

GUEST COMMENTARY

Salmonella Nomenclature

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INTRODUCTION

Salmonellosis is a major cause of bacterial enteric illness in both humans and animals. Each year an estimated 1.4 million cases of salmonellosis occur among humans in the United States (15). In approximately 35,000 of these cases, *Salmonella* isolates are serotyped by public health laboratories and the results are electronically transmitted to the Centers for Disease Control and Prevention (CDC). This information is used by local and state health departments and CDC to monitor local, regional, and national trends in human salmonellosis and to identify possible outbreaks of salmonellosis (1, 5). Over the past 25 years, the National *Salmonella* Surveillance System has provided valuable information on the incidence of human salmonellosis in the United States and trends in specific serotypes. The recently implemented *Salmonella* Outbreak Detection Algorithm, another valuable tool for the recognition of outbreaks (11), allows users to detect increases in human infections due to specific *Salmonella* serotypes. *Salmonella* surveillance activities depend upon the accuracy of serotype identification and are facilitated by standardized nomenclature. The National *Salmonella* Reference Laboratory at CDC assists public health laboratories in the United States in serotype identification by providing procedure manuals, training workshops, updates, and assistance with the identification of problem isolates.

There are currently 2,463 serotypes (serovars) of *Salmonella* (18). The antigenic formulae of *Salmonella* serotypes are defined and maintained by the World Health Organization (WHO) Collaborating Centre for Reference and Research on *Salmonella* at the Pasteur Institute, Paris, France (WHO Collaborating Centre), and new serotypes are listed in annual updates of the Kauffmann-White scheme (18, 19).

Salmonella nomenclature is complex, and scientists use different systems to refer to and communicate about this genus. However, uniformity in *Salmonella* nomenclature is necessary for communication between scientists, health officials, and the public. Unfortunately, current usage often combines several nomenclatural systems that inconsistently divide the genus into species, subspecies, subgenera, groups, subgroups, and serotypes (serovars), and this causes confusion. CDC receives many inquiries concerning the appropriate *Salmonella* nomenclature for the reporting of results and for use in scientific publications.

The nomenclature for the genus *Salmonella* has evolved

from the initial one serotype-one species concept proposed by Kauffmann (12) on the basis of the serologic identification of O (somatic) and H (flagellar) antigens. Each serotype was considered a separate species (for example, *S. paratyphi* A, *S. newport*, and *S. enteritidis*); this concept, if used today, would result in 2,463 species of *Salmonella*. Other taxonomic proposals have been based on the clinical role of a strain, on the biochemical characteristics that divide the serotypes into subgenera, and ultimately, on genomic relatedness. The proposals for nomenclature changes in the genus have been summarized previously (8, 9, 14).

The defining development in *Salmonella* taxonomy occurred in 1973 when Crosa et al. (6) demonstrated by DNA-DNA hybridization that all serotypes and subgenera I, II, and IV of *Salmonella* and all serotypes of “Arizona” were related at the species level; thus, they belonged in a single species. The single exception, subsequently described, is *S. bongori*, previously known as subspecies V, which by DNA-DNA hybridization is a distinct species (21). Since *S. choleraesuis* appeared on the Approved List of Bacterial Names (23) as the type species of *Salmonella*, it had priority as the species name. The name “choleraesuis,” however, refers to both a species and a serotype, which causes confusion. In addition, the serotype Choleraesuis is not representative of the majority of serotypes because it is biochemically distinct, being arabinose and trehalose negative (4, 13).

In 1986 the Subcommittee of *Enterobacteriaceae* of the International Committee on Systematic Bacteriology at the XIV International Congress of Microbiology unanimously recommended that the type species for *Salmonella* be changed to *S. enterica* (17), a name coined by Kauffmann and Edwards in 1952 (13), because no serotype shares this name. In 1987, Le Minor and Popoff of the WHO Collaborating Centre formally made a proposal as a “Request for an Opinion” to the Judicial Commission of the International Committee of Systematic Bacteriology (14). The recommendation was adopted by CDC, by Ewing in 1986 in the 4th edition of *Edward’s and Ewing’s Identification of Enterobacteriaceae* (8), and by other laboratories (16).

Nonetheless, the request was denied by the Judicial Commission. Although the Judicial Commission was generally in favor of *S. enterica* as the type species of *Salmonella*, its members believed that the status of *Salmonella* serotype Typhi, the causative agent of typhoid fever, was not adequately addressed in this request for an opinion. They were concerned that if *S. enterica* were adopted as the type species, *Salmonella* serotype Typhi would be referred to as *S. enterica* subsp. *enterica* serotype Typhi and might be missed or overlooked by physicians in the same way that *S. choleraesuis* subsp. *choleraesuis* serotype Typhi might be overlooked. From this perspective, nothing would be gained by changing the type species name. The Judicial Commission therefore ruled that *S. choleraesuis*

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TABLE 1. *Salmonella* species, subspecies, serotypes, and their usual habitats, Kauffmann-White scheme^a

<i>Salmonella</i> species and subspecies	No. of serotypes within subspecies	Usual habitat
<i>S. enterica</i> subsp. <i>enterica</i> (I)	1,454	Warm-blooded animals
<i>S. enterica</i> subsp. <i>salamae</i> (II)	489	Cold-blooded animals and the environment ^b
<i>S. enterica</i> subsp. <i>arizonae</i> (IIIa)	94	Cold-blooded animals and the environment
<i>S. enterica</i> subsp. <i>diarizonae</i> (IIIb)	324	Cold-blooded animals and the environment
<i>S. enterica</i> subsp. <i>houtenae</i> (IV)	70	Cold-blooded animals and the environment
<i>S. enterica</i> subsp. <i>indica</i> (VI)	12	Cold-blooded animals and the environment
<i>S. bongori</i> (V)	20	Cold-blooded animals and the environment
Total	2,463	

^a The Kauffmann-White scheme has been described elsewhere (18, 19).

^b Isolates of all species and subspecies have occurred in humans.

be retained as the legitimate type species pending an amended request for an opinion (24). To comply with this ruling, in 1999 Euzéby (7) made an amended request, which is pending, to adopt *S. enterica* as the type species of *Salmonella* while retaining the species "*S. typhi*" as an exception.

In 1987, Le Minor and Popoff (14) also proposed that the seven subgenera of *Salmonella* be referred to as subspecies (subspecies I, II, IIIa, IIIb, IV, V, and VI). Subgenus III was divided into IIIa and IIIb by genomic relatedness and biochemical reactions. Subspecies IIIa (*S. enterica* subsp. *arizonae*) includes the monophasic "Arizona" serotypes and subspecies IIIb (*S. enterica* subsp. *diarizonae*) contains the diphasic serotypes. All "Arizona" serotypes had been incorporated into the Kauffmann-White scheme by Rohde in 1979 (22).

THE CURRENT SYSTEM USED BY CDC

In this report we update the nomenclature used at CDC for members of the genus *Salmonella*. The nomenclatural system is based on recommendations from the WHO Collaborating Centre and is summarized in Tables 1, 2, and 3.

According to the CDC system, the genus *Salmonella* contains two species, each of which contains multiple serotypes (Table 1). The two species are *S. enterica*, the type species, and *S. bongori*, which was formerly subspecies V (19, 21). *S. enterica* is divided into six subspecies (4, 19), which are referred to by a Roman numeral and a name (I, *S. enterica* subsp. *enterica*; II, *S. enterica* subsp. *salamae*; IIIa, *S. enterica* subsp. *arizonae*; IIIb, *S. enterica* subsp. *diarizonae*; IV, *S. enterica* subsp. *houtenae*; and VI, *S. enterica* subsp. *indica*). *S. enterica* subspecies are differentiated biochemically (4, 19) and by genomic relatedness (6, 19, 21).

Serotypes. CDC uses names for serotypes in subspecies I (for example, serotypes Enteritidis, Typhimurium, Typhi, and Choleraesuis) and uses antigenic formulas for unnamed serotypes described after 1966 in subspecies II, IV, and VI and in *S. bongori* (see discussion below). The name usually refers to the geographic location where the serotype was first isolated. For named serotypes, to emphasize that they are not separate species, the serotype name is not italicized and the first letter is capitalized (Table 2). At the first citation of a serotype the genus name is given followed by the word "serotype" or the abbreviation "ser." and then the serotype name (for example, *Salmonella* serotype or ser. Typhimurium). Subsequently, the

name may be written with the genus followed directly by the serotype name (for example, *Salmonella* Typhimurium or *S. Typhimurium*) (18, 19). CDC uses the format for formula designations used by the WHO Collaborating Centre. Both versions of the serotype name are listed as key words in manuscripts to facilitate the search and retrieval of information on *Salmonella* serotypes from electronic databases. Table 3 lists other serotype designations seen in the literature.

Serotype names designated by antigenic formulae include the following: (i) subspecies designation (subspecies I through VI), (ii) O (somatic) antigens followed by a colon, (iii) H (flagellar) antigens (phase 1) followed by a colon, and (iv) H antigens (phase 2, if present) (for example, *Salmonella* serotype IV 45:g,z₅₁:-. For formulae of serotypes in *S. bongori*, V is still used for uniformity (for example, *S. V* 61:z₃₅:-.).

Before 1966 all serotypes in all subspecies except subspecies IIIa and IIIb were given names. In 1966 the WHO Collaborating Centre began naming serotypes only in subspecies I and dropped all existing serotype names in subspecies II, IV, and VI and *S. bongori* from the Kauffmann-White scheme. For surveillance purposes, i.e., for compatibility with old data, as stated above, CDC continues to use pre-1966 names for serotypes in subspecies II, IV, and VI and *S. bongori* (2, 3, 4). A common example of an old serotype name used at CDC and seen in the United States is *S. ser. Marina* (*S. IV* 48:g,z₅₁:-.).

The majority (59%) of the 2,463 *Salmonella* serotypes belong to *S. enterica* subsp. I (*S. enterica* subsp. *enterica*) (19). Within *S. enterica* subsp. I, the most common O-antigen serogroups are A, B, C1, C2, D and E. Strains in these serogroups cause approximately 99% of *Salmonella* infections in humans and warm-blooded animals (19). Serotypes in *S. enterica* subspecies II (*S. enterica* subsp. *salamae*), IIIa (*S. enterica* subsp. *arizonae*), IIIb (*S. enterica* subsp. *diarizonae*), IV (*S. enterica* subsp. *houtenae*), IV (*S. enterica* subsp. *indica*), and *S. bongori* are usually isolated from cold-blooded animals and the environment but rarely from humans (10).

TABLE 2. *Salmonella* nomenclature in use at CDC, 2000^a

Taxonomic position	Nomenclature
Genus (italics).....	<i>Salmonella</i>
Species (italics)	<ul style="list-style-type: none"> ● <i>enterica</i>, which includes subspecies I, II, IIIa, IIIb, IV, and VI ● <i>bongori</i> (formerly subspecies V)
Serotype (capitalized, not italicized) ^b	<ul style="list-style-type: none"> ● The first time a serotype is mentioned in the text; the name should be preceded by the word "serotype" or "ser." ● Serotypes are named in subspecies I and designated by antigenic formulae in subspecies II to IV, and VI and <i>S. bongori</i> ● Members of subspecies II, IV, and VI and <i>S. bongori</i> retain their names if named before 1966

^a In 1984 Farmer et al. (10) updated the reporting system used at CDC for *Salmonella*. The major changes that CDC made and that result in a difference from the 1984 reporting system are (i) capitalization of the serotype name, (ii) inclusion of subspecies VI and *S. bongori*, and (iii) adoption of the type species name *S. enterica*.

^b Examples of serotype designations are *Salmonella* serotype (ser.) Typhimurium, *Salmonella* II 50:b:z₆, *Salmonella* IIIb 60:k:z, and *Salmonella* ser. Marina (IV 48:g,z₅₁:-.).

TABLE 3. Examples of *Salmonella* nomenclature currently seen in the literature

Complete name	CDC designation	Other designations
<i>S. enterica</i> ^a subsp. <i>enterica</i> ser. Typhi	<i>Salmonella</i> ser. Typhi	<i>Salmonella typhi</i>
<i>S. enterica</i> ^a subsp. <i>enterica</i> ser. Typhimurium	<i>S.</i> ser. Typhimurium	<i>Salmonella typhimurium</i>
<i>S. enterica</i> ^a subsp. <i>salamae</i> ser. Greenside	<i>S.</i> ser. Greenside	<i>S.</i> II 50:z:e,n,x, <i>S. greenside</i>
<i>S. enterica</i> ^a subsp. <i>arizonae</i> ser. 18:z ₄ ,z ₂₃ :–	<i>S.</i> IIIa 18:z ₄ ,z ₂₃ :–	“ <i>Arizona hinshawii</i> ” ser. 7a,7b:1,2,5:–
<i>S. enterica</i> ^a subsp. <i>diarizonae</i> ser. 60:k:z	<i>S.</i> IIIb 60:k:z	“ <i>A. hinshawii</i> ” ser. 24:29:31
<i>S. enterica</i> ^a subsp. <i>houtenae</i> ser. Marina	<i>S.</i> ser. Marina	<i>S.</i> IV 48:g,z ₅₁ :–, <i>S. marina</i>
<i>S. bongori</i> ser. Brookfield	<i>S.</i> ser. Brookfield	<i>S.</i> V 66:z ₄₁ :–, <i>S. brookfield</i>
<i>S. enterica</i> ^a subsp. <i>indica</i> ser. Srinagar	<i>S.</i> ser. Srinagar	<i>S.</i> VI 11:b:e,n,x, <i>S. srinagar</i>

^a *S. choleraesuis* and *S. enteritidis* are also used (8).

CONCLUSIONS

The nomenclature for *Salmonella* is still evolving and the debate on the name for the type species is not likely to be settled any time soon. In the meantime, the work of isolating, identifying, and reporting on *Salmonella* serotypes must go on for diagnostic, therapeutic, and public health purposes. We believe that the nomenclature system used at CDC, essentially based on the recommendations established by the WHO Collaborating Centre, adequately addresses the concerns and requirements of clinical and public health microbiologists. Because the type species name has not been officially approved and in order to shorten reports, *Salmonella enterica* subsp. *enterica* serotype Typhimurium, for example, is shortened to *Salmonella* serotype (ser.) Typhimurium or *Salmonella* Typhimurium. To ensure backward compatibility with literature searches on *Salmonella* serotypes from electronic databases, both versions of the serotype name should be listed as key words in manuscripts. In 1999, at the American Society for Microbiology (ASM) Publications Board Meeting, a proposal that relevant ASM journals adopt the *Salmonella* nomenclature currently used at CDC was unanimously endorsed by the board, with plans to update 2000 ASM Instructions to the Authors (20).

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