INFECTION AND IMMUNITY, July 1982, p. 318–326
0019-9567/82/070318-09$02.00/0

Vol. 37, No. 1

Adherence of Slime-Producing Strains of *Staphylococcus epidermidis* to Smooth Surfaces

GORDON D. CHRISTENSEN,[1]* W. ANDREW SIMPSON,[1,2] ALAN L. BISNO,[1] AND EDWIN H. BEACHEY[1,2]

Department of Medicine, University of Tennessee College of Medicine,[1] and Veterans Administration Medical Center,[2] Memphis, Tennessee 38163

Received 3 December 1981/Accepted 2 March 1982

Slime production is not a generally recognized feature of *Staphylococcus epidermidis*. In a recent outbreak of *S. epidermidis* intravascular catheter-associated sepsis, we noted that 63% of clinically implicated strains grew as a slimy film coating the culture tube walls when propagated in tryptic soy broth. Only 37% of randomly collected blood culture contaminants and skin isolates demonstrated a similar phenomenon ($p < 0.05$). Transmission electron micrographs of these coating bacteria showed them to be encased in an extracellular matrix that stained with alcian blue. Slime production was most evident in autoclaved media containing Casamino Acids and glucose supplementation (0.25% wt/vol). There were strain and media preparation variability of slime production in the presence of other carbohydrates. Some strains were not able to produce slime under any of the tested conditions. The production or nonproduction of slime did not influence growth rate. When grown in vitro, slime producers accumulated on the surface of intravascular catheters as macrocolonies, whereas non-slime, producers did not. Transmission and scanning electron micrographs showed slime producers to be encased in an adhesive layer on the catheter surface, whereas nonproducers were not encased. These results suggest that slime-mediated adherence may be a critical factor in the pathogenesis of *S. epidermidis* infections of medical devices.

Formerly considered a harmless organism, *Staphylococcus epidermidis* is now a recognized opportunistic pathogen of foreign bodies, particularly prosthetic cardiac valves (7, 10, 14, 19, 31), cerebrospinal fluid shunts (8, 15, 28, 29), orthopedic appliances (24, 34–36), and intravascular catheters (1, 5). A critical determinant in this association of opportunist with foreign body could be the adhesiveness of the bacteria to the surface of the foreign body. Investigation of this relationship may shed light on the pathogenesis of these infections. Nevertheless, the issue of *S. epidermidis* adherence to smooth surfaces has not been extensively examined.

Bayston and Penny (4) reported that many *S. epidermidis* strains of Baird-Parker's SII biotype produce a mucoid growth in vitro which adheres to the walls of culture tubes. They attributed the adhesiveness to a viscid material that stains with alcian blue. These same strains were responsible for cerebrospinal fluid shunt infections, and it was speculated that mucoid growth is important in the pathogenesis of shunt infections.

Mucoid growth is not a generally recognized characteristic of *S. epidermidis*. Baird-Parker simply notes that 26% of SII strains exhibit mucoid growth (2), and Jones et al. observed a high incidence of slime production (mucoid growth) when strains were grown in the presence of pyruvate (16). Aside from these reports, there is little further characterization of this phenomenon.

During a recent investigation of an outbreak of *S. epidermidis* catheter-associated infections (9), we noted that many strains of *S. epidermidis* associated with clinical infections produced slime. This report summarizes our findings.

(This paper was published in abstract form [G. D. Christensen and A. L. Bisno, Clin. Res. **29**:382A, 1981], and was presented in part at the 21st ICAAC [G. D. Christensen, W. A. Simpson, A. L. Bisno, and E. H. Beachey, Program Abstr. Intersci. Conf. Antimicrob. Agents Chemother. 21st, Chicago, Ill., abstr. no. 364, 1981].)

MATERIALS AND METHODS

Microorganisms. Between June 1979 and September 1980, we collected 146 isolates of staphylococci while investigating an outbreak of intravascular catheter-associated *S. epidermidis* sepsis at the City of Memphis and University of Tennessee Hospitals, Memphis. A total of 143 isolates were gram-positive clustering cocci that were catalase positive, coagulase

negative, and sensitive to novobiocin, fermented glucose but not mannitol, and were therefore identified as *S. epidermidis*. The *S. epidermidis* collection consisted of 97 blood culture isolates from 58 patients and 46 skin and nares isolates from hospital personnel. These isolates were characterized by antibiotic susceptibilities, biotype (by the schemes of both Baird-Parker [3] and Bentley et al. [6]), and phage type (courtesy of J. Parisi, University of Missouri). By these criteria, eight patients with 25 isolates were found to have the identical organism in more than one blood culture. The duplicate isolates (16) were excluded from further analysis, for a final collection of 127 individual patient and staff strains. A total of 17 patients with 35 individual blood culture strains were suspected or proven to have *S. epidermidis* sepsis or bacteremia (clinical groups 1 and 2 [9]). These strains were designated the symptomatic infection collection. The remaining 41 patients with 46 strains were asymptomatic, and their blood culture strains were presumed to be cultural contaminants. Stock cultures of these isolates were stored in outdated human blood at −70°C and later as lyophilized cultures. Working cultures were maintained on tryptic soy agar with 5% sheep blood and transferred every 2 to 3 months.

Culture media. Bacteria were propagated in standard laboratory media prepared according to the specifications of the manufacturers. Media utilized included: Trypticase soy broth (TSB; BBL Microbiology Systems, Cockeysville, Md., and Difco Laboratories, Detroit, Mich.), thioglycolate (BBL Microbiology Systems), brucella broth (BBL Microbiology Systems), brain-heart infusion broth (Difco Laboratories and GIBCO Laboratories, Grand Island, N.Y.), Mueller-Hinton broth (Difco Laboratories, GIBCO Laboratories, and BBL Microbiology Systems), Todd-Hewitt broth (Difco Laboratories), synthetic broth AOAC (Difco Laboratories), and nutrient broth (Difco Laboratories). The following individual supplements were used: phytone (BBL Microbiology Systems), tryptone (BBL Microbiology Systems), and yeast extract (Difco Laboratories). Sucrose broth was prepared as described by Vera and Power (32). Saccharide-free basal medium was constructed with tryptone, phytone, and sodium and potassium salt similarly to TSB but without glucose supplementation. This basal medium was supplemented (0.25%, wt/vol) in some experiments with the following carbohydrates: glucose (Fisher Scientific Co., Pittsburgh, Pa.), D-fructose (Fisher Scientific Co.), lactose (Difco Laboratories), maltose (Fisher Scientific Co., and Difco Laboratories), sucrose (Fisher Scientific Co.), D-mannose (Fisher Scientific Co.), D-ribose (Fisher Scientific Co.), cellobiose (Fisher Scientific Co.), D-xylose (Fisher Scientific Co., and Difco Laboratories), D-galactose (Fisher Scientific Co.), α-l-rhamnose (Sigma Chemical Co., St. Louis, Mo.), D-arabinose (Sigma Chemical Co.), D-mannitol (Difco Laboratories), α-methylmannoside (Sigma Chemical Co.), and dextran sulfate (Sigma Chemical Co.)

Fermentation and oxidation tests. Fermentation of glucose and oxidation of lactose and maltose was tested as described by Baird-Parker (3).

Relative growth. *S. epidermidis* organisms were subcultured 1:200 from stationary-phase TSB cultures into the chosen media and monitored by absorbance at 550 nm on a Junior II spectrophotometer (Coleman Systems, Irvine, Calif.). Cultures were incubated at 37°C and intermittently agitated.

Test of transferability of adherent growth from slime-producing to non-slime-producing *S. epidermidis*. TSB from 24-h cultures of a slime-producing strain of *S. epidermidis* was cleared of organisms with centrifugation (5,000 × *g*, 30 min), sterilized by filtration through a 0.45-μm filter (Millipore Corp., Bedford, Mass.), and diluted 1:2 and 1:4 with fresh TSB. The tubes were then inoculated with a non-slime-producing strain and observed for adherent growth.

Adherence to smooth surfaces. Plastic conical tubes (Falcon Plastics, Oxnard, Calif.) or standard glass culture tubes were used to assay for adherence. Adherent growth was considered to be present if a film was present lining the inner surface of the tube. Ring formation at the liquid-air interface was not considered to be indicative of adherent growth. In some experiments, the contents of the tubes were removed, and the tube was stained with safranin or trypan blue to demonstrate the adherent growth. The presence of adherent growth was taken as evidence of slime formation. Adherence to intravascular catheters was studied by sectioning the catheters (14-gauge Intracath; Deseret Co., Sandy City, Utah) with a sterile instrument and incubating them in TSB or saccharide-free basal media with either a slime-forming or a non-slime-forming strain. After 24 h, the catheters were removed in a sterile manner and transferred to fresh media. Daily transfers were conducted for 5 days.

Electron microscopy. Specimens were stained with alcian blue by the method of Shea (30), using alcian blue 8GX (Tousimis Research Corp., Inc., Rockville, Md.) and lanthanum nitrate (Tousimis Research Corp.). Samples for transmisson electron microscopy were fixed and dehydrated as reported earlier (23), with the following modification: after the last ethanol rinse, the specimens were placed in a 50% solution of Spurr (Polysciences Inc., Warrington, Pa.) in ethanol for 1 hour, then in Spurr overnight, and finally embedded in Spurr and polymerized overnight at 65°C. Blind specimens were examined with an EM6B electron microscope (AEI Scientific Instruments, Inc., Elmsford, N.Y.). Samples for scanning electron microscopy were dehydrated in a desiccator, mounted on aluminum stubs, shadowed with gold paladium, and examined with an AMR-1000A, scanning electron microscope (Advanced Metals Research Corp., Bedford, Mass.).

RESULTS

Production of slime by *S. epidermidis* strains. The coating of polystyrene test tube walls by an adherent film of *S. epidermidis* cells is shown in Fig. 1. The production of this film required static incubation in TSB for 18 to 24 h at 37°C. The coating was equally apparent in glass or polystyrene tubes. Agitation of the test tube during growth flocculated the bacteria, leaving the vessel walls visibly free of colonial growth. Washing the bacteria was difficult because they formed a sticky precipitate. Transmission electron micrographs of these strains indicated that the bacteria were enmeshed in extracellular material. This material stained with alcian blue,

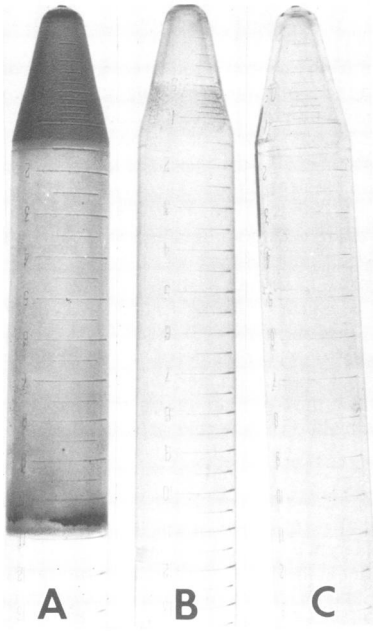

FIG. 1. Adherence of *S. epidermidis* grown in broth to the walls of plastic test tubes. The test tubes were emptied and stained with trypan blue. (A) Strong slime-producing strain in TSB; (B) weak slime-producing strain in TSB; (C) strong slime-producing strain grown in saccharide-free basal medium.

suggesting its polysaccharide nature (Fig. 2). The presence of this material will be referred to as slime production; the coating of artificial surfaces by macroscopic collections of bacteria will be referred to as adherent growth and presumed to be evidence of slime production.

Influence of media and carbohydrates on slime production. TSB is a combination of an enzymatic digest of casein (tryptone) and soy protein (phytone) plus sodium, potassium salt, and glucose supplementation (0.25% wt/vol). Substitution and elimination of these components indicate that the adherent growth required both glucose (0.25% wt/vol) and casein digests for expression. Many commonly used laboratory media were unable to support adherent growth. Brain heart infusion broth unreliably supported adherent growth. Sucrose broth (9), which is used to detect glucan or levan production by streptococci, failed to support adherent growth or to become more viscous (indicating glucan or levan production) when incubated with *S. epidermidis*.

TSB, TSB without phytone, TSB without phytone and with yeast extract, and TSB assembled from components, all of which included 0.25% (wt/vol) glucose, supported adherent growth of slime. Glucose filter-sterilized TSB, including 0.25% (wt/vol) glucose added after

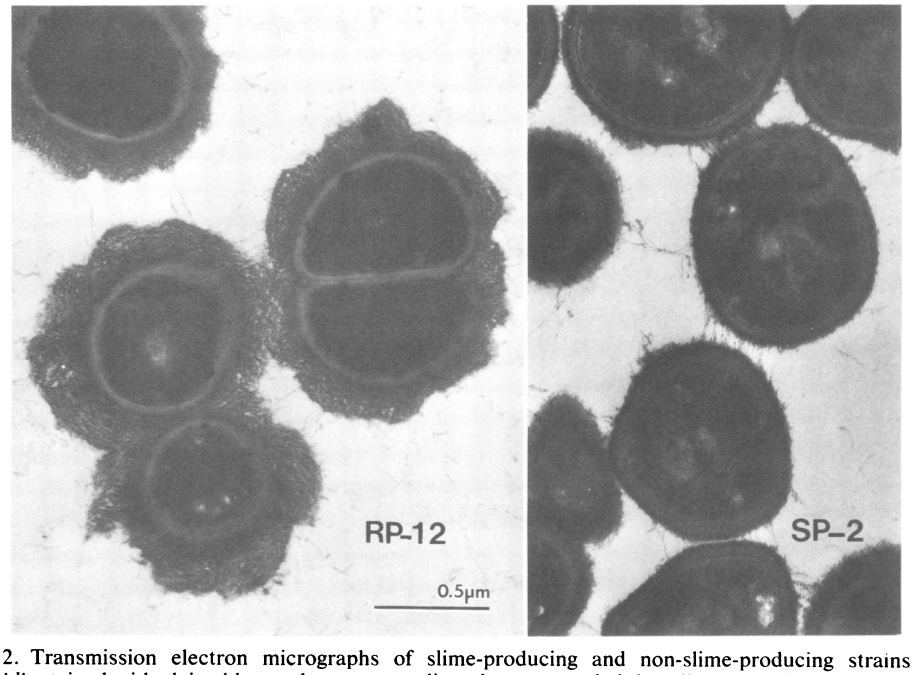

FIG. 2. Transmission electron micrographs of slime-producing and non-slime-producing strains of *S. epidermidis* stained with alcian blue to demonstrate slime that surrounded the adherent strain RP-12 but not the nonadherent strain SP-2.

TABLE 1. Capacity of various carbohydrates to support slime by *S. epidermidis*

Test carbohydrate (concn [wt/vol])	Production of slime (no. of positive/no. of tested strains) by[a]:	
	Slime producers	Non-slime producers
Glucose (0.25 and 5%)	6/6	0/6
Glucose (10%), fructose, lactose, maltose, or sucrose	6/6[b]	0/6
Mannose, ribose, cellobiose, D-xylose, or D-galactose	5/6[b]	0/6
α-1-Rhamnose	4/6[b]	0/6
D-Arabinose, mannitol, dextran, α-methyl-mannoside, or no added carbohydrate	0/6	0/6

[a] TSB without glucose was the basal medium, supplemented, unless otherwise indicated, with 0.25% (wt/vol) test carbohydrate. Six strains that produced slime in standard TSB and six strains that did not produce slime in TSB were compared.

[b] Adherent growth varied from strong to weak in various tests.

autoclaving, diminished adherent growth, and brain heart infusion broth including 0.20% (wt/vol) glucose gave variable support. TSB without glucose; Todd-Hewitt broth including 0.20% (wt/vol) glucose; brucella and synthetic broths including 0.1% (wt/vol) glucose; sucrose broth including 5.0% (wt/vol) sucrose; and Mueller Hinton, nutrient, and tryptone broths, for which glucose is not included in the list of ingredients, were unable to support adherent growth. (All of these media were prepared according to the specifications of the manufacturer, unless otherwise indicated.)

The capacity of other carbon sources to support adherent growth was explored by using six strains of adherent and nonadherent *S. epidermidis* (as judged by the ability to produce adherent growth in TSB) and a basal medium assembled from the components of TSB (but without glucose) and supplemented (0.25%, wt/vol) with a variety of carbohydrates (Table 1). Nonadherent strains remained nonadherent in the presence of all compounds tested. Glucose was the only compound that consistently produced strong reactions. Adherent growth in the presence of most of the remaining compounds varied from strain to strain and from test to test. Some compounds (D-arabinose, mannitol, α-methyl-mannoside, dextran) were unable to support adherent growth. In all cases, adherent growth was best demonstrated when the carbon source was autoclaved with the liquid media. All 12 of the strains fermented glucose and oxidized lactose and maltose regardless of the ability of these saccharides to support adherent growth.

Growth characteristics. The relative total growth of these 12 strains was determined by comparing the optical densities of stationary-phase broth cultures. All strains exhibited greater culture density in the presence of glucose than in its absence (Fig. 3). The ability or inability to produce slime did not appear to be related to final culture density. An adherent strain, RP-12, and a nonadherent strain, SP-2, were further compared for relative degree of growth in media supplemented with other carbohydrates. The non-slime producer grew to a greater density in the glucose-supplemented medium than did the slime producer. In the remaining media (fruc-

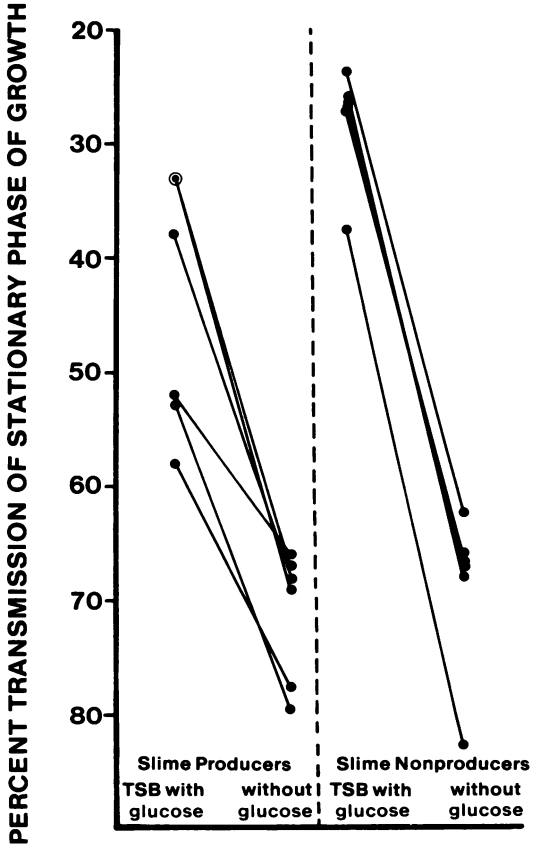

FIG. 3. Relative growth of six slime-producing and six non-slime-producing strains of *S. epidermidis* in media containing glucose (0.25%, wt/vol) or excluding glucose. Growth was determined by relative light transmission at 550 nm.

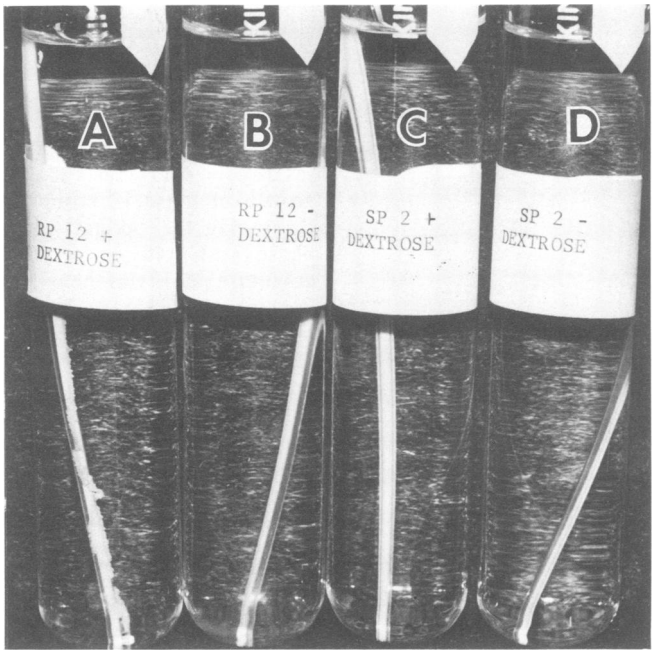

FIG. 4. *S. epidermidis* attached to intravenous catheters. These catheters were transferred daily into fresh media. After 5 days, the slime-producing strain produced adhesive macrocolonies on the catheter section when grown in glucose-rich media (A); macrocolonies were not apparent in saccharide-free media (B) or when a non-slime-producing strain was grown either in glucose-rich (C) or saccharide-free media (D).

tose, maltose, rhamnose, xylose, galactose, mannitol, arabinose, and unsupplemented), the growth of the two strains was equal, or the non-slime producer grew somewhat less than did the slime producer. The culture density did not vary with the ability or inability of the media to support slime production.

The production of extracellular glucosyltransferase by *Streptococcus mutans* (13) and *Streptococcus salivarius* (20) is important to the binding of these streptococci to dental surfaces. These extracellular enzymes also transfer adherent growth to normally nonadherent bacteria by the adsorption of the extracellular glucosyltransferase onto the surface of the cell, with subsequent binding to the dental surface (13, 20). In this situation, adherent growth was not transferable by incubating nonadherent SP-2 in 1:2 or 1:4 dilutions of cell-free, spent RP-12 TSB and fresh TSB. This suggests that either RP-12 does not produce an extracellular polymerase or, if it does produce an extracellular polymerase, that SP-2 is unable to bind the polymerase to its cell surface.

Adherence of slime-producing *S. epidermidis* organisms to smooth surfaces. In a manner similar to the coating of test tube walls, slime-producing *S. epidermidis* also coated the surfaces of intravascular catheters. Figure 4 shows the results of incubating catheter sections in either TSB or saccharide-free basal media seeded with either RP-12 or SP-2. After transferring the catheter daily for 5 days, visible macrocolonies formed on the surface of the catheter incubated with RP-12 but not SP-2 grown in TSB with glucose. Transmission electron micrographs of RP-12 and SP-2 incubated overnight in brain heart infusion broth with a section of catheter showed the RP-12 organism coated in an extracellular material and attached to the surface of the catheter by an apparent pellicle. This was not evident in micrographs of SP-2 in conjunction with the catheter surface (Fig. 5). Scanning electron micrographs of catheters incubated in TSB showed the RP-12 organism matted onto the catheter surface (Fig. 6), whereas the SP-2 bacteria, grown under identical conditions, were found in fewer numbers, were more distinctly outlined, and appeared to be larger.

Clinical isolates of *S. epidermidis*. A total of 127 strains from human sources were collected and characterized in the Memphis intravascular catheter-associated *S. epidermidis* sepsis study (9; G. D. Christensen et al., submitted for publication). The overall frequency of adherent growth in this collection was 44%. The frequency of adherent growth, however, was signifi-

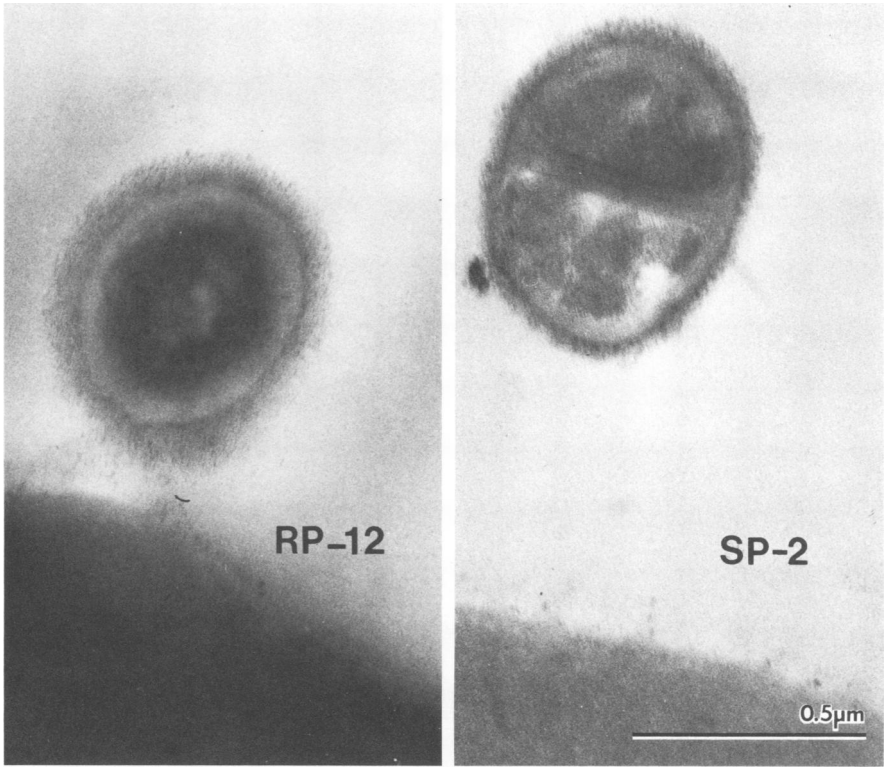

FIG. 5. Transmission electron micrographs of catheters incubated with RP-12 (slime producing) and SP-2 (non-slime producing) *S. epidermidis* grown in brain heart infusion broth. The slime-producing strain is covered by a layer of material and attached to the surface of the catheter by an apparent pellicle.

cantly higher (63%) in strains associated with clinical signs of infection than in strains not associated with such signs (37% [Table 2]).

DISCUSSION

Clearly, some strains of *S. epidermidis* produce a polysaccharide extracellular material or slime. This characteristic of *S. epidermidis* may have been overlooked because it is not apparent in many commonly used laboratory media, *S. epidermidis* is not a common cause of clinical illness, and the issue of *S. epidermidis* adherence to smooth surfaces is unexplored. Only Bayston and Penny (4) have examined *S. epidermidis* slime production to any extent, although others have given it passing mention (2, 16).

The capacity of some strains to produce slime is not surprising. Similar observations concerning the closely related species, *Staphylococcus aureus*, have been made by Sall (26, 27), Wiley and Wonnacott (33), Mudd (21, 22), and Yoshida and Ekstedt (37).

The present work suggests but does not prove that slime production is a stable characteristic of a select subpopulation of *S. epidermidis* strains. So far, we have been unable to manipulate cultural conditions to encourage slime production by a previously nonadherent strain; however, not all possibilities have been exhausted. We do have evidence (G. D. Christensen, unpublished observation) that adherent or nonadherent growth is stable through animal or extended laboratory passage. Nevertheless, it is quite possible that the slime characteristic may be turned on or off in a manner analogous to rough-smooth strains of pneumococci or fimbriate-nonfimbriate strains of *Escherichia coli* (11). An additional possibility is that the slime characteristic is a relative phenomenon rather than a simple positive or negative. We did note that some strains have a greater capacity for adherent growth than other strains. Further examination of this possibility awaits a quantitative determination of the amounts of slime produced rather than the qualitative determination of the presence or absence of slime described in the present study.

The polysaccharide character of the slime is suggested from its staining with alcian blue. Precise characterization awaits biochemical

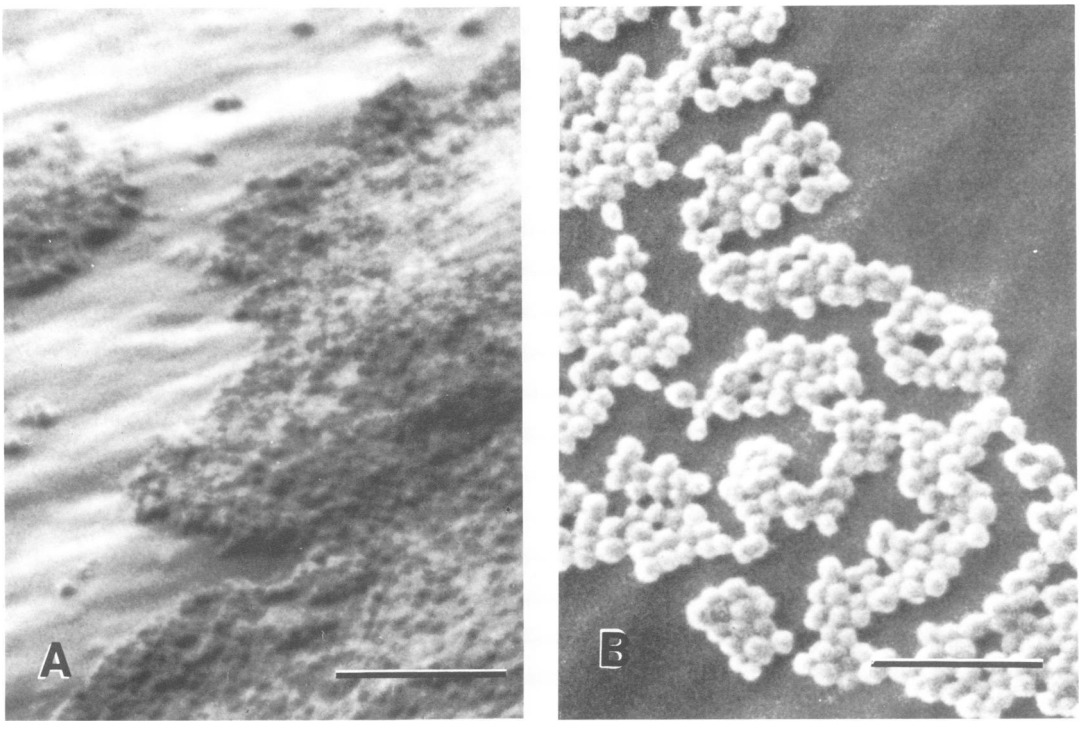

FIG. 6. Scanning electron micrographs of *S. epidermidis* attached to intravenous catheters. The slime-producing strain adhered in large numbers of indistinct bacteria encased in a mat of material (A). The non-slime-producing strain adhered as a mat of clearly defined individual cells (B). Bar, 10 μm.

analysis; however, the nutritional requirements for autoclaved dextrose and tryptone suggest that it is made up from a carbon fragment and an amino acid. The amino acid could be glutamine, a rich component of casein.

The significant aspect of the observation that some strains of *S. epidermidis* produce slime is the potential for greater understanding of the predeliction of *S. epidermidis* for foreign-body infections. If slime production is present in vivo as it is in vitro, new strategies may be developed for the prevention and early detection of *S. epidermidis* foreign-body infections.

TABLE 2. Slime production in 127 *S. epidermidis* strains

S. epidermidis isolated from patients with:	No. (%) of:	
	Slime producers	Nonslime producers
Symptomatic infections (groups 1 and 2 [19])	22 (63)	13 (37)[a]
All other strains	34 (37)	58 (63)
Skin and nose strains	18 (39)	28 (61)
Random blood culture	16 (35)	30 (65)
Total strains	56 (44)	71 (56)

[a] Symptomatic versus all others, $P < 0.05$ by χ^2 analysis with Yates correction for continuity.

There is a precedent for such speculation. In analogous in vitro experiments, *Streptococcus mutans* (12) was found to bind to smooth surfaces by virtue of a glucan slime coat, which in turn has led to a greater understanding of the pathogenesis of dental caries (12). Although the *S. epidermidis* slime is not a glucan, it presumably functions in a similar manner as either an adhesin, providing permanent binding to the foreign body surface, or as a cohesin, binding cells together on the foreign-body surface. In a recent series of publications, Locci, et al. (17, 18, 25) have made morphological studies on the adherence of *S. epidermidis* to plastic catheters. Their studies indicate that small numbers of organisms initially lodge in irregularities along the catheter surface from which micro- and, ultimately, macrocolonies build up. The colonies are cemented to the surface by an unidentified amorphous material (possibly slime) which does not have the fibrillar characteristic of fibrin. Finally, Bayston and Penny (4) described microcolonies of *S. epidermidis* cemented to infected Spitz-Holter valves by alcian blue-staining material.

If slime is important in bacterial adherence during foreign-body infections, it would be both a colonization factor and a virulence factor. We suspect that slime production is one of a number of factors important in colonization of smooth surfaces, since it was usually common in our collection of symptomatic infection strains, but not a universal feature of those strains. Confirmation of this observation and investigation of the role of slime in other *S. epidermidis* infections awaits further investigation.

ACKNOWLEDGMENTS

We thank Gordon Schrank for performing scanning electron microscopy, M. Hester for technical assistance, and B. Eisenstein for critical review of the manuscript.

This work was supported by an award from the University of Tennessee Center for the Health Sciences New Faculty Research Program, research funds from the U.S. Veterans Administration, and Research Grants AI-10085 and AI-13550 from the National Institute of Allergy and Infectious Diseases. W.A.S is the recipient of a Young Investigatorship Award (DE-05773) from the National Institute of Dental Research. E.H.B. is the recipient of a Medical Investigatorship Award from the U.S. Veterans Administration.

LITERATURE CITED

1. **Archer, G. L.** 1978. Antimicrobial susceptibility and selection of resistance among *Staphylococcus epidermidis* isolates recovered from patients with infections of indwelling foreign devices. Antimicrob. Agents Chemother. **14**:353–359.
2. **Baird-Parker, A. C.** 1965. The classification of staphylococci and micrococci from world-wide sources. J. Gen. Microbiol. **38**:363–387.
3. **Baird-Parker, A. C.** 1972. Classification and identification of staphylococci and their resistance to physical agents, p. 9. *In* J. O. Cohen (ed.), The staphylococci. Wiley Interscience, New York.
4. **Bayston, R., and S. R. Penny.** 1972. Excessive production of mucoid substance in staphylococcus SIIA: a possible factor in colonization of Holter shunts. Dev. Med. Child Neurol. **14**(Suppl. 27):25–28.
5. **Bender, J. W., and W. T. Hughes.** 1980. Fatal *Staphylococcus epidermidis* sepsis following bone marrow transplantation. Johns Hopkins Med. J. **146**:13–15.
6. **Bentley, D. W., R.-U. Hague, R. A. Murphy, and M. H. Lepper.** 1967. Biotyping, an epidemiological tool for coagulase-negative staphylococci. Antimicrob. Agents Chemother. **7**:54–59.
7. **Blouse, L. E., G. D. Lathrop, L. W. Kolonel, and R. M. Brockett.** 1978. Epidemiologic features and phage types associated with nosocomial infections caused by *Staphylococcus epidermidis*. Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. Reihe A **241**:119–135.
8. **Callaghan, R. P., S. J. Cohen, and G. T. Stewart.** 1961. Septicaemia due to colonization of Spitz-Holter valves by staphylococci. Br. Med. J. **1**:860–863.
9. **Christensen, G. D., A. L. Bisno, J. T. Parisi, B. McLaughlin, M. G. Hester, and R. W. Luther.** 1982. Nosocomial septicemia due to multiply antibiotic resistant *Staphylococcus epidermidis*. Ann. Intern. Med. **96**:1–10.
10. **Dismukes, E. W., A. W. Karchmer, M. J. Buckley, W. G. Austen, and M. N. Swartz.** 1973. Prosthetic valve endocarditis. Circulation **48**:365–377.
11. **Eisenstein, B. I.** 1981. Phase variation of type 1 fimbriae in *Escherichia coli* is under transcriptional control. Science **214**:337–339.
12. **Gibbons, R. J., and J. van Houte.** 1980. Bacterial adherence and the formation of dental plaques, p. 74–77. *In* E. H. Beachey (ed.), Receptors and recognition, series B, vol. 6. Bacterial adherence. Chapman and Hall, New York.
13. **Hamada, S., and H. D. Slade.** 1980. Mechanisms of adherence of *Streptococcus mutans* to smooth surfaces in vitro, p. 121. *In* E. H. Beachey (ed.), Receptors and recognition, series B, vol. 6. Bacterial adherence. Chapman and Hall, New York.
14. **Hammond, G. W., and H. G. Stirer.** 1975. Combination antibiotic therapy in an outbreak of prosthetic endocarditis caused by *Staphylococcus epidermidis*. Can. Med. Assoc. J. **118**:524–530.
15. **Holt, R.** 1969. The classification of staphylococci from colonized ventriculo-atrial shunts. J. Clin. Pathol. **22**:475–482.
16. **Jones, D., R. H. Deibel, and C. F. Niven.** 1963. Identity of *Staphylococcus epidermidis*. J. Bacteriol. **85**:62–67.
17. **Locci, R., G. Peters, and G. Pulverer.** 1981. Microbial colonization of prosthetic devices. I. Microtopographical characteristics of intravenous catheters as detected by scanning electron microscopy. Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. Reihe B **175**:285–292.
18. **Locci, R., G. Peters, and G. Pulverer.** 1981. Microbial colonization of prosthetic devices. III. Adhesion of staphylococci to lumina of intravenous catheters perfused with bacterial suspensions. Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Abt. 1 Orig. Reihe B **173**:300–307.
19. **Marples, R. R., R. Hone, C. M. Notley, J. F. Richardson, and J. A. Crees-Morris.** 1978. Investigation of coagulase-negative staphylococci from infections in surgical patients. Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. Reihe A **241**:140–156.
20. **McCabe, R. M., and J. A. Donkersloot.** 1977. Adherence of veillonella species mediated by extracellular glucosyltransferase from *Streptococcus salivarius*. Infect. Immun. **18**:726–734.
21. **Mudd, S.** 1965. Capsulation, pseudocapsulation, and the somatic antigens of the surface of *Staphylococcus aureus*. Ann. N.Y. Acad. Sci. **128**:45–56.
22. **Mudd, S., and S. J. DeCourcy.** 1965. Interaction of viscid material of *Staphylococcus aureus* with specific immune serum. J. Bacteriol. **89**:874–879.
23. **Ofek, I., E. H. Beachey, and A. L. Bisno.** 1974. Resistance of *Neisseria gonorrhea* to phagocytosis: relationship to colonial morphology and surface pili. J. Infect. Dis. **129**:310–316.
24. **Patterson, F. P., and C. S. Brown.** 1972. The McKee-Farrar total hip replacement. Preliminary results and complications of 368 operations performed in five general hospitals. J. Bone Joint Surg. **54A**:257–275.
25. **Peters, G., R. Locci, and G. Pulverer.** 1981. Microbial colonization of prosthetic devices. II. Scanning electron microscopy of naturally infected intravenous catheters. Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Abt. 1 Orig. Reihe B **173**:293–299.
26. **Sall, T.** 1962. Interrelationship of extracellular enzymes and pseudocapsulation in a strain of *Staphylococcus aureus*. J. Bacteriol. **83**:1238–1243.
27. **Sall, T., S. Mudd, and J. Taubler.** 1961. Concerning the surface of cells of *Staphylococcus pyogenes*. I. A pseudocapsulation phenomenon under certain experimental conditions. J. Exp. Med. **113**:693–700.
28. **Schimke, R. T., P. H. Black, V. H. Mark, and M. N. Swartz.** 1961. Indolent *Staphylococcus albus* or *aureus* bacteremia after ventriculoatriostomy. N. Engl. J. Med. **264**:264–270.
29. **Schoenbaum, S. C., P. Gardner, and J. Shillito.** 1975. Infection of cerebrospinal fluid shunts: epidemiology, clinical manifestations and therapy. J. Infect. Dis. **131**:543–552.
30. **Shea, S. M.** 1974. Lanthanum staining of the surface coat of cells: its enhancement by the use of fixation containing alcian blue or cetyl-pyridininium chloride. J. Cell Biol. **51**:611–620.
31. **Speller, D. C. E., and R. G. Mitchell.** 1973. Coagulase

negative staphylococci causing endocarditis after cardiac surgery. J. Clin. Pathol. **26**:517–522.

32. **Vera, H. D., and D. A. Power.** 1980. Section XI. Media, reagents, and stains. Culture media, p. 965–999. *In* E. H. Lennette, A. Balows, W. J. Hausler, Jr., and J. P. Truant (ed.), Manual of clinical microbiology, 3rd ed. American Society of Microbiology, Washington, D.C.
33. **Wiley, B. B., and J. C. Wonnacott.** 1962. Isolation and partial characterization of a capsular material from *Staphylococcus aureus*. J. Bacteriol. **83**:1169–1176.
34. **Wilson, P. D.** 1977. Joint replacement. South. Med. J. **70**:55S–60S.
35. **Wilson, P. D., H. C. Amstutz, A. Czerniecki, E. A. Salvati, and D. G. Mendes.** 1972. Total hip replacement with fixation by acrylic cement: a preliminary study of 100 consecutive McKee-Farrar prosthetic replacements. J. Bone J. Surg. **54A**:207–236.
36. **Wilson, P. D., E. A. Salvati, P. Aglietti, and L. J. Kutner.** 1973. The problem of infection in endoprosthetic surgery of the hip joint. Clin. Ortop. **96**:213–221.
37. **Yoshida, K., and R. D. Ekstedt.** 1968. Relation of mucoid growth of *Staphylococcus aureus* to clumping factor reaction, morphology in serum soft agar, and virulence. J. Bacteriol. **96**:902–908.