STUDY OF THE ANAEROBIC CORYNEBACTERIA

Charles H. Zierdt, Charles Webster and Willadene S. Rude

Clinical Pathology Department
National Institutes of Health
Bethesda, Maryland

ABSTRACT. Reduction in number of anaerobic Corynebacterium species is proposed. C. liquefaciens, C. pyogenes, C. granulosum, C. parvum, C. diphteroides (sic) and C. anaerobium are synonyms of C. acnes (Gilchrist) Ebersson 1918 and should be so treated. Evidence is presented separating C. acnes from the genus Propionibacterium where recent proposals have placed it. C. acnes NCTC 737, ATCC 6919 is proposed as neotype strain.

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In the course of work with anaerobic corynebacteria and their L forms in disease, the anaerobic species available from the American Type Culture Collection (ATCC) and the National Collection of Type Cultures (NCTC) and from Dr. A. R. Prévot were acquired and comparisons made. It became increasingly evident that most of the species studied were so closely related biochemically, serologically and morphologically that reduction in the number of recognized species is feasible. Following this, interest was attracted to the proposals of Douglas and Gunter (1946), Gutierrez (1953), Moore and Cato (1963) that C. acnes properly belonged to the genus Propionibacterium partly because of propionic acid production from lactate and glucose.

MATERIALS AND METHODS

Stock cultures of Propionibacterium were acquired from the sources listed in Table 1.

Media: Kohn's charcoal gelatin pellets in Trypticase Soy Broth*, indol broth, nitrate broth, MRVP medium, and bile

* Baltimore Biological Laboratories. All other media and media components were from Difco, Detroit, Michigan.

TABLE 1. Organisms studied and Source of Cultures.

Organism	Culture Number and Source			
	ATCC	NCTC	Prévot	C.Z.
<i>C. acnes</i>	6919*	737		
<i>C. acnes</i>	6921			
<i>C. acnes</i>	6922			
<i>C. acnes</i>	6923			
<i>C. acnes</i>	11827			
<i>C. acnes</i>	11828			
<i>C. acnes</i>				251
<i>C. acnes</i>				254
<i>C. liquefaciens</i>			3044B	
<i>C. pyogenes</i>			637B	
<i>C. granulorum</i>			3024B	
<i>C. parvum</i>			3085	
<i>C. lymphophilum</i>			No Number	
<i>C. diphteroides</i>			2764	
<i>C. anaerobium</i>			2325	
<i>P. arabinosum</i>	4965			
<i>P. freudenreichii</i>	6207**			
<i>P. jensenii</i>	4867			
<i>P. pentosaceum</i>	4875			
<i>P. petersonii</i>	4870			
<i>P. rubrum</i>	4871			
<i>P. shermanii</i>	9614			
<i>P. thoenii</i>	4872			
<i>P. zeae</i>	4964			

* From NCTC, NCTC 737

** Type species

aesculin agar. The base medium for fermentation tests was made with beef extract 3 gm, proteose peptone No. 3 3 gm, gelatin 80 gm, K_2HPO_4 0.3 gm, NaCl 2.0 gm, agar 2.0 gm, phenol red 0.025 gm, and distilled water 1.0 liter. Final pH was 7.4. Carbohydrates were added in 1% concentration following autoclaving. Incubation was anaerobic at 37°C.

Results: Physiological characteristics of the species of the two genera obtained during this study are shown in Table 2. Strong reactions required a massive inoculum in each tube of about 0.5 ml of a heavy broth suspension, neutralized with N/1 sodium hydroxide.

DISCUSSION

Prévot (1957) listed 12 species described by 10 authors (Table 3); he reduced these in 1966 to 9 species, but in 1961 listed 10 species. However, any one of the lists included only species present in the 1957 list. None of the original cultures of the species listed are extant. E.G.D. Murray agreed with the findings of Seeliger (1953) that Prévot's C. liquefaciens was a later synonym of C. acnes, while recognizing in Bergey's Manual (1957 ed.) five species of anaerobic to aerotolerant species of Corynebacterium. Linzenmeier (1954) found close serological relationship among all of Prévot's listed species except C. lymphophilum, and he believed that C. avidum was close to C. acnes. Lentze (1950) had identified C. renale-cuniculi with C. acnes. Seeliger (personal communication) was of the opinion that C. avidum was the same as C. acnes. The work of Lentze, Linzenmeier and Seeliger was provident to this study since Prévot (personal communication) has stated that the strains he isolated as C. renale-cuniculi and C. avidum had died out, and none of the collections mentioned had them. The strains of the species received from Prévot were not the original cultures but were isolated by him.

Prévot's (1960) differential schema is seen in Table 4. In addition, amounts of catalase, proportions of such acids as formic, acetic, and valeric, the relative quality of anaerobiosis, morphology of subsurface colonies, and relative reducing power were noted by Prévot. He separated the species initially on presence or absence of gas production, a test which we have found in our study to be unreliable. Gas has been produced by rare strains on initial cultivation.

TABLE 2. Characteristics of the Organisms Studied

Organism	Culture Collection	Kohn's gelatin	Litmus milk digestion	Indol	Nitrite	Methyl red	Bile aesculin agar slant	Catalase	Dextrose	Arabinose	Mannose	Trehalose	Galactose	Levulose	Glycerol	Dulcitol	Salicin	Amygdalin	Aesculin	Inositol	Adonitol	Sucrose	Coryne. Phage 174	Pigmentation	Aerobic growth	Gas	Growth 24° C
<i>Corynebacterium</i>	ATCC 6919, 6921	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>acnes</i>	6922, 6923, 11827	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	11828	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	NCTC 797	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. liquefaciens</i>	CZ 251, 254	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. pyogenes</i>	Prévot 3044B	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. rennulum</i>	Prévot 637B	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. parvum</i>	Prévot 3024B	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. lymphophilum</i>	Prévot 3085	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. diphteroides</i>	Prévot	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. anaerobium</i>	Prévot 2764	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>C. anaerobium</i>	Prévot 2325	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>Propionibacterium</i>		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>arabinoan</i>	ATCC 4965	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. freudenreichii</i>	ATCC 6207	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. insensit</i>	ATCC 4967	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4975	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4970	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4972	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4974	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4976	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4978	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4980	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4982	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4984	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
<i>P. antarcticum</i>	ATCC 4986	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Litmus Milk Reactions: 1. Acid coagulation with hard clot and expressed water.
 2. Acid coagulation with soft clot followed by clot digestion.
 3. No change.
 4. Acid reaction.

TABLE 3. Anaerobic Species of Corynebacterium Accepted in Different Publications

	Dr. A. R. Prévot					¹ Bergey's		
	1937*	1938	1957	1960	1961	1st-5th Eds. 1923	Bergey's 6th Ed. 1934	Bergey's 7th Ed. 1940
1. <u>C. diphtheroides</u> Jungano 1909 (Prévot, 1938)	X	X	X	X	X			X
2. <u>C. avidum</u> Eggerth 1935 (Prévot, 1938)		X	X	X	X			X
3. <u>C. renale-cuniculi</u> Hanteufel and Herzberg 1929	X	X	X	X	X			
4. <u>C. parvum</u> Mayer 1926 (Prévot, 1938)	X	X	X	X	X			X
5. <u>C. lymphophilum</u> Torrey 1916 (Bergey, 1923)	X	X	X	X	X	X		
6. <u>C. hepatodystrophicans</u> Kucziński 1929 (Prévot, 1938)	X	X	X		X			
7. <u>C. anaerobium</u> Massini 1913 (Prévot, 1938)		X	X	X	X			
8. <u>C. granulosum</u> Jungano 1909 (Prévot, 1938)		X	X	X	X			X
9. <u>C. adamsoni</u> Adamson 1919 (Prévot, 1938)		X	X		X			
10. <u>C. liquefaciens</u> Jungano 1908 (Prévot, 1938)	X	X	X	X	X			
11. <u>C. pyogenes bovis</u> Roux 1905 (Prévot, 1938)			X	X				
12. <u>C. acnes</u> Gilchrist 1901 (Ebersson, 1918)			X			X	X	X

¹ Bergey's Manual of Determinative Bacteriology

*Weinberg, M., Nativelle, R., and Prévot, A. R.

TABLE 4. Reactions of anaerobic Corynebacterium species (adapted from Prévot 1960).*

Cultures	Biochemical Tests					
	Gas	Gelatin	Milk	Indol	H ₂ S	Nitrate
<u>C. anaerobium</u>	-	-	Coag.	- or +	-	+
<u>C. granulosum</u>	-	-	-	+	+	+
<u>C. liquefaciens</u>	-	+	Coag.	+	+	+
<u>C. pyogenes</u>	-	-	-	-	-	-
<u>C. lymphophilum</u>	-	-	-	-	-	-
<u>C. parvum</u>	+	-	Coag.	Trace	- or Trace	+
<u>C. diphteroides</u>	+	-	-	+	-	-
<u>C. avidum</u>	+	+	Coag. Digested	+ or -	+ or -	- or +
<u>C. renale cuniculi</u>	+	-	-	+	+	-

*Ergebnisse der Mikrobiologie, Band 33:

Closeness of C. acnes to its transitional or L forms favors gas production. Production of H_2S always has been positive using lead acetate paper and negative using Triple Sugar Iron Agar.

Initial biochemical reactions produced by anaerobic Corynebacterium isolates in the author's laboratory were subject to change as subcultivation continued. Four reactions, the indol and/or the nitrate reactions, and less often the gelatin or litmus milk reactions may be negative on first testing in about 10% of the cultures. On further subculture, the tendency is always to acquire positive test characteristics, never to delete them. After months of cultivation in broth, anaerobic Corynebacterium isolates usually changed to positive reactions from negative reactions registered on initial testing for these four characteristics. Since species differentiation has been on the basis of reactions to the tests recorded in Table 4, it is easily seen how a number of species could erroneously be derived when the initial reactions are accepted, since an organism was designated a specific name on a single test difference.

Some of the discrepancies in data of different workers may have occurred because of differences in size of inoculum. In our study a large inoculum worked best, i.e., 0.5 to 1.0 ml of a fully turbid broth culture for each test. This often meant the difference between a positive test or a negative if the inoculum was the usual loopful or a few drops. Enzyme contained in the inoculum played a part in reactions obtained in this way, but positive reactions depended also on growth, and a large inoculum was often essential to initiate growth. In this aspect C. acnes was like species of Actinomyces or Mycobacterium.

Corynebacterium phage 174 was isolated during the course of this study from spontaneous plaques on C. acnes ATCC 11827. It did not form plaques on three strains of C. diphtheriae, other aerobic corynebacteria, Lactobacillus species, Actinomyces israelii, Staphylococcus aureus, S. epidermidis, propionibacteria, Arthrobacter species, Listeria monocytogenes, hemolytic and nonhemolytic strains of Streptococcus, Escherichia coli, Salmonella species, Shigella species, and Pseudomonas aeruginosa. It lysed almost all anaerobic corynebacteria studied. The only species received from Prévot which were resistant to phage 174 were C. granulosum and C. lymphophilum, but the latter is evidently not a Corynebacterium. C. acnes strains ATCC 6919, 6921, 6922, 6923, 11827, NCTC 737, and CZ 254 were all lysed by phage 174.

Of 167 C. acnes strains isolated in the writers' laboratory from patients, 147 were lysed by phage 174 (88%) while 20 were not. It was noted that 9 of the 20 strains resistant to phage 174 possessed at least one characteristic aberrant to the normal pattern. Five were initially indol negative instead of positive, three grew slightly in 5% CO₂ atmosphere, and one was indol and nitrite negative. Four of the 147 phage sensitive cultures had converted from phage resistant after one or two transfers.

Prévot's strain of C. lymphophilum in this study (Table 2) exhibited the reactions of Actinomyces israelii. Torrey's original culture of C. lymphophilum is no longer available. His description (Torrey 1916) was identical to that for C. acnes. Linzenmeier (1954) found Prévot's strain of C. lymphophilum to be serologically distinct from the other anaerobic species that he studied. The others cross-agglutinated at approximately equal titers.

Beerens and Demont (1949) reported Prévot's C. anaerobium to be identical biochemically with A. israelii. The culture of C. anaerobium studied here does not confirm this. It is surmised that these identically labeled cultures are actually different organisms.

Aside from consideration of the evidence presented that C. acnes is the only legitimate species of anaerobic Corynebacterium, it is proposed that C. acnes ATCC 6919, NCTC 737, the Ponsonby strain, isolated by A. F. Hayden from facial acne, be considered the neotype strain for the species. It has the characteristics set forth by Gilchrist, and has been suggested as the working type by Sneath and Skerman (1966).

The belief that C. acnes should be placed in Propionibacterium is by no means that of all microbiologists cognizant of this area, but there have been no published data tending to refute those publications supporting this belief. Corynebacterium acnes ATCC 11827, etc., the strain Sereth of Seeliger, was used to compare the nine species of Propionibacterium listed. Data from the literature for the genus Propionibacterium are shown in Table 5. Morphologically, all the species of Propionibacterium studied were Gram-positive bacilli of diphtheroid appearance. However, there was no difficulty in distinguishing the two genera by Gram stain morphology. C. acnes was delicate, of quite uniform bacillary morphology, occurring in pairs and single. It stained unevenly. All species of Propionibacterium were robust, almost coarse, pleomorphic, occurred singly, and

stained uniformly. Sundman et al. (1959) in their detailed study of this problem have stated: "As a remark on the work of Douglas and Gunter (1946), who placed C. acnes in Propionibacterium, we wish to state that the morphological criteria found in the present work did not favour such a transfer."

Data from the literature for the propionibacteria are shown in Table 5.

TABLE 5. Reactions of Propionibacteria According to the Literature

Cultures	ATCC Number	Gas	Gelatin	Milk	Indol	Nitrate	Catalase	Pigment
<i>P. arabinosum</i>	4965	+	-	-	-	NR*	VS**	+
<i>P. freudenreichii</i>	6207	+	-	-	-	-	+	-
<i>P. jensenii</i>	4867	+	-	AC****	-	-	+	+
<i>P. pentosaceum</i>	4875	+	-	AC	-	+	S***	-
<i>P. petersonii</i>	4870	+	-	AC	-	-	+	-
<i>P. rubrum</i>	4871	+	-	AC	-	-	+	+
<i>P. shermanii</i>	9614	+	-	AC	-	-	+	-
<i>P. thoenii</i>	4872	+	-	AC	-	-	+	+
<i>P. zeae</i>	4964	+	-	AC	-	-	+	-

*NR Not recorded

**VS Very slight

***S Slight

****AC Acid coagulation

Serologically, there was low titer agglutination between C. acnes 11827 and some of the Propionibacterium (Tables 6, 7). These cross titers were reduced (Tables 8, 9) with the styrene latex particle flocculation technique of Florman and Scoma (1960).

It should be noted that C. acnes requires anaerobic conditions for production of propionic acid from glucose or lactate while Propionibacterium produce it aerobically as well as anaerobically. Also other organisms produce similar products. Corynebacterium diphtheriae produces chiefly propionic acid from glucose (Tasman and Brandwijk 1938) as does Veillonella gazogenes (Johns 1951). An unidentified Gram-positive coccus from the rumen of sheep was found to

TABLE 6. Tube Agglutination with C. acnes 11827 Antiserum and Propionibacterium Antigens

Propionibacterium	Antiserum Dilutions Homologous Titer 1-640					
	1:20	1:40	1:80	1:160	1:320	
Antigens						Controls*
<i>P. freudenreichii</i>	+	+	+	-	-	-
<i>P. zeae</i>	-	-	-	-	-	-
<i>P. rubrum</i>	+	+	+	-	-	-
<i>P. thoenii</i>	+	+	+	-	-	-
<i>P. jensenii</i>	+	+	+	-	-	-
<i>P. arabinosum</i>	-	-	-	-	-	-
<i>P. shermanii</i>	+	-	-	-	-	-
<i>P. pentosaceum</i>	-	-	-	-	-	-

* Antigen and saline.

TABLE 7. Tube Agglutination with C. acnes 11827 Antigen and Propionibacterium Antisera

Propionibacterium	Homologous	Antiserum Dilutions					Control*
Antisera	- Titer	1:20	1:40	1:80	1:160	1:320	
<i>P. freudenreichii</i>	1-320	-	-	-	-	-	-
<i>P. zeae</i>	1-160	-	-	-	-	-	-
<i>P. rubrum</i>	1-640	+	+	-	-	-	-
<i>P. thoenii</i>	1-320	-	-	-	-	-	-
<i>P. jensenii</i>	1-160	-	-	-	-	-	-
<i>P. arabinosum</i>	1-160	-	-	-	-	-	-
<i>P. shermanii</i>	1-320	-	-	-	-	-	-
<i>P. pentosaceum</i>	1-640	+	+	-	-	-	-

*Antigen and saline.

TABLE 8. Latex Flocculation with C. acnes 11827 Antigen and Propionibacterium Antisera

Propionibacterium	Homologous	Antiserum Dilutions					Control*
Antiserum	Titer	1:20	1:40	1:80	1:160	1:320	
<i>P. freudenreichii</i>	1-320	-	-	-	-	-	-
<i>P. zeae</i>	1-160	+	+	-	-	-	-
<i>P. rubrum</i>	1-640	+	+	-	-	-	-
<i>P. thoenii</i>	1-320	+	+	-	-	-	-
<i>P. jensenii</i>	1-160	+	+	-	-	-	-
<i>P. arabinosum</i>	1-160	+	+	-	-	-	-
<i>P. shermanii</i>	1-320	-	-	-	-	-	-
<i>P. pentosaceum</i>	1-640	+	+	-	-	-	-

* 1. Latex particles, sensitized - no serum added.

2. Latex particles, non-sensitized - serum added.

Table 9. Latex Flocculation with C. acnes ATCC 11827 antiserum and Propionibacterium Antigens.

Propionibacterium	Antiserum Dilutions Homologous Titer 1-640					Control*
Antigens	1:20	1:40	1:80	1:160	1:320	
<i>P. freudenreichii</i>	-	-	-	-	-	-
<i>P. zeae</i>	-	-	-	-	-	-
<i>P. rubrum</i>	+	-	-	-	-	-
<i>P. thoenii</i>	+	-	-	-	-	-
<i>P. jensenii</i>	+	+	-	-	-	-
<i>P. arabinosum</i>	-	-	-	-	-	-
<i>P. shermanii</i>	-	-	-	-	-	-
<i>P. pentosaceum</i>	+	-	-	-	-	-

*1. Latex particles, sensitized - no serum added.

2. Latex particles, non-sensitized - serum added.

produce propionic acid, acetic acid, and CO₂ from lactate (Elsden 1945). It would seem that organisms which have not yet been studied might also yield propionic acid as the chief product from lactate with perhaps similar amounts of acetic acid and carbon dioxide. Until this problem is resolved it would seem unwise to transfer C. acnes to the genus Propionibacterium. The unique characteristics of C. acnes and its position as the predominant and very numerous member of the skin biota (Evans et al. 1950), as an agent in acne (Shehadah and Kligman 1963), and as a cause of systemic disease (Prévot 1960, Wittler et al. 1960, Zierdt et al. 1964) leads to the thought that new classification may be justified.

It seems best at this time, however, to retain C. acnes in the genus Corynebacterium until such time as a definite proposal can be made for establishment of a new genus.

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