AN INVESTIGATION INTO WOUND INFECTION AND ABSCESS FORMATION IN A MINE*

E. D. SONNENFELD,† *Senior Assistant Medical Officer, Goldfields East Native Hospital,* AND H. J. KOORNHOF, S. HAYDEN-SMITH AND R. G. ROBINSON, *Department of Bacteriology, South African Institute for Medical Research, Johannesburg*

The development of abscesses in Bantu mineworkers has for a long time been a problem in the mines and a cause of many lost shifts. In 1964 it was decided to investigate the epidemiology of this problem at a gold mine on the East Rand, and to determine whether the source of infection was the patient, his contacts, or his environment. Information obtained from such a study could form the basis of a rational approach to the prevention of these infections. A predominantly endogenous source of infection, e.g. the skin, would be amenable to prophylaxis by suitable skin antiseptic preparations, while exogenous factors, if found to be important, would be more costly and difficult to eliminate.

*Date received: 26 August 1968.
†Present address: General practitioner, Nigel.

MATERIAL AND METHODS

The first object of the study was to assess the bacteriology of the abscesses and traumatic wound infections and bacterial contamination of fresh wounds in 100 patients treated at the mine hospital or compound dressing station during the period May - August 1964. At the same time an extensive investigation was carried out into the bacteriology of the miners' environment, both underground and on the surface. The bacterial carrier incidence of the mineworkers themselves was determined in various body sites and an

attempt was made to assess the effect of working conditions on the carrier rates.

Abscesses and Wounds

Charcoal-treated swabs were used to take specimens from 100 consecutive fresh wounds and abscesses. Swabs from fresh wounds were taken from the depth of the wounds, avoiding skin edges where possible. These were inoculated into Stuart's transport medium for dispatch to the South African Institute for Medical Research in Johannesburg.

The tribal incidence in the 100 patients compared with the tribal distribution of the workers on the mine for that year (percentage incidence given in brackets) was South Africa and Protectorates* 53 (59%); East Coast workers 19 (22%); and workers from tropical regions 28 (19%).

Occupations were analysed and the incidence of wounds and abscesses showed good correlation with the exposure to trauma. Lashing (shovelling) workers (35) and tramming (8) and winch workers (8) formed the bulk of the cases.

Abscesses constituted 35% of the cases and wounds 65%. The distribution of single lesions affecting anatomical sites was hand 62, wrist to axilla 16, lower limb 18, while head, neck and trunk constituted 9 cases. Five patients had more than one lesion. A total of 108 lesions were examined in the 100 patients.

Environmental Studies

In June 1964 various specimens were collected underground at the mine. These comprised exposed plates, samples of underground water and soil, swabs taken from rock, other materials in travelling ways and at working places, and other sundry samples.

Similar swabs and specimens were then taken from collecting places on the surface, i.e. the crush and the bank at the head of the shaft and the entrance to and within a cage (personnel lift). The same was done at various points in a compound change house and latrine.

Human Sources

Nasal and hand swabs were taken from 100 Bantu miners before they went underground at 6 a.m. They were selected on a tribal distribution basis in conformity with that of the mine. Both anterior nares were swabbed, and a broth-moistened swab was rubbed vigorously on the dorsum of the hands and between the fingers. All swabs were inoculated at once into Stuart's transport medium and sent to the laboratory in Johannesburg.

Finally, another similar 100 Bantu miners were selected and in the same manner nasal and hand swabs were taken before they proceeded underground. The same group of men were visited underground at work approximately 4 hours later and swabs were taken from their hands and axillae. On their return to the surface, swabs were taken from the perineum of each man.

Bacteriological Methods

The swabs were inoculated onto 2 blood agar plates and into a thioglycolate medium. The plates were incubated aerobically and anaerobically. All staphylococci were tested for coagulase production and mannitol fermentation using the plasma-mannitol medium technique.[1] Bacteriophage typing according to the method of Blair and Williams[2] was performed on most of the strains isolated. *Streptococcus faecalis* was identified on colonial morphology and its ability to grow on McConkey plates, and Gram-negative bacilli were identified according to their biochemical reactions.

Sensitivity tests were carried out by the disc method against ampicillin (25 μg.), cloxacillin (5 μg.), streptomycin (50 μg.), tetracycline (50 μg.), chloramphenicol (30 μg.), erythromycin (15 μg.), colistin (10 μg.), novobiocin (10 μg.), kanamycin (50 μg.) and nitrofurantoin (100 μg.).

*Now Botswana, Lesotho and Swaziland.

RESULTS

Bacteriology of Wounds and Abscesses

The culture results of 39 abscesses and infected wounds and 69 fresh wounds are given in Table I. From the infected lesions 52 organisms and from the fresh wounds 86 different bacterial species were isolated. Mixed infections were therefore common.

TABLE I. ORGANISMS FOUND IN WOUNDS AND ABSCESSES

Organisms	*Abscesses and infected wounds* (*39*)	*Fresh wounds* (*69*)
Staph. aureus	31 (80%)	18 (26%)
Staph. epidermidis	1 (3%)	14 (20%)
Strep. faecalis	13 (33%)	35 (50%)
Strep. pyogenes	1 (3%)	0
Klebsiella-enterobacter group	1 (3%)	6 (10%)
Proteus mirabilis	0	3 (4%)
E. coli	1 (3%)	1 (1%)
Ps. aeruginosa	1 (3%)	0
Diptheroids, micrococcus and bacillus species	3 (8%)	9 (13%)

Sensitivity to antibiotics. With one exception, all the *Staphylococcus aureus* isolates were sensitive to ampicillin and the broad-spectrum antibiotics. Sensitivity tests to benzyl-penicillin were not carried out, but if one accepts that in the case of staphylococci there is cross-sensitivity between ampicillin and benzyl-penicillin, then, with the one exception quoted above, all the strains were likely to have been sensitive to penicillin G.

The organisms of the klebsiella-enterobacter group were all sensitive to streptomycin, tetracycline and chloramphenicol. Of the 3 *Proteus mirabilis* strains isolated, one was sensitive to streptomycin, tetracycline and chloramphenicol, and 2 were resistant to tetracycline but sensitive to the other 2 antibiotics. Resistance to chloramphenicol was exhibited by the two strains of *E. coli* and to tetracycline by one of them.

Bacteriophage Typing

Phage typing was carried out on only 25 of the 49 cultures of *Staph. aureus* isolated from lesions. All the organisms typed were coagulase positive and produced acid in mannitol. Seven strains belonged to phage group I, 5 to group II, 5 to group III and 1 to the miscellaneous group, and 7 were untypable at 1,000 routine test dilutions.

Carrier Rate Studies

First staphylococcal carrier rate investigation. Coagulase-positive *Staph. aureus* was isolated from only 7% of the

nasal swabs and 8% of the throat swabs taken from the 100 miners. Phage types were equally distributed in the isolates from the nose, but the majority of those from the throat (75%) fell within group III.

Second carrier rate investigation. The results of investigations carried out on a further 100 miners are contained in Tables II and III.

TABLE II. SECOND CARRIER RATE INVESTIGATION

Site	Phage group	*Staph. aureus*	*Ps. aeruginosa*	*E. coli*	Klebsiella-enterobacter	*Strep. faecalis*
Hand swabs; before going underground	I	2	0	3	10	39
Nasal swabs; before going underground	II	7	2	12	33	17
Hand swabs; while working underground	III	5	0	4	4	53
Axilla swabs; while working underground	IV	4	0	9	9	71
Perineal swabs; on resurfacing	V	24	0	19	18	72

TABLE III. PHAGE TYPING OF THE 42 COAGULASE-POSITIVE STRAINS OF *Staph. aureus*

Site	Phage group				
	I	*II*	*III*	*Misc.*	*Untypable*
Hand swabs; before going underground	—	1	—	—	1
Nasal swabs; before going underground	2	2	1	—	2
Hand swabs; underground	—	3	2	—	—
Axilla swabs; underground	—	1	4	—	—
Perineal swabs; on resurfacing	7	2	11	—	4

The majority of the Bantu miners harboured *Staph. epidermidis* on their skin. In about 50% of the miners, golden-yellow pigment-producing coagulase- and mannitol-negative strains were encountered. Similar yellow *Staph. epidermidis* organisms were also isolated from 22% of the nasal specimens.

The bacteriophage typing results of *Staph. aureus* from the carrier sites are given in Table III.

Environmental Studies

Of the air samples taken by the exposed plate method at 7 widely distributed points underground, the approximate number of viable organisms per cubic foot of air varied from 15 to 1,320, with a mean of 265. Conversion of the number of colonies developing on the plates to approximate number of bacteria-carrying airborne particles per cubic foot of air was calculated according to the method given by Lidwell (Appendix 2 of Bourdillon *et al.*[3]). The air sample yielding the highest concentration of bacteria was collected at the working face on 42 level and was the only sample to show the presence of *Staph. aureus* (3 colonies). These colonies were all untypable at 1,000 routine test dilutions.

Samples of drinking water, water from a drain, and seepage water, as well as samples of sand, sludge and rock collected underground, showed moderate numbers of bacteria. An abundant growth of *Pseudomonas aeruginosa* was isolated from the rock sample collected at the waiting place on 40 level. Organisms typically of faecal origin were not encountered.

Swabs taken from taps, pipes and timber showed high concentrations of saprophytic bacteria, while *E. coli* was isolated from the toilet seat.

Examination for atypical mycobacteria was carried out on 10 samples and 5 of them yielded cultures of scotochromogens.

Ten swabs taken from the crush, bank and a cage showed the presence of the typical soil bacteria, such as various bacillus species, achromobacter bacilli, the klebsiella-enterobacter group and a variety of chromogenic bacilli and micrococci. *Strep. faecalis* was isolated from the window-ledge in the crush and the roof of the cage.

In the change house, *Ps. aeruginosa* was isolated from the drainwater gutter and *E. coli* from the entrance to the shower, while cultures from the wall and shower hand-chain yielded a growth of *Strep. faecalis.*

The swabs taken in the latrine showed the presence of *E. coli* on the door and *Strep. faecalis* on the wall and toilet seat.

In all these investigations from exogenous sources *Staph. aureus* was isolated on only one occasion, namely from the air sample at the working face on 42 level.

DISCUSSION

As expected, the predominant organism isolated from the abscesses and infected wounds was *Staph. aureus* (80%). Striking features, however, were the high percentage of *Strep. faecalis* isolations from infected lesions (33%) and the low incidence of Gram-negative infections (8%).

Staphylococci

The results of this survey leave no doubt that *Staph. aureus* is by far the most important cause of abscess formation and wound infection in the miners studied and its elimination or control would go a long way to markedly reducing the incidence of superficial infections in the mines.

Although the nasal and skin carrier rates of coagulase-positive *Staph. aureus* in this study are lower than those reported in White communities elsewhere in the world,[4,5] the almost complete absence of staphylococcal isolations from the external environment strongly points to the human *Staph. aureus* carrier sites as the sources of infection. The high perineal carrier rate of 24% compared with the dorsum of the hand (5%) and the nose (7%) may be due to accumulation of perspiration carrying *Staph. aureus* down to this area, or the organisms may be of faecal origin. Any programme to reduce *Staph. aureus* on the skin by suitable antiseptic preparations should take cognizance of this high perineal incidence of *Staph. aureus,* and regular washing of this area with hexachlorophene or other suitable soaps is recommended.

The incidence of *Staph. aureus* on the skin of the dorsum of the hand (5%) in this study is lower than Warren's findings in a similar study in African mineworkers in 1954, where 24% of mineworkers carried *Staph. aureus* on the skin of their wrists.[6] However, as different

skin sites were used in the two surveys, the results are not strictly comparable.

An unusual finding in the present survey is the high incidence of coagulase-negative staphylococci producing golden-yellow pigment found in more than 50% of skin swabs. The significance of this is not clear but it is interesting to note that similar yellow, coagulase- and mannitol-negative staphylococci were found in 22% of nasal swabs. They did not, however, appear to play a significant role in skin infections.

Contamination of fresh wounds with *Staph. aureus* (26%) was much higher than the dorsum of the hand skin carrier rate as shown by surface swabbing (5%). This may be an indication that the dorsum of the hand harbours *Staph. aureus* less frequently than most other skin sites exposed to trauma, or that these organisms are located deeper in the skin and may be missed on surface swabbing. *Staph. aureus* may also have been introduced into the open wounds by first-aid helpers either by hand or by droplet contamination.

Specimens of normal skin and the noses of patients with fresh wounds were unfortunately not examined for *Staph. aureus*. Neither were skin and nasal swabs of the patients that developed subcutaneous abscesses examined. Such investigations would have given very useful information on the possible endogenous source of *Staph. aureus* in these patients. However, whether the source was the patient himself or his colleagues, elimination of the human nasal and especially skin reservoirs of *Staph. aureus* is an obvious approach to control this problem.

Foreign material introduced into fresh open wounds and even with minor trauma such as splinters and other small penetrating wounds, probably allowed conditions favourable for *Staph. aureus* multiplication to eventually reach the pus-forming dose of approximately two million organisms, as shown by Elek and Conen in human volunteers.[7] No attempt was made in this investigation to establish how many of the patients with fresh wounds contaminated with *Staph. aureus* later developed *Staph. aureus* infections. Neither do we know how many of the wounds initially free of *Staph. aureus* later developed infection caused by this organism.

The low nasal *Staph. aureus* carrier rate of this study (7%) is almost identical with the findings of Harper in Southern Sudan (9%)[8] and Rountree *et al.* in Papua, New Guinea (7%).[9] In a study in Johannesburg Bantu children and adults compared with comparable White age-groups, a lower incidence of *Staph. aureus* was again found in the Bantu (14% Bantu compared with 28% White adults).[10]

The low incidence of antibiotic-resistant *Staph. aureus* strains is comparable with the findings of Harper in the Southern Sudan,[8] while a much higher incidence of resistance was found in the New Guinea study.[9]

Bacteriophage typing of *Staph. aureus* strains did not show clear-cut patterns and the numbers were too small to draw definite conclusions. However, the majority of carrier strains belonged to the group III phage types, while there was a slight preponderance of group I phage types isolated from the infected wounds and abscesses.

The Streptococci

Streptococcus pyogenes (Lancefield group A) was isolated from only one infection. However, *Strep. faecalis* featured much more prominently and was recovered from 33% of the infections studied. This organism was also found in 50% of fresh wounds and in a surprisingly high percentage of surface skin swabs (39% - 72%, Table II). Many of the *Strep. faecalis* strains showed alpha-haemolysis. The strains resembled *Aerococcus viridans* which is commonly found in air and dust, and the tests performed in this survey did not include catalase, arginine hydrolysis and growth at 45°C which will differentiate between these two organisms. However, subsequent to this study, several alpha-haemolytic organisms isolated from the skins of Bantu workers were tested and, in addition to growing on bile-salt media, they were found to be strongly catalase positive. This strongly suggests that the organisms isolated in the original survey were *Strep. faecalis* and not *Aerococcus viridans*.

It is generally accepted that streptococci do not form part of the residential flora of normal dry skin[11] and that they are susceptible to fatty acids in the skin.[12] *Streptococcus pyogenes* dies off relatively quickly on normal skin but is commonly found in a variety of pathological skin conditions.[13] In contrast to the beta-haemolytic streptococci, Hellat[14] reported that *Strep. faecalis* can survive for prolonged periods on the skin, and Evans *et al.*[15] isolated non-haemolytic streptococci from the forearms of a large percentage of children aged less than 4 years. It is possible that in young children low skin concentrations of fatty acids allow these streptococci to survive for longer periods. Although streptococci are not normally found on normal dry skin of adults, Smith and Waterworth[16] found a high percentage of different types of streptococci including enterococci in moist intertrigenous areas, especially when the skin was eroded in deep creases.

Considering the above-mentioned reports in the literature, it is not surprising to find such a high incidence of *Strep. faecalis* on the skins of the mineworkers, especially if one takes into consideration the high relative humidity underground, copious perspiration and the inevitable skin chafing associated with hard manual labour. The very high incidence in the intertrigenous axillary and perineal regions (71% and 72% respectively) compared with the hands (39%), also follows the expected pattern. The unusually high nasal carrier rate of *Strep. faecalis* (17%) can be explained by postulating a colonization of the nose by enterococci from the skin of the hands.

Strep. faecalis was also found to be fairly widespread in surface samples, e.g. on the wall and the shower chain in the change house, the wall and toilet seat in the latrine and the window-ledge in the crush. It was, however, not recovered from soil, water and rock samples underground.

In spite of its high prevalence compared with *Staph. aureus*, *Strep. faecalis* was recovered from only 33% of infected wounds and abscesses, suggesting that it is of much lower virulence than *Staph. aureus*. However, the importance of this organism as a cause of skin sepsis in mineworkers was probably not fully realized in the past and the high skin carrier rate favoured by the underground mining environment warrants special attention. As in the case of *Staph. aureus* on the skin, the repeated use of antiseptic soaps such as hexachlorophene preparations seems indicated and the workers should be instructed to thoroughly wash the perineal and axillary regions with an appropriate soap.

The Gram-negative Bacilli

A relatively low incidence of Gram-negative infections (8%) was found in this survey. Gram-negative bacilli were recovered from many samples from the external environment. Thus *E. coli* was isolated from a toilet seat and the shower room and *Pseudomonas aeruginosa* from a drain-water gutter. Underground specimens yielded pseudomonads from a rock sample and bacilli belonging to the enterobacter-klebsiella group from soil. In addition, varying percentages of these organisms were recovered from nasal and skin swabs and in fresh wounds. However, in spite of their widespread prevalence, these Gram-negative bacilli, due to either too low numbers or a low virulence, did not contribute significantly to the infections encountered in this study.

If one considers that Bantu mineworkers are reasonably healthy young men and are not frequently exposed to antibiotics and other iatrogenic factors lowering their resistance, the low incidence of Gram-negative infections compared with postoperative hospital-acquired wound infections is not unexpected. One also expects to find a lower incidence of virulent Gram-negative organisms in the mines compared with hospitals, so that the number of Gram-negative bacilli necessary for pus production is probably higher in mine-acquired wounds.

CONCLUSIONS AND RECOMMENDATIONS

As was expected, this investigation clearly showed that *Staphylococcus aureus* is the most important pathogen involved in skin sepsis in mineworkers. Furthermore these organisms were predominantly endogenous and conspicuously absent from the general environment of the worker.

In one-third of cases of skin infection, *Streptococcus faecalis* was present and similarly these organisms were found to be of endogenous origin, although they were also found in several specimens from the environment.

Gram-negative organisms were isolated from only a few cases of skin infection and therefore did not appear to be important in the causation of sepsis.

In view of these findings the obvious approach to the prevention of skin infection in the mines is to attack the endogenous Gram-positive cocci. The method envisaged is regular washing of the body with a hexachlorophene soap, paying special attention to the perineum and axillae. This antiseptic preparation is effective against both *Staphylococcus aureus* and *Streptococcus faecalis* and repeated use provides a residual effect. However, the constant use of hexachlorophene may interfere with the normal skin flora and give a selective advantage to Gram-negative bacilli, leading to an increase in Gram-negative skin infections.[17] For this reason skin infections should be examined as a routine bacteriologically, and if an increase in Gram-negative infections becomes evident other skin antiseptic preparations containing agents active against Gram-negative bacteria, such as chlorhexidene, should be used in addition.

Expensive methods of controlling the external environment are not indicated.

SUMMARY

An investigation into skin sepsis was carried out in a gold mine on the East Rand. *Staphylococcus aureus* was isolated from 80% of skin infections. From one-third of the cases *Streptococcus faecalis* was isolated. Other organisms, including Gram-negative bacilli, only occasionally caused sepsis. Staphylococcal skin and nasal carriage, although thought to be significant, was relatively low, similar to findings in indigenous people in the Sudan and New Guinea.

Streptococcus faecalis was isolated from the skin of up to 72% of the workers examined, the figures varying from 39% on the dorsum of the hands to 71% of axillary and 72% of perineal swabs. Staphylococci were only rarely isolated from the external environment.

In view of the endogenous source of the great majority of the pathogens, elimination by skin antisepsis is recommended.

We wish to thank Prof. J. F. Murray, Deputy Director of the SAIMR, and Mr W. L. Cousens, Manager of the Vlakfontein Gold Mining Co., for encouragement and assistance; and the Director of the SAIMR for providing the facilities.

REFERENCES

1. Keydor, J. and Eylan, E. (1959): Bull. Res. Coun. Israel E, **8**, 43.
2. Blair, J. E. and Williams, R. E. O. (1961): Bull. Wld Hlth Org., **24**, 771.
3. Bourdillon, R. B., Lidwell, O. M. and Lovelock, J. (1948): Spec. Rep. Ser. Med. Res. Coun. (Lond.), No. 262.
4. Williams, R. E. O. (1963): Bact. Rev., **27**, 56.
5. Munch-Petersen, E. (1961): Bull. Wld Hlth Org., **24**, 761.
6. Warren, G. (1954): 'Staphylococcal infections in African mineworkers: an epidemiological study', M.D. thesis, University of the Witwatersrand.
7. Elek, S. D. and Conen, P. E. (1957): Brit. J. Exp. Path., **38**, 573.
8. Harper, J. (1967): Med. J. Aust., **2**, 683.
9. Rountree, P. M., Beard, M. A., Arter, W. and Woolcock, A. J. (1967): *Ibid.*, **1**, 967.
10. Koornhof, H. J. and Hayden-Smith, S. (1962): Unpublished data.
11. Williams, R. E. O. and Miles, A. A. (1949): Spec. Rep. Ser. Med. Res. Coun. (Lond.), No. 266.
12. Burtenshaw, J. M. L. (1942): J. Hyg. (Lond.), **42**, 184.
13. Russell, B. (1956): Trans. St. John's Hosp. Derm. Soc. (Lond.), **36**, 3.
14. Hellat, A. (1948): Ann. Med. exp. Fenn., **26**, suppl. 8.
15. Evans, C. A., Smith, W. M., Johnston, E. A. and Giblett, E. R. (1950): J. Invest. Derm., **15**, 305.
16. Smith, M. A. and Waterworth, P. M. (1962): Brit. J. Derm., **74**, 323.
17. Forfar, J. O., Gould, J. C. and Maccabe, A. F. (1968): Lancet, **2**, 177.