



Streptococcus dysgalactiae subsp. *equisimilis* bacteremia: *Emm* types and clinical characteristics—a 4-year prospective study[☆]

Miia Saukkosaari^{1,2,*}, Janne Aittoniemi³, Reetta Huttunen^{1,2}, Tapio Seiskari³, Hanne-Leena Hyyryläinen⁴, Tiina Luukkaala^{5,6}, Sari Rantala^{1,2}

¹ Department of Internal Medicine, Tampere University Hospital, Tampere, Finland

² Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland

³ Fimlab Laboratories Ltd, Tampere, Finland

⁴ Public Health, Microbiology, Finnish Institute for Health and Welfare, Helsinki, Finland

⁵ Research, Development and Innovation Centre, Tampere University Hospital, Tampere, Finland

⁶ Health Science, Faculty of Social Science, Tampere University, Tampere, Finland

ARTICLE INFO

Article history:

Received 6 October 2025

Revised 4 December 2025

Accepted 4 December 2025

Keywords:

Streptococcus dysgalactiae subspecies

equisimilis

Bacteremia

emm type

Disease severity

Clinical manifestation

ABSTRACT

Objectives: The incidence of *Streptococcus dysgalactiae* subspecies *equisimilis* (SDSE) bacteremia is increasing worldwide, yet studies linking *emm* types to clinical data remain limited. This study aimed to investigate associations between *emm* types, clinical manifestations, and disease severity in patients with SDSE bacteremia.

Methods: We prospectively studied 159 SDSE bacteremia episodes in Pirkanmaa, Finland (November 2015 to November 2019). Severe disease was defined as intensive care unit treatment and/or death within 30 days of hospital admission.

Results: While *emm* type stG480 has remained the most common, stG62647 has increased over tenfold to become the second most prevalent. *Emm* type stC74a was associated with intensive care unit treatment (odds ratio [OR] 5.8 [95% confidence interval (CI) 1.3–26]), severe disease (OR 5.2 [95% CI 1.4–19]), and predominance of male patients (OR 8.5 [95% CI 1.1–67]). Surgical interventions were linked to *emm* type stG62647 (OR 2.8 [95% CI 1.1–7.3]). Potential associations between *emm* type and clinical manifestations were observed: stG643 with endocarditis, stG62647 with foreign-body infections, stG2078 with abscesses, and stG485 with unknown focus.

Conclusions: These results emphasize the importance of *emm* types in connection with disease severity and clinical manifestations.

© 2025 The Author(s). Published by Elsevier Ltd on behalf of International Society for Infectious Diseases. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>)

Introduction

The incidence of bacteremia caused by *Streptococcus dysgalactiae* subspecies *equisimilis* (SDSE), a β -hemolytic streptococcus expressing the C- and G-Lancefield groups, is increasing in various parts of the world [1–4]. In Finland, SDSE has been the fourth most prevalent cause of bacteremia in the past few years [5].

The M protein, which coats the bacterial surface, is a critical virulence factor in SDSE and *Streptococcus pyogenes* [6]. By interacting with various host molecules, it disables the complement sys-

tem and prevents phagocytosis [7]. The M protein is encoded by the *emm* gene, which serves as a basis for molecular epidemiologic typing. Over 100 distinct SDSE *emm* types have been identified so far [8,9]. The distribution of SDSE *emm* types varies across geographical regions, with certain *emm* types predominating in Europe [1,8,10–12]. Several investigators have reported an increase in the prevalence of SDSE *emm* type stG62647 over the past decade [8,12,13].

Studies concerning links between *emm* types and clinical data in SDSE bacteremia are limited and somewhat inconsistent [1,6,8]. In *S. pyogenes* infections, associations have been identified between *emm* types and disease manifestations [14–17]. Similar associations between SDSE *emm* types and clinical manifestations have not been reported [7,12,18]. Studies from Finland and Norway reported higher case fatality rates in SDSE bacteremia caused by rare

[☆] Preliminary results from this study were presented at the European Congress of Clinical Microbiology and Infectious Diseases; April 11–15, 2025; Vienna, Austria.

* Corresponding author: Tel.: +358443007852

E-mail address: miia.saukkosaari@tuni.fi (M. Saukkosaari).

emm types compared with the five most common types [10,19], whereas a Japanese study showed that the most common *emm* type (stG6792) was linked to poor outcomes [20]. In studies involving severe clinical manifestations, such as necrotizing soft tissue infections and infective endocarditis (IE), the most frequently identified SDSE *emm* types have been stG62647, stC74a, stG2078, and stG643 [21,22].

We present a prospective 4-year study from Finland, where we analyzed the changes in epidemiology of SDSE bacteremia *emm* types combined with clinical data. This study aimed to investigate the associations between SDSE *emm* types, clinical manifestations, and disease severity.

Material and methods

This 4-year prospective study was conducted in the Pirkanmaa Health District (HD), Tampere, Finland, from November 2015 to November 2019. All adult patients treated at either Tampere University Hospital, a tertiary care hospital with a catchment population of approximately 535,000 residents, or Hatanpää City Hospital in Tampere, who had at least one positive blood culture for SDSE, were included in the study. Five bacteremia episodes were excluded during the study period: three due to *Streptococcus canis* infection and two because the patients declined to participate.

Throughout the study period, an infectious disease specialist (S.R.) was contacted by a clinical microbiologist (J.A. or T.S.) in connection with all SDSE-positive blood cultures. Simultaneously, the infectious disease specialist (S.R.) monitored SDSE-positive blood cultures recorded in Finland's national register for hospital infections and antimicrobial drug use, which includes all positive blood cultures in the country. The specialist contacted patients with SDSE bacteremia to obtain informed consent for their participation in the study. If a patient was unable to provide informed consent due to a declining condition, consent was obtained from the patient's immediate family members. Clinical data were gathered through patient interviews and reviews of medical records during and after hospitalization.

Blood samples gathered in the emergency department at Tampere University Hospital were studied and cultivated at Fimlab Laboratories, Tampere. From November 2015 to October 2017, blood samples were collected into BacT/Alert FA Plus aerobic and FN Plus anaerobic blood culture bottles and incubated in an automated BacT/Alert 3D microbial detection system (bioMérieux). From November 2017 onward, blood samples were collected in BD BACTEC Plus Aerobic/F and Lytic/10 Anaerobic/F culture vials and incubated in a BD BACTEC FX blood culture system (Becton Dickinson).

SDSE was primarily identified based on typical large colony-forming growth and β -hemolysis on blood agar plates. Bacteria were primarily identified by using latex bead agglutination to determine Lancefield grouping (PathoDextra Strep Grouping Kit; Thermo Fisher Scientific), and the data were confirmed by using API 20 Strep (bioMérieux) or matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry (VITEK MS instrument; bioMérieux) until February 2017. From March 2017, the primary method for identification has been MALDI-TOF mass spectrometry. MALDI-TOF analysis provided results for *Streptococcus dysgalactiae* subsp. *dysgalactiae/equisimilis*, which was interpreted as *S. dysgalactiae* subsp. *equisimilis* associated with human disease.

In 2024, the isolates underwent *emm* sequencing in collaboration with the Finnish Institute for Health and Welfare. *Emm* typing was conducted according to the guidelines of the Centers for Disease Control and Prevention [23]. The *emm* types were compared with those in an earlier study from the same geographic area in 1995–2004 [10].

Severe disease was defined as requiring intensive care unit (ICU) treatment and/or death within 30 days of hospital admission. Streptococcal toxic shock syndrome was defined as identification of SDSE in the blood, septic shock, and multiorgan failure.

Differences between specific *emm* type compared with all other episodes together were tested using Pearson χ^2 or Fisher's exact test if the assumptions of the Pearson test were not valid. For differences that became statistically significant in previous analyses, Mantel–Haenszel odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. The Mann-Whitney U test was used to assess the differences in median age. Two-sided $P < 0.05$ were considered statistically significant. A Bonferroni correction was applied to the interpretation of the results due to multiple comparisons across subtypes. After Bonferroni correction for nine comparisons, the adjusted significance level was $P < 0.0056$. IBM SPSS Statistics for Windows, Version 29 (Armonk, NY: IBM Corp) was used for statistical analysis.

Results

A total of 159 SDSE bacteremia episodes in 157 patients were identified from November 2015 to November 2019. The median age of the patients was 71 years (interquartile range 61–85 years) and 59% were male. A total of 17 (11%) patients had severe disease, and the mortality rate was 5.7%. A total of 15 different *emm* types were identified (Figure 1). The eight most common *emm* types were stG480 (29 isolates, 18%); stG62647 (21 isolates, 13%); stG485 and stG6 (19 isolates each, 12%); stC74a (12 isolates, 7.5%); and stG643, stG652, and stG2078 (10 isolates each, 6.3%), collectively accounting for 82% of all *emm* types. Two (1.3%) isolates remained non-typeable. The two most common *emm* types, stG480 and stG62647, showed an increase over the first 3 study years, followed by a slight decrease in the last year (Figure 2). The *emm* type stG6 appeared to occur slightly more frequently every other year, whereas other *emm* types showed annual fluctuations without a clear temporal trend.

Emm type stC74a was statistically significantly associated with an increased need of ICU treatment (OR 5.8 [95% CI 1.3–26], $P = 0.039$), and severe disease was more common (OR 5.2 [95% CI 1.4–19], $P = 0.026$) than other *emm* types (Table 1). Surgical intervention was required more frequently in cases of *emm* type stG62647 (OR 2.8 [95% CI 1.1–7.3], $P = 0.030$, Pearson χ^2 test) than other *emm* types. The nine surgical procedures among the patients with *emm* type stG62647 were the following: one thigh amputation, one lower leg amputation, two fasciotomies with revision, one prosthesis revision surgery, two abscess drainages, one endoscopic retrograde cholangiography with stenting, and one tooth extraction.

Compared with a previous study conducted in the same geographic area in 1995–2004 [10], *emm* type stG480 remained the most common, whereas *emm* type stG62647 increased more than 10-fold (0.7% vs 13%) to become the second most common *emm* type in SDSE bacteremia (Figure 1). Furthermore, *emm* types stG485 and stG6 remained among the four most common *emm* types. The four most prevalent *emm* types together accounted for over half (55%) of all episodes in the present study. Of the other *emm* types, stC74a doubled (from 3.6% to 7.5%), whereas the proportion of stG643 decreased. Three novel types (stG6792, stG4222, and stG5420) were identified, whereas five *emm* types reported in the earlier study (stG11, stG507-1, stG840, stC9431, and stC839) were not detected. Notably, a larger proportion of samples were successfully *emm*-sequenced in this study compared with the earlier study in the same area.

Emm types accounting for more than 5% of bacteremia episodes (the eight most common *emm* types) were analyzed individually, and less common and non-typeable *emm* types were grouped to-

Table 1
Clinical characteristics of 159 episodes of *Streptococcus dysgalactiae* subsp. *equisimilis* bacteremia from November 2015 to November 2019 in Pirkanmaa Health District, Finland. Differences between specific *emm* type compared with all other episodes were tested using the Mann-Whitney U-test, Pearson χ^2 test (marked as *), or Fisher's exact test. The numbers are **bolded** if $P < 0.05$.

Characteristics	<i>Emm</i> types										Rare <i>emm</i> types ^a n = 29							
	stG480 n = 29		stG62647 n = 21		stG485 n = 19		stG6 n = 19		stC74a n = 12				stG643 n = 10		stG652 n = 10		stG2078 n = 10	
Female, n (%)	12	(41)	7	(33)	7	(37)	12	(63)	1	(8.3)	5	(50)	3	(30)	3	(30)	15	(52)
Male, n (%)	17	(59)	14	(67)	12	(63)	7	(37)	11	(92)	5	(50)	7	(70)	7	(70)	14	(48)
Age, Median (years)	72		70		68		71		65		73		79		71		75	
(Interquartile range, years)	(54-77)		(60-76)		(61-83)		(61-84)		(59-71)		(61-86)		(70-83)		(66-80)		(61-82)	
Severe disease ^b , n (%)	4	(14)	1	(4.8)	3	(16)	3	(16)	4	(33)	1	(10)	1	(10)	0		0	
Admission to ICU ^c	3	(10)	1	(4.8)	3	(16)	1	(5.3)	3	(25)	0		0		0		0	
30-day mortality	1	(3.4)	1	(4.8)	0		3	(16)	2	(17)	1	(10)	1	(10)	0		0	
Septic shock ^d , n (%)	4	(14)	3	(14)	3	(16)	2	(11)	2	(17)	1	(10)	1	(10)	2	(20)	2	(6.9)
Needed mechanical ventilation ^e , n (%)	0		1	(4.8)	1	(5.3)	0		1	(8.3)	0		0		0		0	
Level of consciousness ^f n (%)																		
Desoriented	3	(10)	4	(19)	2	(11)	3	(16)	3	(25)	3	(30)	3	(30)	1	(10)	8	(28)
Unconscious	2	(6.9)	1	(4.8)	3	(16)	1	(5.3)	0		0		0		0		0	
Multiorgan failure, n (%)	4	(14)	1	(4.8)	2	(11)	1	(5.3)	2	(17)	1	(10)	1	(10)	0		0	
DIC ^g , n (%)	2	(6.9)	1	(4.8)	1	(5.3)	0		1	(8.3)	0		1	(10)	0		0	
STSS ^h , n (%)	1	(3.4)	1	(4.8)	0		1	(5.3)	1	(8.3)	1	(10)	1	(10)	0		0	
Thromboembolic ⁱ complication, n (%)	3	(10)	0		3	(16)	1	(5.3)	1	(8.3)	2	(20)	1	(10)	0		3	(10)
Underwent surgical intervention, n (%)	6	(21)	9	(43)*	5	(26)	3	(17)	5	(42)	2	(20)	3	(30)	2	(20)	3	(10)

DIC, disseminated intravascular coagulation; ICU, intensive care unit; STSS, streptococcal toxic shock syndrome.

^a *emm* types stG6979 (n=7), stG10 (n=6), stG6792 (n=5), stG245 (n=4), stG166b (n=3), stG4222 (n=1), stG5420 (n=1), and non-typeable isolates (n=2)

^b intensive care unit treatment or death

^c intensive care unit

^d use of vasopressor and lactate level > 2 mmol/L

^e needed mechanical ventilation within 30 days of positive blood culture

^f observed at least once during the first two days after hospitalization

^g disseminated intravascular coagulation; thrombocytes lower than $100 \times 10^9/l$

^h streptococcal toxic shock syndrome

ⁱ venous or arterial event

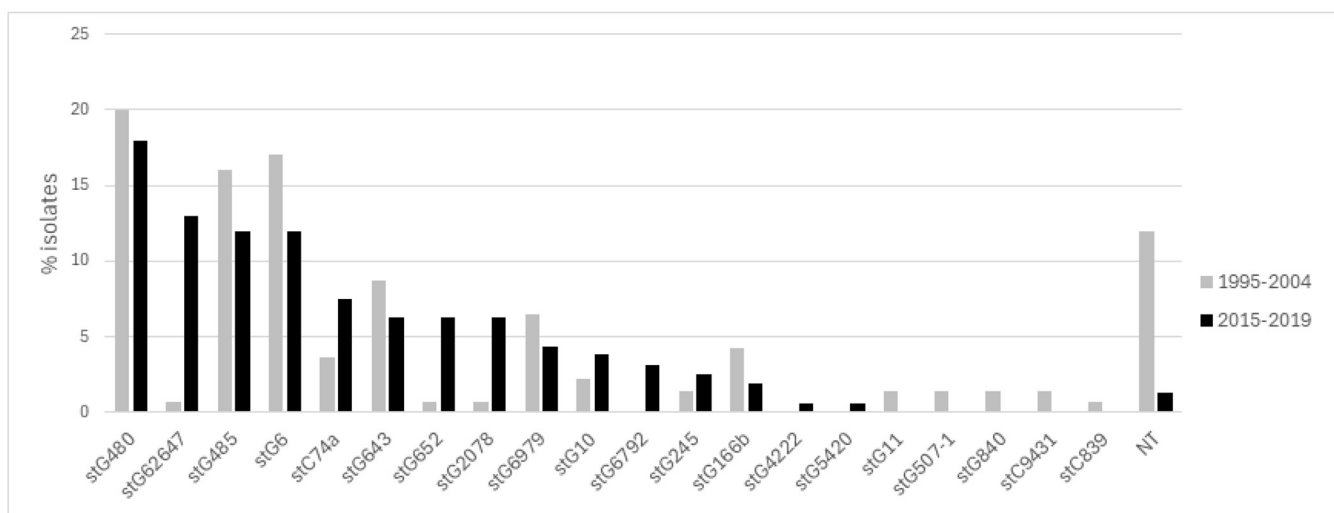


Figure 1. The proportions of *Streptococcus dysgalactiae* subsp. *equisimilis* emm types identified in the present study (2015–2019) and in a previous study (1995–2004) conducted in the same region of Pirkanmaa Health District, Finland.

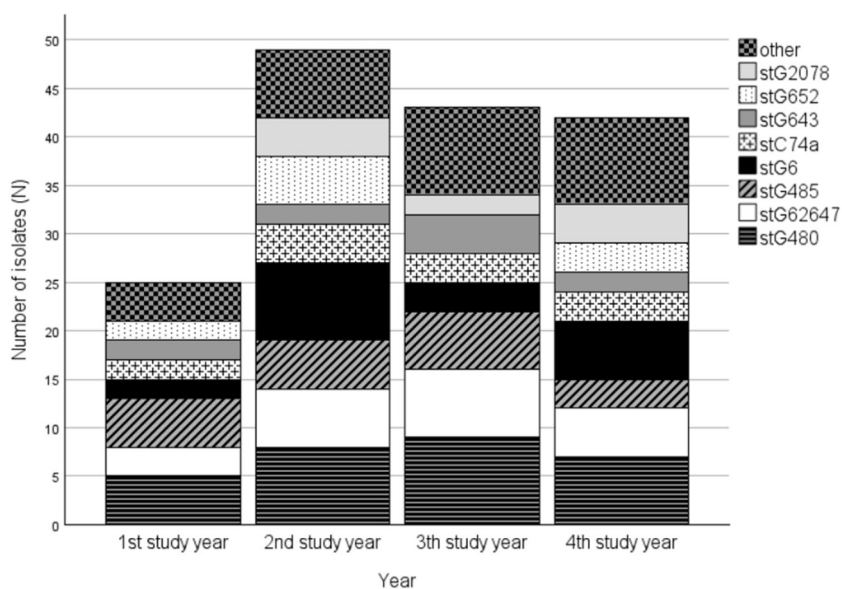


Figure 2. Distribution of the eight most prevalent and other emm types among *Streptococcus dysgalactiae* subsp. *equisimilis* bacteremia isolates by study year, from November 2015 to November 2019, in Pirkanmaa Health District, Finland.

gether as rare types. There appeared to be a predominance of females within emm type stG6 (63%; OR 2.8 [95% CI 1.0-7.6], $P = 0.047$) compared with males, whereas over 90% of patients within stC74a were male (OR 8.5 [95% CI 1.1-67], $P = 0.028$) compared with females (Table 1). The median age of patients was lowest among those with emm type stC74a (65 years) and highest in those with emm type stG652 (79 years), although this difference was not statistically significant.

Several potential associations between emm type and clinical manifestation were detected (Table 2). The prevalence of IE was 3.1%, with 40% (two of five) occurring in cases of emm type stG643 (OR 12 [95% CI 1.8-83], $P = 0.032$). Abscesses were more commonly observed in emm type stG2078 (OR 4.9 [95% CI 1.1-21], $P = 0.055$) and foreign-body infections in emm type stG62647 (OR 14 [95% CI 1.2-167], $P = 0.046$) than other emm types. The highest number of infections with undefined focus was found in emm type stG485 cases (OR 3.8 [95% CI 1.2-12], $P = 0.035$). Cellulitis was more frequently observed in connection with the rare emm types (86% vs 65%) than common ones (OR 3.3 [95% CI 1.1-10], $P = 0.028$).

Severe disease was observed only among patients with the eight common emm types (17 patients [13%]), compared with none within rare types (OR 1.2 [95% CI 1.1-1.2], $P = 0.044$). The mortality rate among those with common emm types was 6.9%, compared with 0% for those with rare types, although the difference was not statistically significant.

Discussion

We found that emm type stG62647 has rapidly emerged and is now the second most prevalent type among SDSE bacteremia cases in Pirkanmaa HD, Finland. A similar dominance has been reported in multiple European countries, including Norway [13], Sweden [21], Switzerland [12], and Spain [7], and in Canada [24]. A national study in Germany revealed a linear increase in invasive SDSE cases caused by emm type stG62647 over the past decade [8]. This phenomenon has been partly attributed to the lack of herd immunity in the population [1]. However, the rapid rise within just

Table 2
Clinical manifestations of *Streptococcus dysgalactiae* subsp. *equisimilis* bacteremia episodes (N = 159), from November 2015 to November 2019, Pirkanmaa Health District, Finland. One episode may involve one or more clinical manifestations. Differences between specific *emm* type compared with all other episodes were tested using Pearson χ^2 (marked as *) or Fisher's exact test. The numbers are **bolded** if $P < 0.05$.

Infection type	Emm types																	
	stG480 n = 29		stG62647 n = 21		stG485 n = 19		stG6 n = 19		stC74a n = 12		stG643 n = 10		stG652 n = 10		stG2078 n = 10		Rare <i>emm</i> types ^a n = 29	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Skin infections, all	22	(76)	16	(76)	10	(53)	14	(74)	10	(83)	5	(50)	9	(90)	6	(60)	25	(86)
Cellulitis	21	(72)	13	(62)	10	(53)	12	(63)	10	(83)	5	(50)	8	(80)	6	(60)	25	(86)
Purulent skin infection	7	(24)	6	(29)	3	(16)	4	(21)	1	(8.3)	1	(10)	3	(30)	1	(10)	5	(17)
Fasciitis	1	(3.4)	2	(9.5)	0		0		0		0		1	(10)	0		0	
Pneumonia	6	(21)	2	(9.5)	1	(5.3)	5	(26)	3	(25)	0		2	(20)	2	(20)	3	(10)
Empyema	0		0		0		0		0		0		0		1	(10)	0	
Abscess	3	(10)	4	(19)	0		2	(11)	1	(8.3)	0		0		3	(30)*	2	(6.9)
Arthritis, all	4	(14)	2	(9.5)	3	(16)	1	(5.3)	0		1	(10)	1	(10)	0		0	
Prosthetic joint infection	1	(3.4)	1	(4.8)	2	(11)	1	(5.3)	0		0		1	(10)	0		0	
Osteomyelitis, all	3	(10)	1	(4.8)	1	(5.3)	1	(5.3)	0		0		0		1	(10)	2	(6.9)
Spondylitis	2	(6.9)	1	(4.8)	1	(5.3)	1	(5.3)	0		0		0		1	(10)	2	(6.9)
Bursitis	1	(3.4)	0		0		0		0		1	(10)	0		0		0	
Endocarditis	1	(3.4)	1	(4.8)	0		0		0		2	(20)	0		0		1	(3.4)
Puerperal infections	1	(3.4)	0		0		1	(5.3)	0		0		0		1	(10)	1	(3.4)
Foreign body infection	1	(3.4)	2	(9.5)	0		0		0		0		0		0		0	
Deep abdominal infections	0		1	(4.8)	1	(5.3)	0		0		0		0		0		0	
Endophthalmitis	0		1	(4.8)	0		0		0		1	(10)	0		0		0	
Aortitis	0		0		0		0		1	(8.3)	0		0		0		0	
Focus unknown	2	(6.9)	1	(4.8)	5	(26)	2	(11)	0		2	(20)	1	(10)	2	(20)	2	(6.9)

^a *emm* types stG6979 (n=7), stG10 (n=6), stG6792 (n=5), stG245 (n=4), stG166b (n=3), stG4222 (n=1), stG5420 (n=1), and non-typeable isolates (n=2)

a few years suggests that increased virulence due to mutation is a more likely cause, as documented in a Norwegian study [1,8,13].

In this prospective study, extensive clinical data were combined with *emm* typing results. The *emm* type stC74a was associated with ICU admission and severe disease, and it more often affected male patients than other *emm* types. In previous studies, *emm* types stG62647 and stC74a have been prevalent in invasive samples and ranked among the three most common causative agents in IE and necrotizing soft tissue infection cases, although no significant statistical association has been found [7,21,22,24–26].

The *emm* type stG62647 was not associated with severe disease in the present study, but patients with this *emm* type required surgical procedures more frequently than those with other *emm* types, suggesting that the bacteremia is prone to complications. Previous reports from Norway and Austria have connected *emm* type stG62647 with severe clinical manifestations and a fulminant course of infection [13,25]. Eraso et al. [27] reported significant variation in virulence in cases with the same *emm* type. For instance, in multilocus sequence typing of SDSE stG62647 isolates, clonal complex 20 exhibited higher near-mortality rates in mice than clonal complex 17 [27]. This variation in bacterial virulence within the same *emm* type may explain the differences in disease severity observed across different geographical areas [28].

The five most common *emm* types in our study (stG480, stG62647, stG485, stG6, and stC74a) are consistent with incidence reports from Norway, Sweden, and Denmark [1,11,29]. Although *emm* types stG485 and stG6 have maintained their prevalence, the frequency of *emm* type stG643 has decreased in Finland and Norway over the last two decades [1,10].

Our findings align with those in previous research, showing a higher incidence of SDSE bacteremia among male patients [19,30,31]. There are limited data on gender distribution of different *emm* types in SDSE infections. This study showed that 92% of SDSE bacteremia cases linked to *emm* type stC74a occurred in male patients, which contrasts with a German study in which invasive stC74a infections were more frequently observed in females [8]. Conversely, bacteremia associated with *emm* type stG6 was more frequently observed in female patients in both studies [8]. In *S. pyogenes* infections, the *emm*28 strain is known to carry a horizontally transferred gene from *S. agalactiae*. The proteins produced by this gene enhance bacterial adhesion to the vaginal mucosal surface causing invasive infection in female patients [3]. Further studies are needed to determine whether similar features exist among SDSE *emm* types.

We identified several possible associations between *emm* types and infection foci. *Emm* type stG2078 was associated with abscesses, stG643 with IE, stG62647 with foreign-body infections, and stG485 with episodes of unknown focus. Oppegaard et al. found osteoarticular infection to be the most common clinical manifestation of *emm* type stG62647, occurring in 42% of cases [13]. To the best of our knowledge, no specific SDSE *emm* type has previously been linked to a particular clinical manifestation [7,12,18,22,29].

In the present study, common *emm* types were associated with severe SDSE bacteremia. This contrasts with the results of earlier studies from Finland and Norway, which revealed higher mortality linked to rarer *emm* types [10,19]. A possible explanation is that changes in prevalent *emm* types, for example, the emergence of *emm* type stG62647, has altered the overall pathogenicity and clinical outcomes of SDSE bacteremia [10]. In Japan, where the *emm* type distribution differs from that in Europe, the most common *emm* type, stG6792, has been associated with poor outcomes [20]. In invasive *S. pyogenes* infections, the most common *emm* types have been associated with the highest mortality rates [14,19]. These findings highlight the complexity of the associations between *emm* types and mortality.

There are several strengths in this study. This is a prospective study, and the data collection was carried out reliably and comprehensively. The study contained an extensive and detailed clinical patient data connected to *emm* types within a good-sized study population. Furthermore, comparing current *emm* type distribution with data from the Pirkanmaa HD, Finland, collected two decades ago, enhances the reliability of epidemiological trend analysis. Some limitations should be noted. This was not a population-based study, and because the study population was drawn from one tertiary care and one secondary care hospital, severe SDSE disease may be over-represented. In addition, the numbers of episodes were relatively small, which may have contributed to the results being influenced by chance. This may also be why the Bonferroni-corrected results did not reach the corrected *P*-value. Because SDSE is highly recombinogenic, *emm* typing has limited discriminatory power, whereas multilocus sequence typing and genome-wide analyses could more accurately characterize strain relationships. Further research involving whole genome sequencing of SDSE strains would be of interest.

Conclusion

Emm type stG62647 has emerged as the second most common *emm* type in Pirkanmaa HD, Finland. *Emm* type stC74a was associated with the most severe disease and primarily affected men. Several potential associations between *emm* type and infection focus were identified. These results emphasize the importance of *emm* in connection with disease severity and clinical manifestations.

Declaration of competing interest

The authors have no competing interests to declare.

Funding

This study was supported by grants from the Tampere Tuberculosis Foundation (S.R.), Tampere University Hospital Support Foundation, Tampere University Hospital, Wellbeing Services County of Pirkanmaa (S.R.), state funding for university-level health research, Tampere University Hospital, Wellbeing Services County of Pirkanmaa (S.R.), and Finnish Society for Infectious Disease Specialists (M.S.).

Ethical approval

This study was performed in line with the principles of the Declaration of Helsinki. The study was approved by the Regional Ethics Committee of Tampere University Hospital (28.10.2015/R15003).

Author contributions

Conceptualization: S.R., M.S., R.H., and J.A. Data curation: S.R., J.A., T.S., and H-L.H. Data analysis: T.L. and M.S. Writing—original draft: M.S. Writing—review and editing: S.R., R.H., J.A., M.S., T.S., H-L.H., and T.L. Supervision: S.R. and J.A. Project administration: S.R. All authors read and approved the final version of the manuscript.

Consent to participate

Informed consent was obtained from all individual participants included in the study. If a patient was unable to provide informed consent due to a declining condition, consent was obtained from the patient's immediate family members.

Data availability

The data sets generated and/or analyzed during this study are not publicly available due to the protection of participant confidentiality. For inquiries regarding the data sets or requests for additional analyses, please contact the corresponding author.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors used GPT-4, produced by OpenAI, to enhance the language and readability of this manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

- [1] Oppegaard O, Glambek M, Skutlaberg DH, Skrede S, Sivertsen A, Kittang BR. Streptococcus dysgalactiae bloodstream infections, Norway, 1999–2021. *Emerg Infect Dis* 2023;**29**:260–7. doi:10.3201/eid2902.221218.
- [2] Wajima T, Morozumi M, Hanada S, Sunaoshi K, Chiba N, Iwata S, et al. Molecular characterization of invasive Streptococcus dysgalactiae subsp. equisimilis, Japan. *Emerg Infect Dis* 2016;**22**:247–54. doi:10.3201/eid2202.141732.
- [3] Nevanlinna V, Huttunen R, Aittoniemi J, Luukkaala T, Rantala S. Incidence, seasonal pattern, and clinical manifestations of Streptococcus dysgalactiae subspecies equisimilis bacteremia; a population-based study. *Eur J Clin Microbiol Infect Dis* 2023;**42**:819–25. doi:10.1007/s10096-023-04607-8.
- [4] Wright CM, Moorin R, Pearson G, Dyer J, Carapetis J, Manning L. Invasive infections caused by Lancefield groups C/G and A streptococcus, Western Australia, Australia, 2000–2018. *Emerg Infect Dis* 2022;**28**:2190–7. doi:10.3201/eid2811.220029.
- [5] Finnish national infectious diseases register. Finnish Institute for Health and Welfare; 2023 <https://thl.fi/en/topics/infectious-diseases-and-vaccinations/surveillance-and-registers/finnish-national-infectious-diseases-register> [accessed 15 May 2025].
- [6] Rantala S. Streptococcus dysgalactiae subsp. equisimilis bacteremia: an emerging infection. *Eur J Clin Microbiol Infect Dis* 2014;**33**:1303–10. doi:10.1007/s10096-014-2092-0.
- [7] Rojo-Bezares B, Toca L, Azcona-Gutiérrez JM, Ortega-Unanue N, Toledano P, Sáenz Y. Streptococcus dysgalactiae subsp. equisimilis from invasive and non-invasive infections in Spain: combining epidemiology, molecular characterization, and genetic diversity. *Eur J Clin Microbiol Infect Dis* 2021;**40**:1013–21. doi:10.1007/s10096-020-04119-9.
- [8] Itzek A, Weißbach V, Meintrup D, Rieß B, van der Linden M, Borgmann S. Epidemiological and Clinical Features of Streptococcus dysgalactiae ssp. equisimilis stG62647 and Other emm Types in Germany. *Pathogens* 2023;**12**:589. doi:10.3390/pathogens12040589.
- [9] Norwegian Study Group on Streptococcus dysgalactiae Kaci A, Jonassen CM, Skrede S, Sivertsen A, Steinbakk M, et al. Genomic epidemiology of Streptococcus dysgalactiae subsp. equisimilis strains causing invasive disease in Norway during 2018. *Front Microbiol* 2023;**14**:1171913. doi:10.3389/fmicb.2023.1171913.
- [10] Rantala S, Vahakuopus S, Vuopio-Varkila J, Vuento R, Syrjänen J. Streptococcus dysgalactiae subsp. equisimilis bacteremia, Finland, 1995–2004. *Emerg Infect Dis* 2010;**16**:843–6. doi:10.3201/eid1605.080803.
- [11] Lambertsen LM, Ingels H, Schönheyder HC, Hoffmann S. Nationwide laboratory-based surveillance of invasive beta-haemolytic streptococci in Denmark from 2005 to 2011. *Clin Microbiol Infect* 2014;**20**:O216–23. doi:10.1111/1469-0691.12378.
- [12] Ruppen C, Rasmussen M, Casanova C, Sendi P. A 10-year observational study of Streptococcus dysgalactiae bacteraemia in adults: frequent occurrence among female intravenous drug users. *Swiss Med Wkly* 2017;**147**:w14469. doi:10.4414/smw.2017.14469.
- [13] Oppegaard O, Mylvaganam H, Skrede S, Lindemann PC, Kittang BR. Emergence of a Streptococcus dysgalactiae subspecies equisimilis stG62647-lineage associated with severe clinical manifestations. *Sci Rep* 2017;**7**:7589. doi:10.1038/s41598-017-08162-z.
- [14] Luca-Harari B, Darenberg J, Neal S, Siljander T, Strakova L, Tanna A, et al. Clinical and microbiological characteristics of severe Streptococcus pyogenes disease in Europe. *J Clin Microbiol* 2009;**47**:1155–65. doi:10.1128/JCM.02155-08.
- [15] Darenberg J, Luca-Harari B, Jasir A, Sandgren A, Pettersson H, Schalén C, et al. Molecular and clinical characteristics of invasive group A streptococcal infection in Sweden. *Clin Infect Dis* 2007;**45**:450–8. doi:10.1086/519936.
- [16] McGregor KF, Spratt BG, Kalia A, Bennett A, Bilek N, Beall B, et al. Multi-locus sequence typing of Streptococcus pyogenes representing most known emm types and distinctions among subpopulation genetic structures. *J Bacteriol* 2004;**186**:4285–94. doi:10.1128/JB.186.13.4285-4294.2004.
- [17] Bessen DE, Sotir CM, Readdy TL, Hollingshead SK. Genetic correlates of throat and skin isolates of group A streptococci. *J Infect Dis* 1996;**173**:896–900. doi:10.1093/infdis/173.4.896.
- [18] Watanabe S, Takemoto N, Ogura K, Miyoshi-Akiyama T. Severe invasive streptococcal infection by Streptococcus pyogenes and Streptococcus dysgalactiae subsp. equisimilis. *Microbiol Immunol* 2016;**60**:1–9. doi:10.1111/1348-0421.12334.
- [19] Oppegaard O, Mylvaganam H, Kittang BR. Beta-haemolytic group A, C and G streptococcal infections in Western Norway: a 15-year retrospective survey. *Clin Microbiol Infect* 2015;**21**:171–8. doi:10.1016/j.cmi.2014.08.019.
- [20] Takahashi T, Sunaoshi K, Sunakawa K, Fujishima S, Watanabe H, Ubukata K, et al. Clinical aspects of invasive infections with Streptococcus dysgalactiae ssp. equisimilis in Japan: differences with respect to Streptococcus pyogenes and Streptococcus agalactiae infections. *Clin Microbiol Infect* 2010;**16**:1097–103. doi:10.1111/j.1469-0691.2009.03047.x.
- [21] Bläckberg A, Nilson B, Özceni V, Olaison L, Rasmussen M. Infective endocarditis due to Streptococcus dysgalactiae: clinical presentation and microbiological features. *Eur J Clin Microbiol Infect Dis* 2018;**37**:2261–72. doi:10.1007/s10096-018-3367-7.
- [22] Bruun T, Rath E, Madsen MB, Oppegaard O, Nekludov M, Arnell P, et al. Risk factors and predictors of mortality in streptococcal necrotizing soft-tissue infections: A multicenter prospective study. *Clin Infect Dis* 2021;**72**:293–300. doi:10.1093/cid/ciaa027.
- [23] Streptococcus Laboratory. Emm typing overview and guidelines. Centers for Disease Control and Prevention (U.S.); 2024 <https://www.cdc.gov/strep-lab/php/group-a-strep/emm-typing.html> [accessed 15 May 2025].
- [24] Lother SA, Demczuk W, Martin I, Mulvey M, Dufault B, Lagacé-Wiens P, et al. Clonal clusters and virulence factors of Group C and G streptococcus causing severe infections, Manitoba, Canada, 2012–2014. *Emerg Infect Dis* 2017;**23**:1079–88. doi:10.3201/eid2307.161259.
- [25] Leitner E, Zollner-Schwetz I, Zarfel G, Masoud-Landgraf L, Gehr M, Wagner-Eibel U, et al. Prevalence of emm types and antimicrobial susceptibility of Streptococcus dysgalactiae subsp. equisimilis in Austria. *Int J Med Microbiol* 2015;**305**:918–24. doi:10.1016/j.ijmm.2015.10.001.
- [26] Kittang BR, Bruun T, Langeland N, Mylvaganam H, Glambek M, Skrede S. Invasive group A, C and G streptococcal disease in western Norway: virulence gene profiles, clinical features and outcomes. *Clin Microbiol Infect* 2011;**17**:358–64. doi:10.1111/j.1469-0691.2010.03253.x.
- [27] Eraso JM, Olsen RJ, Long SW, Gadd R, Boukthir S, Faili A, et al. Integrative genomic, virulence, and transcriptomic analysis of emergent Streptococcus dysgalactiae subspecies equisimilis (SDSE) emm type stG62647 isolates causing human infections. *mBio* 2024;**15**:e0257824. doi:10.1128/mbio.02578-24.
- [28] López de Egea G, González-Díaz A, Olsen RJ, Guédon G, Berbel D, Grau I, et al. Emergence of invasive Streptococcus dysgalactiae subsp. equisimilis in Spain (2012–2022): genomic insights and clinical correlations. *Int J Infect Dis IJID Off Publ Int Soc Infect Dis* 2025;**153**:107778. doi:10.1016/j.ijid.2025.107778.
- [29] Trell K, Sendi P, Rasmussen M. Recurrent bacteremia with Streptococcus dysgalactiae: a case-control study. *Diagn Microbiol Infect Dis* 2016;**85**:121–4. doi:10.1016/j.diagmicrobio.2016.01.011.
- [30] Saukkosaari M, Aittoniemi J, Huttunen R, Luukkaala T, Rantala S. Predictors of severe disease in Streptococcus dysgalactiae subsp. equisimilis bacteremia: a population-based study. *BMC Infect Dis* 2025;**25**:582. doi:10.1186/s12879-025-10966-8.
- [31] Solanki P, Colaco C, Dotel R. Analysis of bacteraemia caused by group C and G Streptococcus (Streptococcus dysgalactiae subsp. equisimilis) in Western Sydney over a 6-year period (2015–2020). *Eur J Clin Microbiol Infect Dis* 2024;**43**:1807–14. doi:10.1007/s10096-024-04903-x.