



Molecular epidemiology and antibiotic resistance phenotypes and genotypes of salmonellae from food supply chains in China



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ABSTRACT

Salmonella is an important zoonotic agent and a vehicle for antibiotic resistance genes. Here, 294 isolates from humans and food-producing animals were subjected to serotyping, multilocus sequence typing, and assessment of phenotypic (15 antibiotics) and genotypic (32 resistance genes) antimicrobial resistance. Twenty-two serotypes and 35 sequence types (STs) were identified, the most common STs being ST11, including *S. Enteritidis* from chickens and humans; ST17, including *S. Indiana* from chickens; and ST40, including *S. Derby* from pigs and humans. Antimicrobial resistance phenotypes and genotypes exhibited ST- and serovar-specific features. ST11, clonal complex (CC) 19, ST40, and ST155 were moderately multidrug-resistant (MDR) clones, most of the isolates of which were resistant to between 3 and 6 antibiotics. Isolates of a super-MDR clone, ST17, demonstrated resistance against 9 to 14 antimicrobials, in particular, ampicillin, amoxicillin-clavulanic acid, cefotaxime, cefepime, cefoperazone, ceftriaxone, and ciprofloxacin. Consistent with this, ST17 (*S. Indiana*) was associated with a gene cluster comprising *bla*_{CTX-M} (and/or *bla*_{OXA-1}-like together with *bla*_{TEM-1}-like), *sul1*, *aacC4*, *aac(6)-1b*, *floR*, and *dfxA17*, while the moderately-MDR clones (ST11, *S. Enteritidis*) were more closely linked to the *bla*_{TEM-1}-like gene. The similar genetic clones isolated from animals and humans indicate a common ancestor, and implicate animals as a major salmonellae source. Antibiotic abuse in animal production appears to be the origin of MDR and super-MDR isolates, the latter being closely associated with the β -lactamase genes *bla*_{CTX-M}, *bla*_{OXA-1}-like, and *bla*_{TEM-1}-like. Carried by chickens, ST17 (*S. Indiana*) is an emerging super-MDR clone whose associated resistance genes are expanding to other ST clones and serotypes being transmitted to animals and humans.

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1. Introduction

Salmonella is recognized as the causative agent of salmonellosis in both humans and animals. Many serovars of this bacterium, such as *S. Enteritidis* and *S. Typhimurium*, are common in food-producing animals, and a clear link between human illness and poultry consumption has been established (Foley & Lynne, 2008;

Guard-Bouldin, Morales, Frye, Gast, & Musgrove, 2007; Mead et al., 2010). Animals used in the production of food also play an important role in the transmission of antimicrobial-resistant *Salmonella* strains to humans (Beutlich et al., 2011). Several *S. enterica* serovars, including *S. Typhimurium*, *S. Newport*, *S. Derby*, and *S. Agona*, exhibit a super-multidrug-resistant (MDR) phenotype characterized by resistance to nine antimicrobial compounds, namely, ampicillin (AMP), amoxicillin/clavulanic acid (AMC), cefoxitin (FOX), cephalothin, ceftiofur, chloramphenicol (C), streptomycin, sulfamethoxazole, and tetracycline (TE). *Salmonella* genomic island 1 (SGI1) and its variants are associated with super-MDR isolates, in that this region contains a gene cluster conferring penta-resistance to AMP (*bla*PSE), C/florfenicol (*floR*), streptomycin/

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Table 1
Salmonella isolates, serotypes, STs, and super-MDR isolates from different sources.

Sources of isolates (no.)	Serotype (no.)	ST (no.)	No. of super-MDR isolates (ST) ^g
Chicken industry chains (88) ^a			
Broiler farms (27)	Environmental soils (8)	<i>S. enteritidis</i> (2) <i>S. aberdeen</i> (5) <i>S. agona</i> (1)	11 (2) 426 (5) 40 (1)
	Feeds (1)	<i>S. montevideo</i> (1)	17 (1)
	Broiler (18)	<i>S. enteritidis</i> (3) <i>S. indiana</i> (13) <i>S. agona</i> (1) B group (1)	11 (2), 17 (1) 17 (13) 11 (1) 17 (1)
			2 (ST11), 1(ST17) 13 (ST17)
Slaughterhouses (49)	Plucking (20)	<i>S. enteritidis</i> (6) <i>S. indiana</i> (12) <i>S. choleraesuis</i> (1) C group (1)	11 (6) 11 (2), 17 (10) 32 (1) 1541 (1)
	Chilling (7)	<i>S. enteritidis</i> (5) Non A-F group (1) <i>S. indiana</i> (1)	11 (5) 11 (1) 17 (1)
	Tools (1)	<i>S. kaapstad</i> (1)	17 (1)
	Whole frozen carcasses (9)	<i>S. enteritidis</i> (1) <i>S. indiana</i> (5) C group (3)	11 (1) 17 (5) 1541 (3)
	Frozen split chicken (12)	<i>S. enteritidis</i> (7) <i>S. indiana</i> (4) <i>S. london</i> (1)	11 (7) 17 (4) 463 (1)
			2 (ST17)
Distribution (2)	Frozen chicken on distribution (2)	<i>S. enteritidis</i> (1) <i>S. lomita</i> (1)	11 (1) 32 (1)
Retail (10)	Frozen chicken at retail (10)	<i>S. enteritidis</i> (6) <i>S. indiana</i> (1) <i>S. typhimurium</i> (1) <i>S. dublin</i> (1) <i>S. lomita</i> (1)	11 (5), 17 (1) 17 (1) 11 (1) 11 (1) 32 (1)
			1 (ST17)
Ill poultry (50) ^b			
Ill poultry (50)	Diseased chicken, layer, and broiler (50)	<i>S. enteritidis</i> (39) <i>S. indiana</i> (2) <i>S. gallinarum-pullorum</i> (2) UT (Vi) (6) D group (1)	11 (35), 17 (3), 19 (1), 17 (2) 92 (2) 319 (6) 17 (1)
			3 (ST17) 2 (ST17) 3 (ST319) 1 (ST17)
Pig industry chains (31) ^c			
Pig Farms (12)	Living donor (12)	<i>S. derby</i> (9) <i>S. ruzizi</i> (1) <i>S. new-rochelle</i> (2)	17 (2), 40 (3), 64 (1), 463 (2), 2441 (1) 40 (1) 40 (1), 2441 (1)
			1 (ST17), 1 (ST40), 1 (ST64)
Slaughterhouses(19)	Carcass (6)	<i>S. derby</i> (5) <i>S. ruzizi</i> (1) <i>S. derby</i> (10) <i>S. ruzizi</i> (1) <i>S. london</i> (1) <i>S. new-rochelle</i> (1)	40 (2), 155 (1), 2441 (2) 155 (1) 40 (9), 2441 (1) 463 (1) 463 (1) 40 (1)
	Iliac lymph nodes (13)		
Food (raw meat) from hotels in Jiangsu (7) ^d			
Hotels (7)	Broiler-meat (3) Pork(4)	<i>S. indiana</i> (3) <i>S. derby</i> (3) <i>S. enteritidis</i> (1)	17 (1), 34 (1), 469 (1) 40 (3) 11 (1)
			1 (ST17), 1 (ST34)
Animals in 1956, 1976, and 1986 (23) ^e			
Chicken (3)	Chicken (3)	<i>S. enteritidis</i> (3)	11 (2), 132 (1)
Pigs (20)	Pigs (20)	<i>S. enteritidis</i> (1) <i>S. choleraesuis</i> (9) <i>S. typhimurium</i> (10)	10 (1), 68 (7), 139 (1), 145 (1) 19 (9), 2939 (1)
Human from different cities of Jiangsu (95) ^f			
Human (44)	human carriers of food employees(44)	<i>S. enteritidis</i> (6) <i>S. typhimurium</i> (11) <i>S. senftenberg</i> (5) <i>S. dublin</i> (2) <i>S. anatum</i> (3) <i>S. derby</i> (3) <i>S. london</i> (2) <i>S. newport</i> (1) <i>S. aberdeen</i> (1) <i>S. rissen</i> (1) <i>S. bovismorbificans</i> (1) B group (1) C group (5) E group (2)	11 (6) 19 (5), 34 (5), 40 (1) 14 (5) 11 (2) 64 (3) 40 (3) 155 (2) 46 (1) 426 (1) 469 (1) 1499 (1) 36 (1) 26 (2), 33 (1), 292 (1), 314 (1) 516 (1), 1956 (1)
			1 (ST19), 2 (ST34) 1 (ST469)
Foodborne pathogens (51)	Patients (51)	<i>S. enteritidis</i> (19) <i>S. typhimurium</i> (10)	11 (17), 14 (1), 40 (1) 19 (5), 34 (3), 155 (1), 1544 (1)

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