.

cent reported by Whyte et al. (1982). *S. aureus* was isolated from only 1.6 per cent of 3,825 wound washouts. This was not significantly affected by prophylactic antibiotics, but did vary according to air contamination; it was 2 per cent for operations in conventionally ventilated rooms, but only 1.3 per cent in ultraclean air. If *S. aureus* was isolated from only 20–25 per cent of the wounds actually contaminated by it, the isolation rate of 2 per cent in washouts in conventionally ventilated rooms would correspond to actual contamination of 8–10 per cent. The incidence of S. aureus joint sepsis after operations in these rooms was 1.4 per cent (16/1,161), or about 1 in 6 of those probably contaminated at the time (Lidwell et al. 1983a). Additional instances of sepsis recorded during extended follow-up (Lidwell et al. 1985) suggest, however, that the ultimate proportion may be around 1 in 3. Although sepsis due to *S. aureus* usually manifests itself earlier than that due to some other species, late staphylococcal sepsis does occur.

Suspected joint sepsis

The incidence of "suspected" joint sepsis for operations done in ultraclean air was lower than that for operations done with conventional ventilation (ratio 1:2.16). It was also less when prophylactic antibiotics had been given (ratio 1:2.33) (Lidwell et al. 1984). The similarity of these ratios to those for confirmed joint sepsis (1:2.6 and 1:4.0) given above suggests that most of the "suspected" cases were, indeed, septic.

The follow-up in the main study was relatively short, a median of about 2.5 years. Most of the patients with "suspected" sepsis (72 of 85) were therefore studied for a longer period, together with 97 matched controls (Lidwell et al. 1985). This extended follow-up was for up to 10 years from the date of operation with a median of about 7 years. Of the patients with "suspected sepsis," 19 (26 per cent) had a reoperation during the extended follow-up and 11 of them were confirmed as septic; 16 more had suffered serious problems, with 6 classed as septic and 9 calling for reoperation, but the patient's general condition made this impracticable in some cases. The corresponding figures for the matched controls were 9 (9 per cent) reoperated with 4 septic, and 9 more (9 per cent) with continuing problems, but none classed as septic, with 3 calling for reoperation. These findings suggest that only about half of the sepsis that manifested itself over 7 years had been observed during the main follow-up period of about 2.5 years. The failure rate, without apparent sepsis, was about 5 per cent at the end of 7 years (Lidwell et al. 1985).

Postoperative wound (not joint) sepsis

Major and minor wound sepsis, as assessed clinically by the surgeon, could not be clearly differentiated from each other in terms of objective signs. For major sepsis, the proportion of wounds associated with sinus, hematoma, abscess, or discharge of pus was higher, and pathogenic bacteria were more often isolated, but there was much overlap between the two grades. However, the effect of operating in ultraclean air, the apparent sources of *S. aureus* and the risk of subsequent joint sepsis were very different for the two groups.

The incidence of major wound sepsis was less after operation in ultraclean air than in the control rooms, and the reduction was similar to that for joint sepsis (Lidwell et al. 1984); it was also less when prophylactic antibiotics were used (Table 4). In contrast, minor wound sepsis was only slightly reduced by these factors.

Confirmed wound sepsis was closely related to the risk of subsequent joint sepsis,. The

Table 4. Incidence of postoperative wound (not joint) sepsis in relation to operating-room ventilation. (Lidwell et al. 1984).

Antibiotic prophylaxis	Grade of sepsis	Wound sepsis (per cent) after operation in room with	
		Conventional ventilation	Ultraclean air
None	Major	2.3	0.7
	Minor	5.1	5.2
Given	Major	0.6	0.45
	Minor	3.7	2.9
All operations	Major	1.1	0.5
	Minor	4.1	3.5

chance of developing joint sepsis was 30 per cent after major wound sepsis, 2.8 per cent after minor or doubtful wound sepsis, and only 0.7 per cent for wounds that healed normally (Table 5). Surin et al. (1983) reported similar differences. Suspected joint sepsis was also more frequent after wound sepsis, which is consistent with the view that such cases were usually genuine sepsis. However, nearly two thirds of confirmed (and 70 per cent of suspected) joint sepsis were not preceded by wound sepsis or any suspicion of it.

When *S. aureus* wound sepsis was followed by joint sepsis, it was nearly always with the same species and phage type, i.e., probably the same organism, in 11 out of 12 cases for which data were available. Intestinal species were isolated from four septic joints that followed wound sepsis; in three of these the same species was isolated from the wound and the joint.

For about half of the wounds that were not followed by joint sepsis, but from which *S. aureus* was isolated from a postoperative wound swab, it was possible to compare the phage types of the isolates with those from the noses of patients and staff present at the initial operation. Unlike the strains from septic joints, less than 50 per cent of those from the wounds were of phage type similar to that from any of the nasal carriers; and in more than half of these, the patient appeared to be the source (Table 3). These differences between the sources of superficial and of deep joint sepsis suggest different mechanisms of infection, most of the superficial infections being acquired not in the operating room, but perhaps, in the ward. Differences in the etiology of superficial and deep infections were postulated by Charnley & Dandy (1974) with reference to ultraclean air, and by Josefsson et al. (1981) with reference to gentamicin-loaded cement. Our results confirm these views and suggest that clinical differentiation of wound sepsis into major and minor corresponds to a significant difference in origin and prognosis.

Table 5. Association of wound sepsis with later joint sepsis[a]

Grade of wound sepsis (No. of operations)	Number (per cent) of patients with indicated association: Not reoperated but "suspected" joint sepsis	Reoperated and confirmed joint sepsis
Healed normally (7.423)	60 (0.8)	51 (0.7)
"Possible" (257)	7 (2.6)	8 (3.1)
Minor (308)	9 (2.9)	8 (2.6)
Major (64)	9 (14.1)	19 (29.7)

[a] Lidwell et al. 1984

Effect of type of joint disease

There were moderate, but statistically insignificant, differences in the rates of sepsis between patients with rheumatoid arthritis and those with osteoarthrosis. There were, however, proportionately more instances of major wound sepsis in the rheumatoid group, 21/1,169 (1.53 per cent) compared with 43/6683 (0.64 per cent) for the osteoarthrosis group – a simple uncorrected ratio of 2.38:1; for confirmed joint sepsis, the proportions were 20/1,369 (1.46 per cent) and 66/6,683 (0.99 per cent), respectively, an uncorrected ratio of 1.48:1. Because there were strong associations between a diagnosis of rheumatoid arthritis, the use of antibiotics, and an operation on the knee, these simple ratios were recalculated to introduce stadardization for use of antibiotics, the joint operated on, and whether reoperation had been in ultraclean air. This reduced them to 2.11:1 for major wound sepsis and to 1.28:1 for joint sepsis, neither being significant at the 0.05 level. The last ratio is considerably less than the 4.7:1 reported by Charnley (1979) and 4.2:1 reported by Fitzgerald et al. (1977), but other authors have reported no evidence of a greater risk associated with rheumatoid arthritis (Lidgren 1973, Poss et al. 1976). The assessment of risk for this minority group is necessarily imprecise and all the data quoted, including those from our study, are consistent with an increased risk ratio of sepsis for the rheumatoid patient of about 2:1 (Lidwell et al. 1984).

Other preoperative or operative procedures

Many factors were examined by the multiregression analysis. It revealed no significant increase in the risk of infection for patients who had had previous surgery on the joint. This differs from the experience of Charnley (1979), Bucholtz et al. (1979), and Stuhmer (1976) , but the numbers were small and the types of operation not necessarily comparable.

Because three fourths of the patients who had received steroids suffered from rheumatoid arthritis, it was not possible to evaluate the effect of steroids independently of this diagnosis.

Suspected joint sepsis was reported more frequently after trochanteric osteotomy than when this procedure was omitted. However, both were closely associated with abnormal pain. This may have led to the diagnosis, but the pain had been due to mechanical causes, particularly the attachment wiring, rather than to infection.

Anticoagulants were administered to only 901 patients, and we could not draw conclusions on their association with sepsis.

Antibiotic-loaded cement was used in only two hospitals and the effects were therefore confounded by interhospital differences. Its effect on the incidence of sepsis was not detectably different from that of systemic antibiotic prophylaxis. Among these patients, there was a higher-than-average incidence of reoperation not associated with sepsis, and of postoperative pain. Conversely, the use of CMW cement, without antibiotic loading, appeared to be associated with a lower incidence of major wound sepsis than when other cements, also without incorporated antibiotic, were used. All of these differences are of very doubtful significance.

Among other factors that showed no correlation with sepsis were the use of adhesive drapes, wound irrigation, type of incision, and duration of operation.

Cost and benefit

Whereas pain and disability cannot readily be equated with monetary values, it is reasonable to compare the cost of measures to prevent infection with that of dealing with joint sepsis when it occurs. The costs for prophylactic antibiotics and for ultraclean-air systems have been so calculated and expressed as cost per septic joint prevented (Lidwell 1984).

Although the use of prophylactic antibiotics gives the greatest return for money expended, comparison with the direct cost of dealing with a septic joint (Howorth 1984) shows that implementing any or all of the effective precautions discussed in this paper is substantially less costly to the health service than dealing with the joint sepsis avoided by so doing. This may sometimes be more realistically expressed as "opportunity cost," that is, "the benefits foregone by not using the resources in their next best use" (Cohen 1984), for example, carrying out more primary operations.

Acknowledgements

We thank the many patients, surgeons, nurses, and microbiologists who participated in this study, and the Department of Health & Social Security and the Medical Research Council for financing the British part of the study.

The hospitals that contributed to the data presented here and in the earlier papers were Aberdeen Royal Infirmary; Academic Hospital, Uppsala; Bethnal Green Hospital, London; Chester City Hospital; Gartnavel General Hospital, Glasgow; Harlow Wood Orthopaedic Hospital, Nottingham; Huddinge Hospital, Stockholm; The London Hospital; Malmö General Hospital; Northern General Hospital, Sheffield; Northwick Park Hospital, Harrow; The Nuffield Orthopaedic Centre, Oxford; The Royal Orthopaedic Hospital, Birmingham; The Royal Postgraduate Medical School, London; The Robert Jones and Agnes Hunt Orthopaedic Hospital, Oswestry; St Thomas' Hospital, London; Stracathro Hospital, Brechin; The University Hospital, Lund.

References

Abel, E. & Allander, C. (1966) Undersökning av nytt inblåsnings system för rena rum. V. V. S. (Stockholm) 8 , 1–12.

Blowers, R. (1963) Operating-room practice. In: *Infection in hospital* (Eds. Williams, R. E. O. & Shooter, R. A.), pp., 202–203. Blackwell Scientific Publications, Oxford.

Bucholtz, H. W., Elson, R. & Lödenkamper, H. (1979) The infected joint implant. In: *Recent advances in orthopedics* , No. 3,(Ed. McKibbin, R.), pp. 139–161. Churchill Livingstone, Edinburgh

Charnley, J. (1964a) A sterile-air operating theatre enclosure. *Br. J. Surg.* **51**, 195–202.

Charnley, J. (1964b) A clean-air operating enclosure. *Br. J. Surg.* **51**, 202–205.

Charnley, J. (1972) Post-operative infection after total hip replacement with special reference to contamination in the operating room. Internal publication no. 38, Centre for Hip Surgery, Wrightington Hospital, Wigan, Lancs., UK.

Charnley, J. (1979) *Low friction arthroplasty of the hip: theory and practice*, pp. 152–183. Springer-Verlag, Berlin.

Charnley, J. (1980) Theatre design. In: *Controversies in surgical sepsis.* (Ed. Karran, S.) Ch. 1. Praeger, New York.

Charnley, J. & Dandy, F. (1974) Wound infection after total hip replacement performed in a clean air operating room. Internal publication no. 45, Centre for Hip Surgery, Wrightington Hospital, Wigan, Lancs., UK.

Charnley, J. & Eftekhar, N. (1969) Postoperative infection in total prosthetic replacement arthroplasty of the hip joint. With special reference to the bacterial content of the air of the operating room. *Br. J. Surg.* **56**, 641–649.

Cohen, D. R. (1984) Economic issues in infection control. *J. Hosp. Infect.* **5**(Suppl. A), 17–25.

Committee on Trauma, NAS-NRC (1964) The influence of ultraviolet irradiation on the operating room and of various other factors. *Ann. Surg.* **160**, see p. 125.

Fitzgerald, R. H. Jr., Nolan, D. R., Ilstrup, D. M., Van Scoy, R. E., Washington, J. A. & Coventry, M. B. (1977) Deep wound sepsis following total hip arthroplasty. *J. Bone Joint Surg.* **59**-A, 847–855.

Hill, C. , Flamant, R., Mazas, F. & Evrard, J. (1981) Prophylactic cefazolin versus placebo in total hip replacement. *Lancet* **i** , 795–796.

Howorth, F. H. (1984) The air in the operating theatre. In: *The design and utilization of operating theatres.* (Eds. Johnston, I. D. A. & Hunter, A. R.), pp. 58–59. Edward Arnold, London.

Josefsson, G., Lindberg, L. & Wiklander, B. (1981) Systemic antibiotics and gentamicin-containing bone cement in the prophylaxis of postoperative infections in total hip arthroplasty. *Clin. Orthop.* **159**, 194–200.

Kamme, C. & Lindberg, L. (1981) Aerobic and anaerobic bacteria in deep infections after total hip arthroplasty. *Clin. Orthop.* **154**, 201–207.

Lindgren, L. (1973) Orthopaedic infections in patients with reheumatoid arthritis. *Scand. J. Rheumatol.* **2**, 92–96.

Lidwell, O. M. (1984) The cost implications of clean air systems and antibiotic prophylaxis in operations for total joint replacement. *Infect. Control.* **5**, 36–37.

Lidwell, O. M., Lowbury, E. J. L., Whyte, W., Blowers, R., Stanley, S. J. & Lowe, D. (1982) Effect of ultraclean air in operating rooms on deep sepsis in the joint after total hip or knee replacement: a randomised study. *Br. Med. J.* **285**, 10–14.

Lidwell, O. M., Lowbury, E. J. L., Whyte, W., Blowers, R., Stanley, S. J. & Lowe, D. (1983a) Bacteria isolated from deep joint sepsis after operation for total hip or knee replacement and the sources of infections with *Staphylococcus aureus* *J. Hosp. Infect.* **4**, 19–29.

Lidwell, O. M., Lowbury, E. J. L., Whyte, W., Blowers, R., Stanley, S. J. & Lowe, D. (1983b) Airborne contamination of the wound in joint replacement operations: the relationship to sepsis rate. *J. Hosp. Infect.* **4**, 111–131.

Lidwell, O. M., Lowbury, E. J. L., Whyte, W., Blowers, R., Stanley, S. J. & Lowe, D. (1984) Infection and sepsis after operations for total hip or knee-joint replacement: influence of ultraclean air, prophylactic antibiotics and other factors. *J. Hyg. (Camb.)* **93**, 505–529.

Lidwell, O. M., Lowbury, E. J. L., Whyte, W., Blowers, R., Stanley, S. J. & Lowe, D. (1985) Extended follow-up of patients suspected of having sepsis in the joint after total joint replacement. *J. Hyg. (Camb.)* **95**, , 655–664.

Lowbury, E. J. L. & Lidwell, O. M. (1978) Multi-hospital trial on the use of ultraclean air systems in orthopaedic operating rooms to reduce infection: preliminary communication. *J. R. Soc. Med.* **71**, 800–806.

Medical Research Council and Department of Health & Social Security (1972). *Report of a joint working party on ventilation of operation suites.* Medical Research Council, London.

Petty, W., Sanier, S., Schuster, J. & Silverthorne, C. (1985) The influence of skeletal implants on the incidence of infection: experiments in a canine model. *J. Bone Joint Surg.* **67**-A, 1236–1244.

Poss, R., Ewald, F. C., Thomas, W. H. & Sledge, C. B. (1976) Complications of total hip-replacement arthroplasty in patients with rheumatoid arthritis. *J. Bone Joint Surg.* **58**-A, 1130–1133.

Stuhmer, G. (1976) Loosening of prostheses. In: *Total hip prostheses* . (Eds. Geschwend, N. & Debnenner, H. V.) Huber, Berne.

Surin, V. V., Sundholm, K. & Bäckman, L. (1983) Infection after total hip replacement. With special reference to discharge from the wound. *J. Bone Joint Surg.* **65**-B, 412–418.

Trexler, P. C. (1973) An isolator system for the maintenance of aseptic environments. *Lancet* **i.**, 91–93.

Whyte, W., Hodgson, R., Tinkler, J. & Graham, J. (1981) The isolation of bacteria of low pathogenicity from faulty orthopaedic implants. *J. Hosp. Infect.* **2**, 219–230.

Whyte, W. Hodgson, R. & Tinkler, J. (1982) The importance of airborne bacterial contamination of wounds. *J. Hosp. Infect.* **3**, 123–135.

Whyte, W., Bailey, P. V., Hamblen, D. L., Fisher, W. D. & Kelly, I. G. (1983a) A bacteriological occlusive clothing system for use in the operating room. *J. Bone Joint Surg.* **65**-B, 502–506.

Whyte, W., Lidwell, O. M., Lowbury, E. J. L. & Blowers, R. (1983b) Suggested bacteriological standards for air in ultraclean operating rooms. *J. Hosp. Infect.* **4**, 133–139.