Review

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Recent Records on Bacterial Opportunistic Infections via the Dietary Route

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Abstract: This literature review was aimed to identifying the opportunistic bacterial pathogens that can be transmitted by contaminated food and represent a current threat for patients particularly susceptible to infections because of underlying conditions or predisposing factors. The analysis was focused on recent case or outbreak reports, and systematic reviews published in years 2019 - 2023 and resulted in sorting 24 bacterial groups comprising genera or species able to cause a variety of systemic or invasive infections if ingested with food or drinking water. These included both bacteria known to cause mild infections in immunocompetent persons and bacteria considered innocuous that are used in food fermentation or as probiotics. No recent cases from dietary routes were reported for bacteria of critical importance as nosocomial pathogens and widely occurring in food products, primarily, *Acinetobacter baumanii* and *Klebsiella pneumoniae*. However, the very first sources of their introduction in the clinical environment still need to be established. In many instances, risky dietary habits such as eating raw fish, seafood, raw meat, unpasteurized milk and derived products or the lack of control on fermentation processes led to the reported illnesses, pointing out to the necessity to improve the hygiene of production and consumer's awareness of risks.

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1. Introduction

The definition of opportunistic infection is "a serious, usually progressive infection by a micro-organism that has limited or no pathogenic capacity under ordinary circumstances, but which has been able to cause serious disease as a result of the predisposing effect of another disease or of its treatment" [1].

Different bacterial groups present in food or drinking water, other than the major pathogens which are object of specific surveillance and control measures according to food legislation norms, may behave as opportunistic pathogens in people with underlying conditions or predisposing factors. These belong to bacterial genera or species that cause mild or no illness in immunocompetent persons but can cause life threatening infections in vulnerable subjects. As an example, lactobacilli, which are essential to food fermentation and probiotics with in vivo proven beneficial effects, were the cause of bacteremia, endocarditis and or other localized infections most often in persons immunocompromised, diabetic or with a history of predisposing events such as medical interventions, diseases or oral infections and dental procedures [2,3].

In the present analysis of the scientific literature the cases or outbreaks caused by opportunistic pathogens most likely linked to a dietary origin were considered. The aim was offering an overview of the risks posed by dietary sources in the transmission of opportunistic bacterial pathogens and obtain indications for prevention.

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2. Article selection process

A preliminary search of literature sources was carried out in GoogleScholar (https://scholar.google.com/schhp?hl=it, accessed on 15 November 2023) with the keywords "opportunistic AND pathogen AND human AND food AND infection" limited to the last five years. This search retrieved 17,500 results that were ordered by pertinence. The first five hundred items were checked for the names of pathogens to be specifically evaluated for involvement in infections of dietary origin, resulting in the identification of 42 bacterial genera or species. These were reduced to 24 after a second search in which the retrieved bacterial names were individually used in the keyword associations "organism name AND food AND human AND infection AND case" or "organism name AND food AND human AND infection AND outbreak". This second search allowed to retrieve reports that indicated the oral route as the most probable source of infection after screening of the content of the first one hundred items obtained for each organism name ordered by pertinence.

3. Results and discussion

A total of 54 recent case or outbreak reports were retained for description, since they fulfilled the criterion of "infection most likely acquired through the dietary route". Some cases caused by bacteria of most probable food origin were included even if a probable food source was not mentioned in the report. In Table 1 the bacterial groups involved in the illnesses are reported in alphabetical order along with the type of infection, source of illness, and underlying diseases or predisposing conditions. The order of listing within the bacterial genus is chronological.

Table 1. Opportunistic bacterial pathogens involved in foodborne severe infections reported since 2019, confirmed or most probable dietary sources, and underlying conditions or predisposing factors.

Infectious agent	Illness	Dietary source	Predisposing/ underlying condition
Aeromonas sobria	peritonitis [4]	stinky tofu	peritoneal dialysis (PD)
A. hydrophila	phlegmonous gastritis, mild renal failure, sepsis [5]	raw fish	gastric ulcer
Arcobacter spp.	pericarditis [6]	chicken	Human Immunodeficiency Virus (HIV) and Covid-19 infections, end-stage renal disease (ESRD)
A. butzleri	prolonged watery diarrhea [7]	unknown	HIV infection
Bacillus licheniformis	bacteremia [8]	probiotic	Intestinal bleeding
B. subtilis (natto)	bacteremia [9]	natto	peritonitis
B. pumilus	bacteremia [10]	rice and meat dish	none
Comamonas testosteroni	bacteremia [11]	unknown	none
Enterococcus casseliflavus	bacteremia, liver cyst infection [12]	unknown	hemodialysis
E. faecalis	gastroenteritis in 690 individuals [13]	drinking water	none
Klebsiella pneumoniae.	bacteremia [14]	breast milk	preterm birth

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K. aerogenes	urinary tract infection (UTI) [15]	water	type 2 diabetes, hypertension
Lacticaseibacillus paracasei	cholecystitis [16]	yogurt	type 2 diabetes, hypertension, cardiac problems, cholelithiasis
L. rhamnosus	septic shock, endocarditis with brain emboli [17]	probiotic	ulcerative colitis, type 2 diabetes, heart surgery, immunosuppression
L. paracasei	lumbar osteomyelitis [18]	probiotic	Type 2 diabetes, ischemic heart disease
Lactobacillus jensenii	endocarditis [19]	yogurt	none
Lacticaseibacillus spp.	endocarditis [20]	probiotic	Type 2 diabetes, cardiomyopathy
L. paracasei *Lactiplantibacillus plantarum*	bacteremia [21]	probiotic	hematopoietic cell transplantation
L. paracasei	septic shock [22]	yogurt	Cardiac surgery, multi-organ failure
L. casei	endocarditis [23]	probiotic	Prednisone immunosuppression
L. paracasei	endocarditis, embolic cerebrovascular infarct [3]	probiotic or yogurt	Dental caries
Lactococcus garviae	recurrent tonsillitis [24]	unknown	none
L. lactis	endocarditis [25]	unknown	Aortic graft placement
	spondylitis [26]	raw fish	diabetes mellitus, hypertension
	bacteremia, cholangitis [27]	unknown	bile duct obstruction
Laribacter hongkongensis	bacteremia [28]	unspecified	end-stage alcoholic cirrhosis
Leuconostoc mesenteroides	bacteremia [29]	raw milk	thyroid cancer, hepatitis C, poor dentition
Pantoea agglomerans	neonatal late onset sepsis (LOS) [30]	suspected milk contamination	none
Pediococcus acidilactici	bacteremia [31]	yogurt	hemorrhagic colitis
Plesiomonas shigelloides	Ulcers in colon and final ileum [32]	oysters	chronic leukemia
	meningitis, brain abscess and septicemia in a newborn [33]	oysters	transplancental transmission
	septic shock [34]	loach	alcoholic cirrhosis
Sarcina ventriculi	esophagitis with ulcerations [35]	unspecified	gastroesophageal reflux
	mucosal/submucosal necrosis [36]		liver-kidney transplantation
Serratia marcescens	bacteremia [37]	unpasteurized donor milk	preterm birth

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Shewanella putrefaciens	bacteremia [38]	raw fish	pancreatic cancer
	bacteremia [39]	unspecified	chronical kidney disease (CKD) cholangitis (two patients) necrotizing fasciitis (one patient)
S. agalactiae	septic arthritis and bacteremia [40]	traditional dishes	none
S. dysgalactiae	knee joint infection by [41]	unpasteurized milk	none
Streptococcus equi subsp. *zooepidemicus*	septic arthritis [42]	raw horse meat and liver	ESRD
	abdominal infection, edema of the extremities, bacteremia [42]	raw horse meat	liver cirrhosis
	meningitis [43]	unpasteurized milk	osteodural defect, chronic otitis
	perinatal bacteremia [44]	artisanal cheese	none
	different infections in 37 patients [45]	raw milk cheese	varying underlying conditions
Streptococcus gallolyticus subsp. *pasteurianus*	acute necrotizing cholecystitis [46]	pork cutlet	past severe gastroenteritis
S. suis	sepsis and intracranial infection [47]	pork	none
	bacteremia, endophtalmitis [48]	fermented pork	stress from sleep deprivation
	meningitis [49]	pork	old age
	meningitis, septicemia [50]	pork	none
Weissella confusa	septicemia, endocarditis [51]	sauerkraut	alcohol associated cirrhosis
	endocarditis [52]	yogurt	none
	bacteremia, meningitis [53]	smashed vegetables	many comorbidities, suspected intestinal microperforations

The recent reports retrieved for each group of opportunistic bacterial pathogens possibly acquired through the dietary route and relevant literature on their relevance to public health are summarized in the following sections.

3.1. Aeromonas

The genus *Aeromonas* comprises Gram-negative gas producing bacilli belonging to the class Gammaproteobacteria and comprising 36 species. Among these *Aeromonas hydrophila*, *A. caviae*, *A. dhakensis*, *A. veronii*, *A. salmonicida*, and *A. sobria* are known to cause human infections mainly in form of mild gastroenteritis [4,54]. These bacteria can be isolated from fresh water and sea water, soil, fish, meat and other foods. The major virulence factors of *Aeromonas* spp. are haemolysins, enterotoxins, invasins, aerolysin, adhesins, proteases, phospholipase and lipase [4].

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A. sobria may act as an opportunistic pathogen and cause bacteremia, intestinal and extraintestinal infections predominantly in patients with chronic hepatic disease, gastroenteritis, malignancy and immunocompromised status. Gastroenteritis is the most common infection caused by *Aeromonas* spp. but peritonitis is not uncommon, especially in patients with cirrhosis [4].

A. sobria caused peritonitis in a 37 years-old man affected by renal failure and under peritoneal dialysis (PD). He was admitted to the hospital with fever, vomiting, abdominal pain, diarrhea and cloudy dialysate several hours after eating stinky tofu. Stinky tofu, a kind of traditional Chinese food, is usually considered unhygienic for the particular production process in which the tofu is placed in water for a long time to increase the unique smell. Therefore, it was speculated that the stinky tofu was the source of infection in this case. Bacterial translocation through the intestinal barrier plays an important role in the pathogenesis of PD-related peritonitis. Amikacin and levofloxacin treatment allowed patient recovery [4].

A. hydrophila causes acute gastroenteritis or diarrhea most often through the ingestion of infected fish and seafood with an incubation period of less than 24 h. A case of gastroenteritis complication involved a 74-year-old woman admitted to the hospital with worsening epigastric pain, vomiting, and diarrhea that started 3 days previously after eating raw Ayu fish. Her husband also had eaten the fish and was affected by mild diarrhea. The woman, who did not present underlying conditions and was not a smoker or alcohol consumer, presented mild renal failure and sepsis. Abdominal computed tomography (CT) revealed branched portal vein gas in the right hepatic lobes and thickened gastric wall and intestinal edema, A submucosal tumor-like elevation in the posterior wall of the gastric corpus, which contained an ulcer at the center of the lesion *A. hydrophila* was isolated from stool identified by microbial identification techniques so the diagnosis was of phlegmonous gastritis caused by *A. hydrophila* with hepatic venous pressure gradient (HPVG) and without necrosis of the intestinal tract. After treatment with levofloxacin, then switched to to cefmetazole, symptoms gradually improved. In this case, the predisposing factor for the *A. hydrophila* infection presentation was most probably the presence of an an ulcer lesion in the stomach that favored invasion of the gastric wall and phlegmon formation [5].

3.2. Acinetobacter spp.

The genus *Acinetobacter* currently comprises about 80 species of strictly aerobic Gram-negative cocco-bacilli [55]. *A. baumannii* is the species most often involved in infections, but also cases attributed to *A. calcoaceticus*, *A. lwoffii*, *A. haemolyticus*, *A. johnsonii*, *A. junii*, *A. nosocomialis, A. pittii*, *A. bereziniae*, *A. serfertii*, *A. schindleri* and *A. ursingii* were described. Community-acquired infections reported for *A. baumannii* include respiratory infections in children, immunocompromised individuals and in patients with risk factors such as alcoholism, smoking and diabetes mellitus as underlying condition [56].

The presence of this genus, mainly represented by the species *A. baumannii*, *A. calcoaceticus* and *A. lowfii*, in different food types, such as milk, even pasteurized, dairy products, bacon, eggs, chicken, fish, fresh meat and fresh fruits and produce is well established based on reports from different countries [55,57,58]. In the latter food category these bacteria may persist after mild disinfection with vinegar or hypochlorite [58]. Moreover, *A. lwoffii* and *A. johnsonii*, can survive in a wide range of temperatures, low pH values, and are resistant to disinfectants, irradiation and desiccation [57].

However, the relevance of *A. baumannii* as an opportunistic pathogen is mainly attributable to nosocomial infections that can be transmitted from one patient to another as a consequence of environmental contamination transmitted to medical devices such as tubes and catheters, as observed in Covid 19 patients [56,59]. In clinical settings the origin of the infection remains unknown in many cases [56].

A. baumannii, and in particular its carbapenem resistant variants (CRAB), that emerged in contexts with high antibiotic pressure and the under-regulated usage of antibiotics [60], is among the six "ESKAPE" pathogens (*Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa*, and *Enterobacter* species), which pose increasing

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concerns due to multi-drug resistance and ability to escape antimicrobial treatments. These are responsible for the majority of nosocomial infections with high mortality rate [61].

Hospital acquired *Acinetobacter* infections may occur in patients with malignancies, patients in intensive care units (ICU) and burn units, patients who have undergone major surgical procedures, are neutropenic or have underlying chronic diseases such as diabetes mellitus and chronic pulmonary diseases [62].

A. baumannii was included in the World Health Organization's (WHO) Global Antimicrobial Resistance Surveillance System (GLASS) [63]. This species can cause bacteremia, meningitis, pneumonia and other infections such as central nervous system infections after neurosurgery. Colistin sulfate, a derivative of polymyxin E, is the last resort drug to treat CRAB infections [64]. The viable but not culturable (VBNC) state was proposed as a persistence mechanism allowing *A. baumannii* to cope with environmental stresses [65].

An outbreak of *A. baumannii* infections that occurred through ingestion was reported in mechanically ventilated patients in an emergency ICU who received oral care with drinking water from contaminated taps [66].

Recent reports on the direct involvement of the dietary route in the transmission of *Acinetobacter* spp. are lacking and one retrieved was published in 2009 [57]. The case regarded gastrointestinal symptoms and bacteremia caused by *A. lwoffii* in a previously healthy 64-year-old man who had dined in two different restaurants the day before hospitalization. The absence of a catheter line, which is usual in *Acinetobacter* spp. infections, led to suspect food as source of the infectious agent.

3.3. Arcobacter spp.

Arcobacter spp. is a genus of aerotolerant, gram-negative bacteria of the class Epislonproteobacteria and family Campylobacteraceae, that can grow at temperatures higher than 30 °C and comprises more than 30 known species. Four of these have been reported to infect humans, namely *Arcobacter butzleri*, *A. cryaerophilus*, *A. skirrowii* and *A. thereius* [6,67].

A. butzleri was first isolated in aborted bovine fetuses and was later linked to reproductive disorders and late-term abortions in cattle, pigs, and sheep. It can be present in a range of commonly consumed meat [7] and in bovine milk [68].

Arcobacter spp. was indicated by EFSA as an "An issue that deserves further attention in terms of the burden of disease as it is most probably underreported" since it was mentioned for the first time in 2021 by the International health intelligence (IHI) platform for a prevalence study in bivalve molluscs carried out in Sardinia, Italy [69]. Reported cases include an infection cluster involving eight patients treated for acute diarrhea in a tertiary hospital in Cantabria, Northern Spain. The *Arcobacter* infection originated from different sources since the patients belonged to three categories, namely erderly persons, persons recently returned from abroad journeys, and persons with co-morbidities. Fingerprinting methods indicated no clonal relationships among the isolates, all identified as *A. butzleri* [67].

Several sporadic outbreaks of *A. butzleri* gastroenteritis were observed in US, Europe and South Africa in years 1990 - 2000. *A. butzleri* was identified as a causative organism for 24 out of 4636 cases of gastroenteritis in a prospective study in Germany, while several studies have identified *A. butzleri* to be among the most frequently isolated Campylobacteraceae in human clinical samples [6,7]. Persistent watery diarrhea is the main symptom of *Arcobacter* spp. infection though also bacteremia, and septicemia were reported. The prevalence of this emerging pathogen is not well documented also for the difficulty of its identification in clinical settings [6].

According to a phylogenetic analysis of isolates from Thailand, the *A. butzleri* STs, are defined by sequencing of the seven housekeeping genes, *asp*A, *atp*A, *gln*A, *glt*A, *gly*A, *pgm*, and *tkt*. Those more often involved in human infections are ST-94 and ST-166, found in both human diarrheal stool samples and chicken offal or meat samples [70].

A case of pericarditis caused by *Arcobacter* spp. was reported for a 32-year-old male with a past medical history of well-controlled Human Immunodeficiency Virus (HIV), on antiviral therapy, and end-stage renal disease (ESRD), admitted to internal medicine for COVID-19 pneumonia. This patient

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presented worsening cardiac tamponade that was successfully managed with an urgent pericardiocentesis, steroids, antibiotics, and pericardial drain. The patient reported that about a month earlier he had several episodes of diarrhea after consuming chicken from a local restaurant. Cultures of pericardial fluid and blood on aerobic blood agar were positive for gram-negative rods identified by VITEK 2 as *Arcobacter* species. This case highlighted that COVID-19 infection can increase the risk and severity of secondary bacterial infections by damaging the respiratory tract and compromising the immune system [6].

A 38-year-old man with a history of HIV infection presented with symptoms of acute watery diarrhea lasting for two weeks. There was no recent travel history or intake of raw or uncooked food. Stool cultures were positive for *A. butzleri*. The infection was successfully treated with ciprofloxacin but, unfortunately, the patient passed away for hospital acquired severe pneumonia. The authors concluded that clinicians should recognize the pathogenicity of *A. butzleri* in immunocompromised hosts [7].

3.4. Bacillus spp.

Bacillus strains belonging to the species *B. subtilis, B. amyloliquefaciens, B. licheniformis, B. circulans, B. pumilus,* and *B. brevis* are used in Asian and African countries to produce popular fermented foods from different bean types. With the exception of *B. subtilis* natto, a starter used in industrial natto production, all the other *Bacillus* spp. used in these foods are naturally occurring [71]. Moreover, different *Bacillus* species are used as probiotics, including *B. clausii*, *B. coagulans*, *B. licheniformis*, *B. polyfermenticus*, *B. pumilus*, *B. subtilis* and non-toxigenic strains of *B. cereus* [72].

Two cases of bloodstream infections occurred after administration of a *B. licheniformis* probiotic preparation to treat gastrointestinal bleeding due to *Clostridium difficile* colitis. One occurred in a 67-years old woman with Covid-19 and hepatic diseases who developed antibiotic associated diarrhea with positive occult blood. This condition worsened after administration of capsules with 250 million live *B. licheniformis* trice a day. Moreover, sepsis caused by this organism was observed and, despite discontinuation of the probiotic therapy, the patient died for severe pneumonia and septic shock due to the ineffectiveness of therapy with levofloxacin and vancomycin. The other case regarded a 76-old woman admitted to a resuscitation unit for respiratory failure caused by pneumonia. This patient had a history of hypertension, coronary artery disease, heart failure and obesity. She was treated with different antibiotics in succession that caused diarrhea with occult blood, so she was started with the *B. licheniformis* probiotic. While diarrhea improved, she developed *B. licheniformis* sepsis that was successfully treated with moxifloxacin and vancomycin [8].

In these two cases whole genome sequencing confirmed that blood isolates were identical to the administered probiotic. Treatment with *B. licheniformis* probiotic should be therefore avoided in patients with intestinal bleeding that indicates a disruption of the mucosal barrier and can determine the translocation of the probiotic in the bloodstream [8].

A case of *B. subtilis* variant natto bacteremia was identified a 56-year-old woman in Japan in May 2021. She presented abdominal pain after assuming barium for gastric radiographic examination and used to eat fermented soybeans (natto) daily. A perforation of the sigmoid colon and generalized peritonitis were diagnosed. Sepsis caused by *B. subtilis* was ascertained from the blood cultures and was successfully treated with antibiotics. The *bio*F region of the blood isolate was 100% homologous to the *B. subtilis* var. natto strain. Other cases of *B. subtilis* bacteremia consequent to intestinal perforation were reported previously in Japan and this constitutes a risk related to the consumption of fermented products containing this bacterial strain [9].

A case of infection caused by *B. pumilus* involved a 51-year-old Japanese man who started to experience strong chills some hours after eating reheated rice and stewed minced meat from a Kenyan restaurant. He recovered after 2 days of therapy with probiotics and ciprofloxacin. The blood cultures were positive for *B. pumilus* identified by physiological standardized tests and 16S rDNA sequence analysis. Previous studies reported that meat dishes, eggs, baked products, and canned tomato juice were involved in presumptive food poisoning by *B. pumilus* and that this bacterium can produce a heat-stable toxin, as observed in milk isolates in Finland. Moreover, pre-cooked rice

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contaminated with pumilacidin-producing *B. pumilus* strain was implicated in a case of food poisoning in Norway [10].

3.5. Burkolderia spp.

The *Burkolderia* genus comprises Gram-negative, rod-shaped, motile bacteria among which strains able to cause infections with food as possible source, mainly attributed to *B. gladioli* and to the *B. cepacia* complex [73,74]. However, no case reports directly linked to food consumption are available for this genus.

3.6. Chryseobacterium spp.

Chryseobacterium indologenes is a gram-negative bacterium found in soil, water, plants, and food products for which water systems are a reservoir and is not eliminated by chlorination. Therefore, when present in municipal water supplies, it can cause infections such as pneumonia, bacteremia, cellulitis, urinary tract infections, ocular infections, meningitis, peritonitis and, in clinical settings, surgical wound infections and catheter-related infections, also in immunocompetent individuals [75]. The comparison of antibiotic sensitivity spectra indicated that this bacterium is becoming increasingly resistant to antibiotics. A Taiwanese study reported that 98.8% of *C. indologenes* infections were nosocomial, with a mortality rate of 25%, and 79.8% of the patients had comorbidities [76].

A case of catether related *C. indologenes* infection in a previously healthy 2 month old female newborn was recently recorded in Spain. The symptoms were vomit after breast feeding, soft stools and weight loss lasting for three weeks. She initially received intravenous omeprazole treatment for the suspicion of gastro-esophageal reflux and after 4 days of admission progressive disappearance of vomiting was observed. However, the 5th day, she showed fever and rejection of food. The aerobic blood culture showed bacteremia by *C. indologenes* [77].

3.7. Coagulase negative staphylococci

Coagulase negative staphylococci (CNS) are responsible for 90% cases of late onset sepsis (LOS) in neonatal intensive care units (NICUs) with *Staphylococcus epidermidis* responsible for most cases but also *S. capitis*, *S. haemolyticus*, *S. hominis* and *S. warneri* in some instances [78]. LOS is defined as bloodstream infection occurring between 3 and 28 days of life and is caused by bacteria transmitted horizontally in the hospital or community environments [79]. CNS are the most common organisms in mucocutaneous sites and nasofarinx in the first week of life and infection risk factors are extreme prematurity and parenteral nutrition with intravascular catheters. The increasing prevalence of CNS infection is attributable to their increasing antibiotic resistance and their ability to produce biofilms [78].

While CNS endocarditis mostly occurred in patients with prosthetic valves and in situ grafts, there was a notable increase in the incidence of CNS-induced native valve endocarditis. Rare cases of right-sided infective endocarditis (RSIE), that affects the tricuspid or pulmonary valve, have been reported after septic abortion, abscess, and septic arthritis [80].

S. saprophyticus is the cause of uncomplicated urinary tract infection (UTI) in the 10%–20% of young women with a high recurrent infection frequency. Rare complications include acute pyelonephritis, nephrolithiasis, and endocarditis. Meat and other foods are suspected to be sources of human gut colonization by *S. saprophyticus*. From the genomic data of 321 human UTI isolates collected from 8 countries in 4 continents during 1997–2017, two lineages, G and S, with distinctive evolutionary histories, were identified, enriched in different sets of genes and both disseminated geographically. The high relatedness of UTI isolates from different patients in the same country and in different countries let to the hypothesis that these could belong to a cross-border chain of transmission through a food source [81].

Pork is frequently contaminated with *S. saprophyticus* that was found in slaughterhouse samples including meat, equipment and workers' hands, most likely introduced by live pigs. The comparison

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of 104 isolates collected from a slaughterhouse and 128 isolates collected from human UTIs in Lisbon during 2016–2017 showed that all isolates belonged to lineage G. Phylogenetic reconstruction of all isolates based on single nucleotide polymorphisms (SNPs) analysis showed examples of relatedness of slaughterhouse and human isolates.

Genes that seemed to be associated with an increased pathogenic potential of *S. saprophyticus* were those encoding a SplE-like protein and a gene cluster encoding a complete accessory secretory system associated with a serine-rich adhesion, similar to SraP. In addition, genes encoding resistance to the antimicrobial drugs trimethoprim (*dfr*G), lincosamide (*lnu*A), streptogramin B (*erm*44v), or to macrolides (*mph*C-*msr*A) were also associated with strains from human infections [81].

3.8. Comamonas spp.

Comamonas testosteroni is an aerobic Gram-negative bacillus, previously denominated *Pseudomonas testosteroni*, able to use testosterone as sole carbon source. It is commonly found in soil, plants, wastewater/sludge, fresh water, and the animal intestinal microbiome. It was also isolated from activated sludge, polluted soil, hospital environment and clinical samples [11,82]. Rare cases of infection caused by this bacterium include peritonitis, cellulitis, endocarditis, meningitis, pneumonia, endophthalmitis, and tenosynovitis and were community acquired in most cases. *C. testosteroni* bacteremia recently regarded a 46-year-old Indian woman from a rural area who, differently from previously reported cases, was immunocompetent and with no underlying conditions. The source of infection was supposed to be contaminated food or water, though this was not proven [11].

A recent analysis of the medical reports highlighted that also other species, *C. kerstersii*, *C. aquatica*, *C. thiooxydans* and *C. terrigena* can cause infections that are on the rise together with increased antibiotic resistance [82].

3.9. Enterobacter spp.

The *Enterobacter cloacae* complex (ECC) comprises different species of Enterobacteriaceae, including *E. cloacae*, *E. mori*, *E. ludwigii*, *E. kobei*, *E. asburiae*, *E. cancerogenus* and *E hormaechei* [83,84] and is considered to be of low-virulence and to cause infections in immunocompromised patients. However, *E. bugandensis* was identified as a hypervirulent species responsible for fatal septic shock of newborns in France. Moreover, an epidemic hypervirulent clone of *E. hormaechei*, sequence type ST-133, in 2022 showed high invasiveness and mortality in clinical settings [83]. This clone was first isolated in the UK from blood samples and showed multidrug resistance (MDR), though it did not carry carbapenemase genes.

Enterobacter cloacae is responsible of human infections as pneumonia, urinary tract, skin, soft tissue and intravascular infections, more frequent in patients who underwent antibiotic treatments in intensive care units (ICUs). But the most severe infection caused by this bacterium is endocarditis that most commonly affects mitral valve and showed a mortality rate of 30% according to a recent systematic review. Fever occurred in 92.3% of patients, sepsis in 38.5% of patients and shock in 25% of patients. Predisposing factors were the presence of a prosthetic valve, intravenous drug use, end stage renal disease, cardiac surgery within one month and presence of a central venous catheter (CVC) [85].

A recent investigation carried out in Spain reported the presence of bacteria of the *E. cloacae* complex able to produce AmpC β-lactamases in 10.2% of samples of fresh vegetables intended for raw consumption. In two isolates from tomato and irrigation water also extended spectrum β-lactamases (ESBL) and carbapenemase were found. AmpC positive isolates, without coproduction of other important β-lactamase enzymes, are controlled by cefepime and carbapenems. However, isolates of *E. hormaechei*, an emerging human pathogen, were not inhibited by cefepime. Such strains might represent a direct public health concern through the consumption of fresh vegetables [84].

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3.10. Enterococcus spp.

The genus *Enterococcus* comprises lactic acid bacteria (LAB) that commonly inhabit the gut of humans and animals. *Enterococcus faecium* and *E. faecalis* are the species most often encountered in various fermented foods. Some *Enterococcus* strains are utilized as probiotics and some produce bacteriocins with promising application perspectives in food safety improvement. However, enterococcal strains can carry and easily transfer plasmid-mediated antimicrobial resistance genes that have contributed to the emergence of Vancomycin-Resistant Enterococci (VRE), listed by WHO in the Priority 2 level bugs requiring special surveillance [86]. Moreover, some *E. faecalis* strains can carry genes for the production of a two component cytolysin that has been proven to increase the severity of liver disease and mortality in patients with alcoholic hepatitis [87].

Recent reports on the ascertained or presumptive involvement of these bacteria in foodborne infections are two. One regarded a 59-year-old hemodialysis patient with a 5-day history of fever and diarrhea, which were possibly caused by the ingestion of contaminated food. *Enterococcus casseliflavus* was isolated from blood cultures and upper abdominal magnetic resonance imaging (MRI) scan revealed polycystic liver and kidney, and some cysts with potential bleeding as a complication possibly caused by the infection. Also, the cyst fluid culture was positive for *E. casseliflavus*, confirming that the patient had both bacteremia and a liver cyst infection caused by this bacterium. Long-term dialysis is a known risk factor for colonization by *E. casseliflavus* and ampicillin associated to gentamicin or streptomycin is considered a standard treatment. The patient was treated with meropenem and β-lactamase inhibitors, but the infection remained difficult to control possibly because it was internal to the hepatic cyst. A better outcome was indeed achieved after cyst drainage [12].

Another report regarded an outbreak presumably caused by drinking water contaminated by *E. faecalis*. The clinical signs were abdominal pain, vomiting, fever and diarrhea, varying among persons, in 690 patients who required treatment by the emergency room at the Kruja Hospital, Albania. The analysis of water samples analyzed in the national Institute of Public Health were found to be contaminated with *E. faecalis*. The enterococcal isolate from water was not characterized further. Only 22 stool samples of the patients were analyzed of which two tested positive for Norovirus G2 and one among ten tested positive for *Salmonella* species. The occurrence of these two pathogens was considered fortuitous and not linked to the outbreak. The interruption of the drinking water supply led to the ceasing of clinical cases [13].

3.11. Klebsiella spp.

The genus *Klebsiella* belongs to the Enterobacteriaceae family and was included by WHO among the most critical group of multidrug resistant bacteria that pose a particular threat in hospitals, nursing homes, and among patients whose care requires devices such as ventilators and blood catheters [88,89]. Antibiotic resistance is widespread within the genus and the plasmid-mediated spread of genes encoding carbapenemases is of particular concern since clones of *K. pneumoniae* and other *Klebsiella* species carrying these genes are very frequent in non-clinical contexts including livestock and wastewater. A One Health approach to investigate the public health risks posed by the non-clinical reservoirs of antibiotic resistance is therefore needed.

A large-scale study was based on WGS data for 3,482 isolates recovered from 6,548 clinical, community, veterinary, agricultural and environmental samples collected around the city of Pavia, in Northern Italy, within a 17-month period. The isolates were assigned to 15 *Klebsiella* species, including *Raoultella*, a genus most probably invalidly separated from *Klebsiella*. Approximately half of the isolates were identified as *K. pneumoniae*. This unprecedented sampling and sequencing effort within a restricted geographical area that is a known hotspot for healthcare-associated multidrug-resistant *K. pneumonia*, led to observe low levels of resistance and virulence genes outside the clinical settings and in species other than *K. pneumonia*, suggesting that the emergence of highly virulent and/or resistant lineages within the environment is rare. Moreover, data showed the emergence of potentially high-risk lineages within the hospital setting in *K. pneumoniae* and other species, such as the newly described lineage *K. quasipneumoniae* ST571. Since the analysis revealed that transmission

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is much more common within, than between settings, it was concluded that *Klebsiella* spp. niche adaptation plays a role in mitigating transmission from animal and environmental sources to humans [88].

However, *K. pneumoniae* infections of food origin, though occurring in a clinical setting, were reported. An outbreak was caused by a *K. pneumoniae* clone producing CTX-M-15 extended-spectrum β-lactamase in a neonatal ICU in Norway, where 58 children were colonized but only one developed bacteremia. The *K. pneumoniae* strain was probably introduced with the breast milk of one mother [14].

Community-acquired *Klebsiella aerogenes*, formerly *Enterobacter aerogenes*, infections are rare, while most reported cases were associated with hospital-acquired infections. A case of urinary tract infection (UTI) occurred in a 63-years old woman from Bangladesh who was probably infected from contaminated water while working in the house. The patient had an history of type 2 diabetes and hypertension. The infection with water as source was considered possible since drinking water from tube wells, that are common in Bangladesh, was previously shown to be contaminated by *K. aerogenes*. The genome sequence showed that the isolate was multidrug resistant for the presence of 17 antibiotic resistance genes to aminoglycosides (*aph*(3')-Ib, *aph*(6)-Id, *aac*(3)-Ile, *aac*(6')-Ib-cr), β-lactams (*bla*TEM − 1B, *bla*CTX − M−15, *bla*OXA − 1, *blaamp*C), fluoroquinolones (*oqx*A, *oqx*B), amphenicol (*cat*B3), fosfomycin (*fos*A) and tetracyclines (*tet*D). Folate pathway antagonists, resistance genes *dfr*A14 and *sul*2, and the efflux pumps *acr*AB associated to tigecycline resistance were also present. Indeed, the strain was resistant to aminoglycosides, penicillin, cephalosporins, amphenicol, fluoroquinolones, folate drugs, tetracyclines, phosphonic acid, and glycycline. However, it was susceptible to carbapenems and polymyxins. After 14th day of antibiotic treatment the patient recovered completely [15].

3.12. Lactobacilli

The role of lactobacilli as opportunistic pathogens was summarized in recent reviews that illustrated routes of infection, type of illnesses caused and some genetic traits that could discriminate potentially pathogenic strains [2,90]. However, in the last year other seventeen case reports of infections caused by lactobacilli, of which nine with a link with probiotic or yogurt ingestion, were published. It must be underlined that the new nomenclature of lactobacilli approved since 2020 is still not in use in clinical reports, indicating difficulties in the application of taxonomic updates in the clinical practice.

A 76-year-old woman with a medical history of atrial fibrillation, congestive heart failure, type 2 diabetes, and hypertension was hospitalized for acute and chronic systolic heart failure and cholelithiasis with possible cholecystitis and gallbladder wall thickening. The fluid obtained by percutaneous drainage of the gallbladder was positive for *Lacticaseibacillus paracasei*. The patient underwent antibiotic treatment but cholecystectomy was not carried out because of her critical conditions. The increased intake of yogurt seen in this patient may have possibly contributed to the infection [16].

A man in his late 60s, with a history of moderately severe ulcerative colitis treated with a blend of *L. paracasei*, *L. acidophilus*, *Lactiplantibacillus plantarum*, *L. casei*, *Ligilactobacillus salivarius*, *L. rhamnosus* and bioprosthetic aortic valve replacement some months earlier, complicated by acute respiratory distress syndrome requiring tracheostomy and extracorporeal membrane oxygenation, had septic shock with a presumed respiratory source of infection. The patient was immunosuppressed for a recent therapy with prednisone. The blood cultures were found to be positive for *L. rhamnosus* identified by matrix-assisted laser desorption ionization time of flight mass spectrometry (MALDI TOF MS). Bacteremia persisted for three days while antibiotic therapy was carried out with penicillin and meropenem later changed to intravenous ampicillin. Post-hospitalisation the patient developed subacute bioprosthetic aortic valve endocarditis and secondary septic emboli to the brain, intravenous gentamycin and ampicillin allowed complete symptom resolution. Intestinal translocation of *L. rhamnosus* was possibly favored by immunosuppression and microbiome-disrupting antibiotic therapy [17].

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A 74-year-old man was hospitalized for fever and severe back pain. He had type 2 diabetes and ischemic heart disease underlying conditions. He often took laxatives and probiotics for chronic constipation. Histological examination of lesions involving L1/L2 vertebrae revealed inflammation and showed the presence of *L. paracasei* detected also in the blood cultures. Treatment with ampicillin and clindamycin healed the infection. Unfortunately, the patient experienced two heart attacks, the first during hospitalization, and the second, that was fatal, after he was discharged [18].

A 22-year-old woman presented native mitral valve endocarditis with severe regurgitation and required valve replacement. *L. jensenii*, identified by MALDI TOF MS, was isolated from blood cultures and from the excised valve. She reported to regularly consume probiotic yogurt for chronic constipation in the past years. Antimicrobial therapy with vancomycin and meropenem was effective in eliminating the infectious agent [19].

A 61-year-old immunocompetent woman with uncontrolled diabetes mellitus, nonischemic cardiomyopathy, ventricular tachycardia, and ventricular fibrillation status post biventricular automated intracardiac defibrillator (AICD), presented nausea, emesis, a systolic murmur and extensive redness around the upper thigh. She was recently hospitalized for bacteremia and blood cultures were positive for *L. casei*, *L. paracasei*, and *L. zeae*. She presented vegetations on the tricuspid valve and the right atrial lead and underwent catheter-based thrombectomy and removal of the AICD. The removed material was positive for lactobacilli and after six weeks of antibiotic therapy with multiple negative blood cultures the patient did not show cardiac vegetation any more. The patient reported habitual taking a lactobacillus probiotic [20].

L. paracasei and *L. plantarum* were involved in six cases of bacteremia in pediatric hematopoietic cell transplant recipients who received probiotic blends. The identity of strains isolated from blood and from the probiotic preparations was confirmed by whole genome sequencing [21]

Bacteraemia induced by the probiotic bacterium *L. casei* was reported in a 63-year-old patient after the attempted removal of implantable cardioverter-defibrillators (ICD) electrodes, complicated by tricuspid valve damage and replacement. After the intervention, the patient required intensive care treatment with mechanical ventilation, continuous renal replacement therapy, broad-spectrum empirical antibiotic therapy, parenteral nutrition, and blood transfusion because of multiple organ failure. After 14 days the patient developed septic shock. *L. casei* was isolated from the dialysis catheter. Based on antibiotic susceptibility of the isolate, piperacillin-tazobactam and linezolid therapy was initiated and the patient improved. The possible source of infection was the Actimel Danone® product, including *L. casei*, that the patient regularly consumed [22]

Endocarditis involving native valves in a 71-year-old woman immunocompromised for reumathoid arthritis treatment with prednisone was caused by *L. casei*. The patient declared she took 2 grams daily of an over-the-counter probiotic containing *L. casei* for several months. After treatment with ampicillin and daptomycin she underwent replacement of both aortic and mitral valves [23].

A case of *L. paracasei* bacteremia complicated by native valve endocarditis and embolic cerebrovascular infarct regarded a 56-years old immunocompetent man. He presented dyspnea, aortic sclerosis and diastolic dysfunction. *L. paracasei* grew in the blood cultures that later were negative, so he was not treated with antibiotics. However, two months later he experienced dysarthria, and was found to have an embolic stroke, for which he was discharged with antiplatelet therapy. After three months he presented acute dysarthria due to stroke recrudescence. *L. paracasei* grew in the blood cultures again. The patient referred that he had taken daily probiotics one year before for diarrhea and consumed yogurt daily. He presented multiple dental caries, a known predisposing factor for lactobacilli infections. Transesophageal echocardiogram revealed an aortic valve vegetation and a calcified nodule indicating old vegetation that led to suspect that the strokes were caused by emboli deriving from the valvular vegetation. Finally, he was treated with ampicillin and underwent valve replacement [3].

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3.13. Lactococcus spp.

The genus *Lactococcus* comprises technologically relevant homofermenting lactic acid bacteria with *L. lactis* and *L. cremoris* as the most widely applied in dairy fermentations. Among lactococci *L. garviae* was recognized as a fish pathogen affecting aquaculture establishments since 1950. It becomes part of the human intestinal microbiota after raw fish ingestion and can behave as an opportunistic pathogen in immunosuppressed individuals and also infect cardiac protheses in immunocompetent patients.

Recently, it was the cause of recurrent tonsillitis in two young males of 15 and 8 years of age. It was suggested that the infectious agent established in the tonsillar crypts after ingestion by forming a biofilm. *L. garvieae* was isolated from tonsillar exudate in both cases and showed multi-resistance to penicillin, cephalosporins, macrolides, and quinolones. Based on these results, a combination of amoxicillin-clavulanic acid coupled with a sublingual bacterial autovaccine containing an inactivated suspension of the pathogen was successfully used as treatment [24].

This bacterium was also a cause of infectious endocarditis favored by graft placement in a 65-years old man who was hospitalized for headache and dysarthria caused by an intracranial aneurysm. *L. garviae* was isolated from blood cultures and the patient was treated with intravenous antibiotics, ceftriaxone and gentamycin [25].

In a 77-year-old man admitted to the hospital with back pain that had lasted for 5 days and *L. garvieae* caused spondylitis. He had diabetes mellitus, hypertension, and histories of pulmonary tuberculosis and abdominal aortic aneurysm repair. *L. garvieae* grew in the blood cultures and was identified by MALDI-TOF MS. The condition worsened because of insufficient duration of the first antibiotic treatment and was resolved after six months of treatment with levofloxacin. The most probable access of *L. garviae* into the bloodstream can be the gastrointestinal tract in case of physiologic defects and loss of integrity. However, this patient, who was exposed to raw fish, did not suffer from gastrointestinal diseases [26].

The species *L. lactis* caused cholangitis in a 70-year-old man with distal cholangiocarcinoma with bile duct obstruction. An anaerobic blood culture turned positive for Gram-positive cocci identified as *L. lactis* by MALDI TOF MS. The bacteremia had originated from cholangitis and the clinical course after initiating the antibiotic treatment was good. However, the patient died because of metastatic cancer. Only another case report of *L. lactis*-associated cholangitis and bacteremia was described previously in a female patient in which it was the consequence of presence of a bile duct stone. The colonization of *L. lactis* in the digestive tract and the occurrence of biliary obstruction are considered to be the two predisposing factors for this rare condition. *L. lactis* colonization of the digestive tract is occasional and occurs after consumption of foods containing this bacterial species [27].

3.14. Laribacter hongkongensis

Laribacter hongkongensis is a Gram-negative, S-shaped bacillus of the Chromobacteriaceae family, class β-proteobacteria, first isolated from the blood and thoracic empyema of a patient with alcoholic liver cirrhosis in Hong Kong. It is associated with community-acquired gastroenteritis and traveler's diarrhea and was found in about 60% intestines of commonly consumed freshwater fish of the carp family.

A recent case of bacteremia caused by *L. hongkongensis* occurred in a 31-years old patient with end-stage alcoholic cirrhosis. Similar to other cases of invasive and noninvasive *L. hongkongensis* infections, the gastrointestinal tract was likely the portal of entry, as in three other cases described previously. All patients suffered from severe liver disease that favored *L. hongkongensis* translocation through the gastrointestinal mucosa due to portal venous congestion vasculopathy that can cause edema of the intestinal mucosa and local immunosuppression [28].

3.15. Leuconostoc spp.

Leuconostocs are heterofermentative lactic acid bacteria associated with fermented dairy products and vegetables rarely associated with serious human infections. Most cases of human illness

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caused by *Leuconostoc* spp., such as peritonitis and endocarditis, occurred in immunocompromised patients or patients with central venous catheters or endotracheal tubes but a few occurring also in immunocompetent patients. Cases have also been reported in association with short-gut syndrome, gastrointestinal procedures, and preterm birth.

A recent case regarded a 30-years old man with a history of papillary thyroid cancer and hepatitis C infection who presented stabbing chest pain with radiation to the jaw. He reported that he had partially curdled raw milk from a friend's farm some weeks before hospitalization and had already completed four days of antibiotic therapy. Blood cultures showed the growth of Gram-positive cocci but did not originate colonies, so *L. mesenteroides* subsp. *cremoris* was identified directly in the blood cultures by MALDI-TOF MS. Due to the intrinsic resistance of *Leuconostoc* spp to vancomycin for the presence of D-lactate instead of D-alanine in peptidoglycan, a 7-day course of antibiotics with daptomycin was undertaken. The next blood cultures were negative. The predisposing condition for this case was considered to be poor dentition [29]. Indeed, *Leuconostoc* spp. have been isolated from one acute facial cellulitis and an acute apical periodontitis [91].

3.16. Pantoea spp.

Pantonea agglomerans, previously denominated *Erwina herbicola* and later *Enterobacter agglomerans*, is ubiquitous in the environment and can contaminate plants and foods. It causes local or systemic opportunistic infection that can be severe in newborns and in the elderly. Infant formulas can be food sources of infection. Neonatal cases and outbreaks were often nosocomial with main risk factors the immunocompromised state due to the immature immune system and comorbidities [30].

In a cross-sectional study carried out in the Nigerian city of Zaria the first community acquired newborn infection cases in Sub-Saharan Africa were identified. *P. agglomerans* was isolated from eight among 94 neonates who presented LOS. None of them had comorbidities, invasive procedures, intravenous catheterization or maternal risk factors for infection, and a polymicrobial infection. All the neonates were treated with Ampiclox and gentamicin and one was changed to ciprofloxacin after 7 days. Mortality was 12.5%. The source of infection could not be infant formula, since all the babies were breastfed, so it was suspected to be hands of family members and the household environment, that can be contaminated by this bacterium [30].

3.17. Pediococcus spp.

Pediococci are coccoid shaped homofermenting lactic acid bacteria present in a variety of fermented food and beverages that have both technological and probiotic relevance. However, some cases of infection caused by these bacteria were reported. A recent case of *Pediococcus* bacteremia occurred in a 16-year-old male who developed dasatinib-induced hemorrhagic colitis during maintenance therapy for leukemia. He was eating yogurt almost daily. Gram-positive cocci were isolated in pairs from the aerobic blood culture and in tetrads from the anaerobic blood cultures after 24 h of incubation at 37 °C. Analysis by MALDI-TOF MS identified the pathogen as *P. acidilactici*. Because his general conditions were improving, antibiotic therapy was not started. The pathogenesis most probably began for the disruption of the gastrointestinal mucosa by hemorrhagic colitis, resulting in transient bacteremia [31].

3.18. Plesiomonas shigelloides

Plesiomonas shigelloides, previously *Aeromonas shigelloides* [32], is the only species in the genus *Plesiomonas*, which is allocated in the Enterobacteriaceae family. It is a cause of gastroenteritis with higher frequency in summer in the tropical or subtropical regions. Transmission most often occurs by consumption of contaminated seafood, commonly shellfish, uncooked food, or contaminated water [33]. In immunocompromised patients and patients with underlying conditions *P. shigelloides* can cause bacteremia, meningitis in neonates, cholangitis, cellulitis, and abscesses. The case fatality rate was 40% (17/43) [34].

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In a 75-years old patient with chronic lymphocytic leukemia and diarrhea caused by *P. shigelloides* lasting for four weeks a colonoscopy revealed multiple ulcers in colon and final ileum. To the patient oral ciprofloxacin was administered for 5 days with complete resolution of diarrhea. *P. shigelloides* in this patient was identified by the gastrointestinal (GI) multiplex molecular panel (Newfoundland and Labrador Public Health Laboratory). The patient reported that he usually ate raw oysters for many years [32,33].

A case of newborn meningitis with brain abscess and septicemia caused by *P. shigelloides* via the transplacental route was diagnosed in Prato, Italy, and was linked to the consumption of oysters by the mother one week before delivery. The prompt recognition of the infectious agent in this case soon allowed an appropriate antibiotic treatment, excluding ampicillin and penicillin to which the bacterium is resistant, and survival of the patient [32].

A 49-year-old man previously diagnosed with alcoholic cirrhosis was hospitalized for severe gastroenteritis, abdominal pain, and generalized weakness. The evening before developing the symptoms, he had eaten "Dojo nabe" hotpot containing freshly caught loaches some of which appeared undercooked. Other 20 people with no medical problems had eaten the hotpot with him and none of them developed symptoms. Infective enterocolitis was ascertained and gram-negative bacilli, identified as *P shigelloides* by MALDI-TOF MS, grew in the blood cultures. *P. shigelloides* is known to occur in the intestine of loaches, that were the most probable source of the infection. The patient fully recovered from multiorgan dysfunction after treatment with Meropenem, later switched to cefotaxime and levofloxacin. People with cirrhosis are thought to be susceptible to *P. shigelloides* infection through chronic iron overload beyond increased intestinal permeability [34].

3.19. Proteus mirabilis

P. mirabilis is a Gram-negative swarming bacterium that is frequently found in the environment and is part of the human and animal microbiota. It is considered a commensal but many reports highlighted its potential as an opportunistic pathogen, mainly involved in urinary tract infections (UTIs). In a study regarding its presence in meat, *P. mirabilis* was isolated from all chicken samples, and in 27.80% and 23.05% of beef and pork samples, respectively. Based on the presence of virulence genes, enterobacterial repetitive intergenic consensus (ERIC) fingerprinting and strong biofilm forming capacity, strains from UTI and meat appeared to be closely related, reinforcing the hypothesis that meat can be considered an important source of *P. mirabilis* in the community [92].

Strains of *P. mirabilis* have been isolated in hospitals from patients suffering of sepsis, food poisoning, peritonitis, and meningitis. In recent years, a rise in food poisoning outbreaks with clinical symptoms like abdominal pain, diarrhea, nausea, and dizziness associated with *P. mirabilis* was reported worldwide. Epidemiological investigations indicated that meat products, bean products, fish, and cold dishes are commonly associated with food poisoning caused by *P. mirabilis* [93].

3.20. Sarcina ventriculi

Sarcina ventriculi, formerly *Clostridium ventriculi*, is a rarely occurring, non-motile, anaerobic, Gram-positive coccus with a carbohydrate fermentative metabolism. It survives and grows in acidic environments and is associated with delayed gastric emptying. It may be responsible for dyspepsia, abdominal pain, gastric ulcers, and rare emphysematous gastritis that can lead to gastric perforation. *S. ventriculi* is a commensal organism found in the soil and feces of humans, especially in those following a vegetarian diet. It was not ascertained whether it naturally colonizes the human intestinal tract or if its presence is due to contamination from food intake [94]. The organism appears to be innocuous in a stomach with intact mucosa and normal emptying, but proliferation and gastritis can occur in patients with mucosal injury for diabetic gastroparesis, surgery or neoplastic obstruction [35].

One case regarded a 67-year-old woman with a long-standing gastroesophageal reflux worsening during several months. She presented a diffuse esophagitis with ulcerations and whitish patches interspersed between the ulcerations. Biopsies from the esophagus and duodenum showed the presence of Gram-positive cocci in tetrads. Therefore, *S. ventriculi* infection was diagnosed

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according to the method currently accepted to obtain a diagnosis of this infection, that is microscopic observation. The patient was treated with metronidazole and pantoprazole and had an almost complete resolution [36].

In a 35-year-old patient with liver and kidney transplantation for primary sclerosing cholangitis and diabetic nephropathy due to Type 1 diabetes, pharmacologically immunosuppressed, severe epigastric pain, nausea, vomiting with episodes of coffee ground-like emesis, and diarrhea occurred. Biopsies of the stomach showed areas of inflamed mucosa and areas with complete mucosal/submucosal necrosis and abundant clusters of *S. ventriculi* in the exudates. Treatment with piperacillin-tazobactam and clindamycin led to an apparent improvement of gastritis. However, the patient died for other complications because he could not comply with immunosuppressive treatments before hospital admission for financial problems [35].

3.21. Serratia marcescens

The genus *Serratia* comprises 23 species of gram-negative bacterial that can be found in different environments. These organisms caused different human infections and are intrinsically resistant to many antibacterial agents. The type species of the genus, *Serratia marcescens*, is widespread in the environment and has the ability to cause a wide variety of infections in immunocompromised individuals such as nosocomial wound, respiratory, and urinary tract infections, bacteremia and meningitis with a possibly lethal outcome [95]. *S. marcescens* has repeatedly caused outbreaks in neonatal intensive care units (NICUs), where the sources of infection are colonized patients, the personnel hands, contaminated infant food, breast pumps and breast milk, medical devices, parenteral nutrition solutions, drugs, and care products [37,96].

Outbreaks in NICUs can be caused by the contamination of breast milk. An outbreak of *S. marcescens* was transmitted by contaminated breast pumps and stopped after changing the disinfection procedure. Three consecutive outbreaks of *S. marcescens* in a NICU were caused by cross contamination of breast milk and the colonization of neonates stopped after the reorganization of procedures in the milk kitchen [37].

Pasteurization of donor milk at 62.5°C for 30 minutes inactivates relevant pathogens but the use of unpasteurized donor milk, though not recommended by most international guidelines, is carried out in several German and Norwegian hospitals due to the better immunological properties of raw donor milk and presumptive better effect on child development. According to outbreak description, *S. marcescens* was spread among patients by different means [37].

In an outbreak reported in 2019 in the University Hospital Magdeburg, Germany, an early phase in of infant colonization was likely caused by unpasteurized donor milk. In this outbreak 17 neonates were colonized and two developed bacteremia. One of these, who was a preterm infant, developed meningitis and died. Culture-negative milk portions of the suspected donor, that probably contained viable *S. marcescens* below the detection limit, were given to the neonates and resulted in colonization or infection of other seven preterm infants. In a later phase of the outbreak, the fatal case of meningitis occurred because the infant temporarily shared the room with a colonized neonate. Genome sequencing highlighted sequence identity for all patient and breast milk isolates with the exception of one isolate with only a single-nucleotide polymorphism (SNP), confirming the common origin of the isolates [37].

3.22. Shewanella spp.

There are currently 80 species classified in the genus *Shewanella*, class Gammaproteobacteria. Among these, *S. putrefaciens*, *S. algae* and *S. xiamenesis* are recognized human pathogens. They occur in fresh, marine, and sewage water mainly in moderate and warm climates and were also isolated from foods such as milk, cream, butter, eggs, poultry, raw fish or seafood and beef. *S. putrefaciens* is a biofilm former and important spoilage agent of protein-rich refrigerated foods [97].

S. putrefaciens is a rare oppurtunistic pathogen associated with skin- and soft-tissue and intra-abdominal infections, mainly biliary tract infections and peritonitis, for which cholelithiasis or liver cirrhosis are predisposing factors. Another major predisposing factor for infection with this pathogen

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is ESRD. *S. putrefaciens* can also lead to bacteremia with possibly lethal courses. In addition, *S. putrefaciens* is able to invade human intestinal epithelial cells. Since *S. putrefaciens* infections are often polymicrobial, the pathogenic role of the bacterium must be better clarified [97].

Neonatal and pediatric infections such as bacteremia by *S. putrefaciens*, sometimes lethal, were reported in infants with low birth weight or preterm. Infective endocarditis developing in septic shock with multiple organ failure were reported mainly in predisposed individuals. In addition, diseases such as diabetes mellitus, peripheral vascular disease, malignant neoplasies, and immunosuppression, are underlying conditions that favor *Shewanella* infections that are mostly community acquired and favored by low hygiene and exposure to and consumption of contaminated seafood or fish [97,98].

Among the virulence determinants detected or overrepresented in clinical *Shewanella* spp. isolate genomes, several are related to adherence, toxicity, swarming and swimming motility, and iron metabolism. Genes overrepresented in clinical isolate genomes include the peroxidase encoding gene *kat*G previously reported as an important factor to survive under oxidative stress [98].

A recent case report regarded an 84-year-old man with pancreatic cancer and liver metastases who presented fever. He declared to have ingested raw fish several days before. Ceftriaxone administered once and cefmetazole assumed for two weeks by the patient successfully treated the infection. A blood culture showed the growth of gram-negative bacilli that were identified as *S. algae* by MALDI-TOF-MS and 16S rRNA gene sequence analysis [38].

An analysis of cases of *Shewanella* infections in patients admitted to a regional hospital in Hong Kong in years 2012 – 2020 showed that none of the uremic patients with peritoneal dialysis suffered from peritonitis. Three cases of bacteremia caused by *Shewanella* were observed in patients with chronical kidney disease (CKD) and none had a vascular access. Two of the involved patients suffered from cholangitis, and one had necrotizing fasciitis. Therefore, the association between *Shewanella* infections and CKD was found not to be related to the modality of dialysis employed, but might be explained with the dysregulated iron homeostasis resulting in an overall positive iron balance in CKD with iron binding to the siderophores produced by *Shewanella* species. The majority of *Shewanella* infections had not documented seawater contact but the habitual consumption of raw or undercooked seafood in Hong Kong could explain the relatively large number of local cases [39].

3.23. Streptococcus spp.

The genus *Streptococcus* comprises different groups of cocci shaped Gram-positive bacteria able to cause opportunistic infections, with some groups strongly associated to foodborne illnesses [99].

S. agalactiae commonly colonizes human intestine and urogenital tracts and can cause invasive infections in neonates, pregnant women and in patients immunocompromised and with underlying diseases, such as type II diabetes or cancer. Most recently it has been recognized as a foodborne pathogen responsible of infections such as meningo-encephalitis, septicemia and septic arthritis consequent to the consumption of raw fish traditional dishes in South East Asian countries [100,101]. An outbreak occurring in Singapore in year 2015 involved the clone ST283, which caused invasive and systemic infections also in individuals with no underlying conditions [102]. This clone was isolated in eleven countries of four continents and can be considered an emerging pathogen of wide diffusion. The time-calibrated phylogeny of 328 genomes from ST283 isolates collected between 1998 and 2021 indicated as most recent common ancestor an isolate from year 1982 [101].

A recent case report regarded two sisters of 58 and 55 years of age who contracted *S. agalactiae* ST283 after consumption of traditional raw fish dishes in Lao PDR. The older sister manifested muscoloskeletal pain, nausea, vomiting, and watery diarrhoea, while the other sister had fever and joint infection. The organism was isolated from the blood cultures already after 24 h from symptom onset. A more severe progress of the illness was probably prevented by prompt antibiotic treatment with ceftriaxone and gentamicin [40]. Other two recent cases associated to raw fish consumption were recorded in Malaysia and were the first reported in this country. One occurred in a 36-year-old Chinese man presenting septic arthritis with no comorbidities and no association with raw or undercooked food, the other was observed in a 74-years old Chinese woman who had diarrhea and

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vomiting after a visit to a durian orchard two weeks before and presenting to the hospital with symptoms of meningoencephalitis. In this case too there was no association with raw fish consumption. Whole genome sequencing showed that the *two S. agalactiae* ST283 strains isolated from the patients differed by three single nucleotide polymorphisms (SNPs) from each other, and by only one and two SNPs from isolates from human sepsis cases in Singapore [103]. It was speculated that the increasing number of infections caused by *S. agalactiae* ST283 in fish might derive from water contamination from human sources and could be prevented by improving wastewater management [101].

S. dysgalactiae is a β-haemolytic streptococcus able to cause mastitis in milk producing animals and a recognized zoonotic agent that can cause infection in humans by ingestion of contaminated food. Related illnesses are mainly skin and soft-tissue infections, including pyoderma, cellulitis, wound infections, abscesses, erysipelas, tonsillitis, infectious endocarditis, necrotizing fasciitis and hematogenous complications of bacteremia. This bacterial species is susceptible to β-lactams but, to avoid delayed or poor responses of infections because of failure of penicillin/cephalosporins, the addition of an aminoglycoside should be considered for severe infections [41,104]. Bloodstream infections with *S. dysgalactiae*, in which the subspecies *equisimilis* is most often involved, are frequent in the elderly and may lead to sepsis, septic shock and complications such as symmetric peripheral gangrene that can require art amputation [104,105].

A retrospective study regarding years 2006-2020 carried out in Finland, where infections caused by β-hemolytic streptococci must be mandatorily notified, showed that the incidence of invasive infections attributable to these bacteria are rising, together with those due to *S. agalactiae*, for patients older than 55 years, showing also a higher percentage of relapses. This trend was observed also globally and was explained with an improvement of identification tests, an increase of the older population with comorbidities and the diffusion of epidemic clones [105,106]. One recent case of suspected food origin regarded a 77-years old man who had a history of unpasteurized milk consumption and presented a periprosthetic joint infection at one knee that became swollen and hyperemic. *S. dysgalactiae* was isolated from knee aspirate. The case was resolved surgically and by antibiotic treatment [41].

Another zoonotic *Streptococcus* species involved in foodborne infections is *S. equi* subsp. *zooepidemicus* (SEZ), a highly contagious opportunistic pathogen of horses and other farm animals. Human infections are considered rare and may occur in persons exposed to animals or in consumers of raw horse meat and unpasteurized milk [42]. Clinical minifestations include meningitis, sepsis, peritonitis, necrotizing myositis, purulent arthritis, purulent pericarditis and endocarditis [107]. Of three cases registered in Jeju Island, South Korea, between 2009 and 2019, one regarded a 59-years old man with hypertension and end-stage renal disease on dialysis. The infection was probably caused by consumption of raw horse meat and liver and manifested as joint infection of both knees evolving in septic arthritis. The patient recovered after drainage of joint fluid, intravenous levofloxacin treatment and rehabilitation [42].

Another case regarded a 49-years old woman with liver cirrhosis who manifested abdominal pain and edema of the extremities four days after eating raw horse meat. She developed SEZ bacteremia and healed after treatment with teicoplanin and ceftriaxone. A review of the literature showed that cases of SEZ infections occurring in other countries, 19 were linked to the consumption of raw horse meat or unpasteurized milk and foodborne infections showed higher mortality than those caused by the contact with horses [42].

A retrospective study for the period 2005 – 2020 carried out in Thailand identified 18 cases of SEZ infection, septicemia in 61% cases, and 72% linked to raw pork consumption. The isolates belonged to ST194 and those from different patients had identical pulsotypes. Based on the SNP phylogenetic analysis, the clinical strains were closely related to swine ST194 strains, reported to cause with high mortality infections with sudden death in pigs from China, Canada and USA. Other STs of clinical importance are STs 5, 10, 65, 72, 209, 306 and 364 [107].

Two infection reports attributable to the consumption of unpasteurized milk and derived products have been published since 2019. One regarded a 73 years old woman with osteodural defect,

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chronic otitis, and other underlying disease who developed meningitis. The other case regarded bacteremia in a newborn and her 31 years old mother caused by the consumption of artisanal cheese five days before baby birth [43,44].

A recent large outbreak, with 37 cases, occurred in Central Italy in the period November 2021 – May 2022 and was traced back to the consumption of unpasteurized milk cheese from a single manufacturer [45]. The patients manifested different infective states, including septicemia, pharyngitis, arthritis, uveitis, endocarditis and meningitis. Five patients who developed meningitis died. Based on SNP analysis of genomes, 21 clinical isolates were closely related, indicating a single source of infection. Thirty-one patients had consumed soft cheeses from local producers and inspection of eight producers led to the identification of one cheese production plant contaminated by *S. equi* subsp. *zooepidemicus*, found to be present in both raw milk and raw milk cheese. The isolates from the producer clustered with the clinical ones and with an isolate from cow mastitis obtained in November 2021 and originating from the same farm. The reported outbreak indicated that SEZ is an important emerging pathogen with high virulence. Use of whole genome sequencing of the isolates coupled with epidemiological investigation allowed to prevent further infection cases.

The *Streptococcus bovis*/*Streptococcus equinus* complex (SBSEC) bacterial group colonizes the intestinal tract of both humans and animals and can cause bacteremia and localized infections, more often endocarditis but also peritonitis [108] and meningitis [109] if they cross the intestinal barrier that can be damaged by diseases or medical procedures, behaving as opportunistic pathogens. Some case reports regard cholecystitis [46] and pancreatitis [110].

Moreover, a strong association between *S. bovis*, mainly the biotypes I and II/2, reclassified as *S. gallolyticus* [111], and colorectal cancer (CRC) was known since 1977. Therefore, the Infectious Diseases Society of America (IDSA) recommends that patients with SBSEC bacteremia should be evaluated for CRC. Some theories suggest that these bacteria favor the development of malignant lesions from premalignant ones by inducing inflammatory responses and mutations in tumor suppressor genes [99].

Though it is hypothesized that the dietary route favors intestinal colonization by these bacteria, no case reports or outbreaks have been linked to food except one alluding to a possible food origin of the infectious agent and involving *S. gallolyticus* subsp. *pasteurianus*. This case regarded a 63-years old man with a history of severe gastroenteritis many years before who presented burning epigastric pain and vomiting due to acute necrotizing cholecystitis that started two hours after ingestion of a pork cutlet. The gallbladder contained more than 30 dark brown bilirubin calcium stones 2–3 mm in diameter covered with bacterial colonies. The colon did not present malignant lesions. The case was successfully treated surgically and by antibiotic administration [46].

S. iniae is another pathogen causing infections in aquatic animals of great concern in aquaculture but also capable to cause bacteremia cellulitis, arthritis, meningitis, and endocarditis in humans [112]. No case reports related to food consumption seem to have occurred recently.

Streptococcus suis causes infectious diseases that can be transmitted to humans by direct contact with sick pigs and ingestion of contaminated meat, resulting mainly in meningitis but also septicemia, pneumonia, toxic shock, arthritis, endocarditis and endophthalmitis. The most frequent sequela is hearing loss, occurring in more than 50% cases [47]. Consumption of or contact with contaminated raw pork, contact with sick pigs, pig-related occupation and male sex are risk factors for the infection by *S. suis* [48].

In recent years, the number of reported human *S. suis* cases has increased, mostly in Southeast Asian countries. While in industrialized countries *S. suis* zoonosis is more an occupational disease affecting workers in close contact with infected pigs or contaminated pork, in Southeast Asia it is more linked to foodborne infections. Indeed, high pig densities and consumption of raw or undercooked pork determined more than 50% of the total human *S. suis* cases in Asia. This important zoonotic pathogen is classified into 29 serotypes. Serotype 2 is the most frequently recovered from human infections, although also human cases due to serotypes 4, 5, 7, 9, 14, 16, 21, 24, and 31 have been reported with higher diversity in Southeast Asia. A study from Vietnam showed significant problems with mobility, self-care, performance of usual activities, and emotional impact caused by

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hearing impairment and dizziness sequelae of *S. suis* infections with also a sanitary burden. The infection spread in Southeast Asian countries is favored by the lack of proper identification of infected animals, poor meat inspection and limited access to hygiene measures when handling raw pork at slaughter or in kitchens. Consequently, *S. suis* can contaminate working surfaces and hands of the operators in the whole pig supply chain, from slaughterhouses to retail markets [113].

Four large outbreaks of *S. suis* infections in humans have been recorded in Thailand, mainly in the North [114]. The incidence of *S. suis* disease in Thailand peakes during the rainy season, and an association was found between occurrence of human *S. suis* meningitis and porcine reproductive and respiratory syndrome virus (PRRSv) outbreaks on pig farms. More than 70% of cases with *S. suis* infections were associated with the consumption of traditional raw pork and raw blood dishes but also of a cooked pork traditional dish in Vietnam, thus indicating cross contamination events. Though prevalence data were not available, human *S. suis* meningitis cases were reported in Indonesia, Lao People's Democratic Republic and Philippines, all countries with a tradition of raw pork consumption [115]. To evaluate the genotypic relationship between *S. suis* isolates recovered from either human or pig origins, *S. suis* isolated from pig tonsils at a slaughterhouse in Phayao province between April 2010 and March 2011 were studied and compared to human isolates recovered in the same region. Thirteen out of 17 serotype 2-ST1 isolates, 5 out of 7 isolates of serotype 2-ST25, 1 out of 4 isolates of serotype 2-ST28, and all serotype 2-ST103 and ST104 isolates revealed pulsotypes identical to those of human isolates [115].

S suis infection is endemic in China owing to frequent pork consumption and small-scale swine farming. Although human *S suis* normally presents as a sporadic disease, there were two outbreaks in China with toxic shock syndrome as the most severe presentation. The fatality rate of human *S suis* infection in China was up to 18% [47].

A recent case in Shandong province involved a 75-year-old previously healthy man who presented a 1-day history of fever, vomiting, coughing, chills, and unconsciousness and received a diagnosis of sepsis and intracranial infection. Gram-positive cocci able to form small colonies that were identified as *S suis* grew in blood cultures. Based on antibiotic susceptibility testing, the patient was treated with levofloxacin and recovered, though with hearing loss. It was ascertained that the patient had eaten pork from a sick pig before disease manifestation [47].

A 48-year-old man, who often consumed raw fermented pork presented endopthalmitis at the right eye that evolved in perforated cornea and vitreous haemorrhage. Two days later, he developed a low-grade fever, neck, joint and waist pain and blurred vision at his right eye along with a decrease in hearing ability of the right ear. His physical weakness from sleep deprivation and underlying conditions were probably predisposing factors for infection. *S. suis* was detected in blood cultures and vitreous from the right eye. The audiogram was done at 5-day post admission suggesting irreversible bilateral sensorineural hearing loss (SNHL) resulting from disseminated *S. suis* infection [48].

A case of meningitis in a Brazilian elderly male occurred after consumption of pork and was successfully treated with ceftriaxone. Another case reported in Brazil regarded a 49-years old woman who was probably infected by contact with pork contaminated with *S. suis* while cooking and suffered meningitis and bacteremia [49,50]

3.23. Weissella confusa

Among the 22 recognized species of the heterofermentative lactic acid bacteria genus *Weissella*, *W. confusa* is the most frequently associated with human infections, more often with bacteremia. It was also isolated in co-infections, especially in the gastrointestinal tract. The majority of serious infections caused by this bacterial species have been reported in immunocompromised patients with co-morbidities. Generally, translocation from gut is the most common mode of infection, especially in immunocompromised but also in immunocompetent individuals and individuals with prolonged hospital stays where multi-drug-resistant clones are selected [116].

On the other hand, *W. confusa*, which is associated to different foods, mainly fermented, of plant origin, was proposed to be safe for food production and as a probiotic [117].

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A case of *W. confusa* infection was diagnosed in a 11-year-old male child admitted to the hospital with high fever, difficulty if breath, tachycardia, and tachypnea. He was diagnosed with acute pancreatitis with severe inflammatory response syndrome (SIRS) and evolving in acute respiratory distress syndrome (ARDS). He was managed by percutaneous draining. From a blood culture Gram-positive cocci identified as *W. confusa* were isolated. A co-infection with *C. parapsylopsis* was revealed and piperacillin-tazobactam, ceftazidime, and voriconazole, were administered leading to patient recovery [116].

A 65-year-old man with alcohol associated cirrhosis, and currently undergoing liver transplant evaluation, presented to the hospital with confusion, weakness, and weight loss. He had a negative chest x-ray and urinalysis but blood cultures grew Gram-positive rods, identified as *W. confusa*, in less than 24 hours. He reported eating sauerkraut on a weekly basis for several years and had no new food exposures. Repeat blood cultures were negative but aortic valve infectious endocarditis was diagnosed. The patient was treated with penicillin V followed by oral amoxicillin-clavulanate and recovered after some complications. Another case of *W. confusa* infection attributed to the consumption of sauerkraut was reported previously [51].

In a 63 years old man of Ghanaian origin who presented with chest tightness and palpitations lasting for four weeks, blood cultures were positive for Gram positive coccobacilli identified as *W. confusa* by MALDI-TOF MS. Therefore, intravenous amoxicillin and ceftriaxone were administered. Transthoracic echocardiogram revealed a thickened bicuspid aortic valve with suspicion of a mobile vegetation. He needed aortic valve replacement and the debrided aortic material was negative for bacteria, so antimicrobial therapy was not restarted. The patient was discharged after a full recovery on day 62 of his admission. *W. confusa* is used in the fermenting process of commonly consumed Ghanaian food products, such a nunu, a yoghurt-like product prepared from raw cow's milk and it was considered possible that the patient's Ghanain diet contributed to gut colonisation with *W. confusa* [52].

A 78-year-old male patient, bedridden due to an old stroke and many comorbidities and history of infectious states, presented a high fever and altered mental status for 2 days. He was lethargic, responsive only to painful stimuli and had generalized stiffness. The CSF was turbid but with no microorganisms. The blood culture were positive for Gram-positive cocci in pairs and chains that were identified as *W. confusa* by MALDI-TOF MS. These were found later also in CSF. Vancomycin, to which *W. confusa* is intrinsically resistant, was then stopped and the patient was treated with meropenem and ampicillin returning to his previous health status. Age, diabetis and a prior history of cholangitis and manipulation of the biliary tract and possible intestinal microperforations might have contributed to the translocation of *W. confusa* to the bloodstream causing bacteremia with secondary meningitis. The diet of the patient consisting of mashed fruits and vegetables for the past few weeks, might also have played a role, given the frequent occurrence of *W. confusa* in vegetables [53].

4. Conclusions

This review was based on outbreak or case reports that can be the only a small part of the number of illnesses really occurring and have only an indicative value in terms of risk factors and hints for prevention. Not all the opportunistic pathogens considered in the survey are object of surveillance by public health authorities, and some are so only in some countries. This might contribute to the lack of real prevalence data that in turn determine the missed adoption of specific prevention measures, among which correct information of the consumers on the risks linked to the food products involved when associated to particular medical conditions.

For some of the opportunistic pathogens considered in this survey, e.g., *Acinetobacter* spp., *Chryseobacterium* spp., *Klebsiella* spp., *Enterococcus* spp., coagulase negative staphylococci (CNS), the investigation focus was centered mainly on nosocomial infections caused by multidrug resistant clones selected in clinical settings whose origin was most often not identified. However, the occurrence of those bacterial genera and species in food or water is very frequent. Therefore, study of the possible connections between food and drinking water consumption and environmental or

host colonization should be intensified to allow the interruption of the chain of contamination events leading to illnesses.

Lactobacilli were the bacterial group with the highest number or infection cases reported in the current year. This can be explained with the most frequent exposure of persons to a high number of these bacteria through the intake of probiotic preparations and fermented dairy products. Therefore, it is opportune to more carefully select strains devoid of possible virulence traits for use as probiotics and for the production of fermented food products.

In many reports surveyed here the pathogenic agent was not characterized by molecular typing methods and this constitutes a relevant obstacle to the identification of the food sources involved in transmission and the source of contamination. Therefore, the introduction of practices that facilitate isolate typing in the clinical practice might aid in the reduction of foodborne illness cases by focusing the surveillance on specific clones. This could lead to the development of molecular methods for direct analysis of food products in the early safety control phase.

Finally, it was highlighted that risky traditions of raw food consumption are implied in the occurrence of infections in some countries. This points out to the necessity to improve hygiene practices and increase microbiological testing of foods before commercialization also for opportunistic pathogens beyond major pathogens.

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