Molecular Genetic Profiling of Clinical and Foodborne Strains of Enterococci with High Level Resistance to Gentamicin and Vancomycin

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Abstract

Enterococci often acquire antimicrobial resistance through horizontal gene transfer. Relatedness between enterococci with high level resistance to gentamicin and vancomycin isolated from humans, food, and hospital environment in Tandil County (Argentina) was investigated. PCR amplification for species determination was carried out. Resistance to seven antimicrobials was studied; virulence genes (esp, cylA), vancomycin and gentamicin resistance genes were investigated. In the isolates with high level antimicrobial resistance (gentamicin, vancomycin), pulse-field gel electrophoresis was performed. Vancomycin-resistant E. faecium (n=13) were recovered from human, food and hospital environment samples. All the isolates expressed high-level vancomycin and teicoplanin (vanA genotype), as well high-level gentamicin and streptomycin resistance. Vancomycin-resistant E. faecium were distributed among seven clonal types; esp gene was detected in clinical strains. There was no clonal relationship with food vanA E. faecium, but these strains could pose a risk in intra/inter genus transfer of vanA determinant to human-adapted strains. High-level gentamicin resistant E. faecalis (n=7) were recovered from human and food samples. Glycopeptide resistance was not observed; cylA gene was detected in most of the clinical high-level gentamicin resistant E. faecalis isolates. PFGE patterns showed four clonal types in high-level gentamicin resistant E. faecalis strains; there was demonstrated clonal relatedness between isolates from different origin. In Argentina, this is the first study showing a clonal relationship between high-level gentamicin resistant E. faecalis isolated from food and humans. These results encourage the study of dissemination of clonal complexes with mobile resistance genes.

Keywords: Enterococci; Relatedness; Food; Humans; Environment

Introduction

Enterococci are intrinsically resistant to many antimicrobials groups. Furthermore, these bacteria are capable of acquiring drug resistance genes through horizontal gene transfer, such as high level aminoglycosides and vancomycin resistance genes [1,2].

Enterococci colonize raw and fermented meat, as well as dairy products, since they are part of the indigenous microbiota of mammal’s gastrointestinal tract and are able to survive under adverse environmental conditions [3,4].

Enterococcus faecalis and Enterococcus faecium have been recognized as etiological agents of bacteremia, meningitis, endocarditis, urinary tract and neonatal infections. Both species are relevant pathogens for immunosuppressed patients or with prolonged hospitalization [5-8].

Enterococci remain for long time-periods on environmental surfaces, including medical equipment, bed rails and doorknobs. Also, they are tolerant to heat, chlorine and some alcohol-based preparations [9].

In enterococcal species, vancomycin resistance can be associated with different van genotypes and Van phenotypes. VanA resistance is mediated by transposon Tn1546 or closely related elements. Expression of vanA gene leads to inducible high-level vancomycin (Minimum Inhibitory Concentration, MIC, ≥ 64 µg/mL) and teicoplanin (MIC ≥ 16 µg/mL) resistance, while vanB gene encodes for variable levels of inducible vancomycin resistance. VanA is the most frequent glycopeptide resistance type in clinical enterococci. Nowadays, there is an increasing concern about vanA plasmid-mediated transfer to methicillin-resistant Staphylococcus aureus [10-12].

Over the last decades, detection of vanA genotype in E. faecium from animals and from food of animal origin has been reported. Initially, vancomycin resistance was linked with the use of avoparcin (glycopeptide) as an animal growth promoter in the European Union, EU [13-15]. After avoparcin was banned, glycopeptide-resistance persisted, likely due to co-selection processes. However, at the same time of avoparcin ban in the EU, vancomycin-resistant E. faecium were not isolated from animal food products in the US [16,17]. In Argentina, Delpech et al. [18] recovered vancomycin-resistant E. faecium from artisanal salami, cow cheese and goat cheese.

The incidence of health-care associated infectious diseases produced by vancomycin-resistant E. faecium in US hospitals has increased significantly, becoming a nosocomial pathogen almost as prevalent as E. faecalis [19].
Frequently, hospitalized patients are treated with broad spectrum antimicrobials. Therefore, presence of VanA or VanB vancomycin-resistant enterococci in patients’ gastrointestinal tract and the risk of invasive infections can be significantly increased. In humans, E. faecium is the main reservoir of VanA and VanB type resistance. In recent years, worldwide, colonization with vancomycin-resistant E. faecium was considered endemic in many hospitals. Antimicrobial use in patients seems to be a critical factor related to vancomycin-resistant enterococci infections [20-22].

In South America, a multicenter study found that, ca. 22% of enterococcal infections were caused by multi-resistant E. faecium, similarly to what was reported in the US [23]. In Argentina, Corso et al. [24], through a nation-wide antimicrobial resistance survey, proved that most of vancomycin resistant enterococci carried vanA gene (98%). In addition, these strains, expressed high-level resistance to gentamicin (77.2%) and streptomycin (95.8%).

Many putative virulence factors from E. faecium have been identified. One of the most relevant is a large surface protein (Esp) covalently linked to the bacterial cell wall. Leavis et al. [25] demonstrated that, in E. faecium, esp gene was encoded in a large pathogenicity island and its presence was associated with nosocomial outbreaks.

In enterococci, acquisition of high-level gentamicin resistance (MIC ≥ 2,000 μg/mL) is a significant therapeutic problem, particularly for patients with severe infections. High-level aminoglycoside resistance makes ineffective the synergistic effect between aminoglycosides and a cell-wall-active agent, e.g. beta-lactams or vancomycin. aac(6')-Ie-aph(2´)-Ia gene, associated with high-level gentamicin resistance, is widely spread in E. faecalis. This gene has been detected in strains from human infections and among enterococci from food of animal origin [26,27]. Bifunctional enzyme AAC6’-Ie-APH2-‘-Ia confers resistance to available aminoglycosides, except for streptomycin. aac(6')-Ie-aph(2")-Ia gene is generally flanked by inverted repeats of IS256, making up composite transposons, such as Tn5281 in E. faecalis. Fast dissemination of the genetic determinant led to consider the impact of its horizontal transferability among enterococcal species from different origin. Hence, human enterococcal isolates are not the only ones to be regarded as a reservoir of gentamicin resistance genes [28]. Among high-level gentamicin resistant enterococci, chromosomal aph(2")-Ib, aph(2")-IId and plasmidic aph(2")-Ic encode for gentamicin modifying enzymes as well [29].

Recently, our group studied antimicrobial resistance profiles in enterococci from minced meat, cow and goat cheese. In E. faecalis recovered from these products, high-level gentamicin resistance was detected [18].

In Argentina, genomic relationship between vancomycin-resistant E. faecium and E. faecalis isolates with high-level gentamicin resistance from human and food origin has not been studied so far.

The aim of this study was to investigate the relatedness between HLGR E. faecalis and vancomycin-resistant E. faecium strains isolated from humans, food and hospital environment in Tandil City, Argentina.

Methods

Samples

Enterococci were recovered from the following sources: human, hospital environment and food of animal origin. Isolates were collected during the period January-December 2013, in Tandil County, at the Southeast region of Buenos Aires Province, Argentina. All isolates were stored, by triplicate, in brain heart infusion (BHI) broth with 30% glycerol at -70°C.

Human source: Samples for microbiological diagnosis of invasive infections caused by enterococci were collected from ICU’s (Intensive Care Unit) patients at Hospital Ramon Santamarina de Tandil (HRS).

Samples: Blood, cerebrospinal, abdominal, pleural and synovial puncture fluids. They were inoculated into BacT/ALERT® culture bottles (BacT/ALERT® 3D Microbial Detection System, BioMérieux, Argentina). One significant isolate per patient, with an identifying number, was included in the study.

Hospital environment: Samples from surveillance cultures, in order to investigate the presence of vancomycin-resistant E. faecium in ICU-HRS. Study of ICU’s environmental contamination was performed investigating the surfaces close to patients (mattresses, bed rails and doorknobs) and medical instruments in contact with them. This procedure was carried out each time a vancomycin-resistant E. faecium was isolated from a patient. Samples were spread on bile esculin agar azide (BEEA) with 8 μg/mL of vancomycin and incubated for 48 h at 35°C. Each vancomycin-resistant E. faecium isolate from different places was labelled with a numerical identification code.

In all patients, admitted and discharged from the UCI, rectal swabs were done and processed as environmental samples.

Food: Artisanal meat and dairy products were purchased from 20 food retailers of Tandil County (ET1-ET20). In total, 146 samples (35 goat cheese, 32 cow cheese, 37 salami, 42 minced meat) were analyzed. Samples were sent (refrigerated at 4°C) to the Microbiology Laboratory and immediately processed.

Sampling and isolation techniques used have been previously described by Delpech et al. [26]. Additionally, enrichment in BHI broth with vancomycin (8 μg/mL) was performed for all samples. After incubation for 24 h at 35°C, 10 μL of each enrichment culture were spread on BEEA with vancomycin (8 μg/mL).

Susceptibility tests

MICs of all enterococcal isolates were determined by the agar dilution method, according to Clinical and Laboratory Standards Institute’s (CLSI) recommendations [34]. The following antimicrobials, used in human medicine, were tested: ampicillin, ciprofloxacin, linezolid, vancomycin, teicoplanin, gentamicin and streptomycin. Quality control strains: E. faecalis ATCC 29212 (susceptible to vancomycin and gentamicin), E. faecalis ATCC 51299 (resistant to...
gentamicin and vancomycin) and E. faecium ATCC 51559 (multidrug-resistant).

Phenotypic characterization was performed by Gram staining, catalase production, hydrolysis of pyrrolidonyl beta-naphthylamide, and growth in BHI broth with 6.5% NaCl. Species-level characterization was carried out by hydrolysis tests (arginine, pyruvate and methyl-a-d-glucopyranoside), tolerance to tellurite 0.04%, fermentation of carbohydrates (mannitol, arabinose, sorbitol, sucrose, raffinose, and sorbose), motility in thioglycolate broth, and agar pigment production [27].

Phenotypic confirmation was done using the Automated VITEK® 2 System (BioMérieux, Argentina).

Genomic DNA was extracted from phenotypically identified E. faecalis and E. faecium isolates by a previously described boiling method [35]. Molecular identification (polymerase chain reaction, PCR) was performed.

For genus confirmation, the protocol described by Ke et al. [36] was used. A *tuf* gene fragment (803 bp), encoding for a specific elongation factor of the genus *Enterococcus* was amplified (Table 1). One nanogram of genomic DNA was transferred directly to a 19 μL PCR mixture containing 50 mM KCl, 10 mM Tris-HCl (pH 9.0), 0.1% Triton X-100, 2.5 mM MgCl₂, 0.2 mM each Enterococcus-specific primer, 200 mM each deoxynucleoside triphosphate, 3.3 mg/mL of bovine serum albumin and 0.5 U of Taq polymerase. The PCR mixtures were subjected to thermal cycling: 3 min at 96°C, then, 40 cycles of 1 s at 95°C (denaturation) and 30 s at 55°C (annealing-extension step).

<table>
<thead>
<tr>
<th>Gene (type)</th>
<th>Nucleotide sequence (5′-3′)</th>
<th>Annealing Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>tuf</em> (Genus marker)</td>
<td>TACTGACAAACCATTCATGATG</td>
<td>55°C</td>
</tr>
<tr>
<td></td>
<td>AACTTCGTACCAACCCGAAC</td>
<td></td>
</tr>
<tr>
<td><em>ddl</em> for <em>E. faecalis</em> (Species identification)</td>
<td>ATCAAGTACAGTTAGTCT</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>ACGATTTGAAGCTAACTG</td>
<td></td>
</tr>
<tr>
<td><em>ddl</em> for <em>E. faecium</em> (Species identification)</td>
<td>TAGAGACATTGGATATGCC</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>TCGAATGTGCTACAATC</td>
<td></td>
</tr>
<tr>
<td><em>cylA</em> (Virulence factor)</td>
<td>ATGGATGGGACAGAATAGGAAA</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>AGCTGCGCTTGTAGTCTGGAG</td>
<td></td>
</tr>
<tr>
<td><em>esp</em> (Virulence factor)</td>
<td>GGAACGCGTCTTTGGATG</td>
<td>58°C</td>
</tr>
<tr>
<td></td>
<td>CCCTTTCGTTGATCC</td>
<td></td>
</tr>
<tr>
<td><em>vanA</em> (Glycopeptide resistance)</td>
<td>GTAGGCTGCGATATCCAAAGGC</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>CGATTCAATTCGATGTC</td>
<td></td>
</tr>
<tr>
<td><em>vanB</em> (Glycopeptide resistance)</td>
<td>GGTATCAAGGAACCCCT</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>CTTCGGCCTACATAGCT</td>
<td></td>
</tr>
<tr>
<td><em>aac(6′)-Ie-a</em> - <em>aph(2″)-Ia</em> (Aminoglycoside resistance)</td>
<td>CAGGAATTATTCGAAAAATGTAGAAAAG</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>CACAAATCGACTAAAGAGATCCAATC</td>
<td></td>
</tr>
<tr>
<td><em>aph</em> (2″)-Ib (Aminoglycoside resistance)</td>
<td>TATGGATCATGGTTACCTGGACGGCTGAG</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>ATTAAGCTTTCTGCTGTAATAAAATATAAACATCTGCT</td>
<td></td>
</tr>
<tr>
<td><em>aph</em> (2″)-Ic (Aminoglycoside resistance)</td>
<td>GGAAGTGATGGA AATCCCTTCGGTG</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>GCTCTAACCCTTACGAGATCCAGTCC</td>
<td></td>
</tr>
<tr>
<td><em>aph</em> (2″)-Id (Aminoglycoside resistance)</td>
<td>GGTG GTTTTACAGGAATGCCATC</td>
<td>54°C</td>
</tr>
<tr>
<td></td>
<td>CCCTCTTACACCATAATCCATAACC</td>
<td></td>
</tr>
</tbody>
</table>

| Table 1: Primers for identification of enterococci and antimicrobial resistance genes by PCR. |

For species identification, PCR with species-specific primers: *ddl* for *E. faecalis* (941 bp) and *ddl* for *E. faecium* (550 bp), for the chromosomally encoded D-alanine: D-alanine (D-Ala:D-Ala) ligases was carried out. A final volume of 100 μL containing 250 ng of DNA as template; 50 pmol of each oligodeoxynucleotide primer; 500 mM (each) dATP, dCTP, dGTP and dTTP; 67 mM Tris-HCl (pH 8.8); 7 mM MgCl₂; 17 mM ammonium sulfate; 10 mM b-mercaptoethanol; and 2 U of Taq DNA polymerase. The cycles used were 94°C for 2 min for the first
cycle; 94°C for 1 min, 54°C for 1 min, and 72°C for 1 min for the next 30 cycles; and 72°C for 10 min for the last cycle [37].

For detection of the cytolysin encoding gene cylA, PCR was performed in a 25 μL total volume containing 20 pmol of each primer (517 bp fragment), 200 mM of each dNTP, 1 U of Taq polymerase, 2.5 mM MgCl₂, 2.5 μL of 10X PCR buffer and 2 μL of template DNA. Reaction settings: 2 min at 94°C (initial denaturation) followed by 30 cycles of 30 s at 90°C (denaturation), 30 s at 54°C (annealing) and 1 min at 72°C (extension). A final extension cycle was performed at 72°C for 8 min [27].

Enterococcal strains were screened for the esp gene by PCR, according to the protocol of Coque et al. [38]. Primers were used for amplifying an 800 bp gene fragment, encoding for esp 5'-GGAACGCCTTGGTATG-3' and 5'-CCTGTGTGGTGTAGTTC-3'. The reaction mixture consisted of 25 μL PCR master mix, 5 μL primers (2μM), 15 μL sterile water and 5 μL of bacterial DNA. PCR was carried out with the following thermal cycling profile: initial activation step at 95°C for 15 min; 30 cycles of denaturation at 90°C for 30 seconds, annealing at 58°C for 1 min, and extension at 72°C for 1 min; final extension at 72°C for 10 min.

Resistance genes were detected by PCR using specific primers for the aminoglycoside-modifying enzymes aac(6’)-Ie-aph(2’)-Ia (369 bp), aph (2’)-Ib (867 bp), aph (2’)-Ic (444 bp) and aph (2’)-Id (641 bp) genes. Detection of high-level gentamicin resistance genes was done according to Sparo et al. [27]. PCR was performed in a final volume of 25 μL, with 20 pmol of each primer, 1-2 colonies of each bacterial isolate, 200 μM of each dNTP, 1 U of Taq polymerase, 1.5 μM MgCl₂, 2.5 μL PCR 10X buffer and 2 μL of template DNA. Setting: a first cycle, 2 min at 94°C; followed by 30 cycles of 30 s at 90°C, 30 s at 54°C and 1 min at 72°C. A final extension cycle for 8 min at 72°C was done.

PCR for detection of vanA and vanB genes fragments (732 bp and 625 bp, respectively), which encode for D-Ala:D-Ala ligases of altered substrate specificity, was carried out according to the same protocol of Dutka-Malen et al. [37] for detection of ddl genes.

PFGE typing

Bacterial isolates were grown overnight in BHI broth. Chromosomal DNA was prepared in agarose plugs, digested with the restriction enzyme SmaI. DNA fragments were separated in a CHEF-DRIII apparatus (Bio-Rad Laboratories, Richmond, CA, USA), following the protocol of Corso et al. [24]. SmaI was chosen upon the base composition (%G+C content) of the DNA of the microorganisms in study. In the case of low GC bacteria, as E. faecalis and E. faecium, SmaI (CCCGGG) is preferred, since it is advisable to use enzymes which recognize relatively few sites on the genome and give a resolvable and informative number of DNA fragments on the PFGE gel. Lambda ladder (New England Biolabs, Beverly, MA, USA) was used as molecular size standard. Similarity between isolates was determined by visual comparison of isolates DNA banding pattern. Interpretation of band patterns was carried out according to Tenover et al. [39].

Isolates were defined as distinct strain types, or unrelated, if their PFGE patterns differed by more than six bands. Types were named using a capital letter following the alphabet order (e.g. type A, B, C, D). Subtypes were defined as strains that differed by 2-6 bands, which were considered closely or possibly related, and were named using an Arabic number (e.g. subtype D1, D2) following the capital letter. Those isolates whose restriction patterns had the same number and size of bands were considered genetically indistinguishable and were assigned to the same strain type.

Results

Vancomycin-resistant E. faecium were isolated from samples from different sources: human, hospital environment and food of animal origin. Food enterococci were recovered from samples collected at five retailers (ET1, ET2, ET3, ET4, ET5).

Clinical vancomycin-resistant E. faecium were isolated from six (n=6) patients with invasive infections, five from hemoculture and one from abdominal puncture fluid (Figure 1). Also, vancomycin-resistant E. faecium, were recovered from n=3 rectal swabs from patients without enterococcal invasive diseases and n=1 in a mattress of a patient (HRSER460) near other one with a positive rectal culture.

Three vancomycin-resistant E. faecium were isolated from food: handmade "salame", cow cheese and sheep cheese from ET1, ET3 and ET5, respectively. In all vancomycin-resistant E. faecium (n=13), vanA gene was detected and MICs were as follow: vancomycin ≥ 256 μg/mL; teicoplanin ≥ 256 μg/mL; linezolid ≤ 2.0 μg/mL; streptomycin >2,000 μg/mL. Moreover, human and hospital environment vancomycin-resistant E. faecium were resistant to ampicillin (MIC ≥ 32 μg/mL), ciprofloxacin ≥ 8.0 μg/mL and showed high-level resistance to gentamicin (MIC > 500 μg/mL). In contrast, vancomycin-resistant E. faecium isolates from food were susceptible to ampicillin (MIC ≤ 2.0 μg/mL), ciprofloxacin (MIC 1.0-2.0 μg/mL) and without high-level gentamicin resistance (MIC < 500 μg/mL).

Vancomycin-resistant E. faecium could be differentiated in seven clonal types: VRE- A, VRE- B, VRE- C, VRE- D, VRE- E, VRE- F and VRE- G. Clone A, were detected from two blood culture isolates, from patients HRSER501 and HRSER503 with invasive infections and other patient (HRSER509) with rectal colonization; all of them hospitalized in ICU for the same period. Clone B included three
isolates, a positive hemoculture from patient HRSER461 and an environment contamination of a mattress following the discharge from ICU of patient HRSER459 and a rectal colonization of a patient (HRSER460) next to him; both without enterococcal invasive disease. Clone C was represented by 2 clinical isolates from hemoculture and an abdominal puncture fluid (patients HRSER456 and HRSER457), admitted in ICU at different time. Clone D was identified in two isolates of food, “salame” and sheep cheese, from different industrial plants (ET1 and ET4), not produced in the same period. Those isolates were identified as belonging to two subtypes (D1, D2) and considered as closely related. Clonal types E (hemoculture), F (cow cheese) and G (rectal swab) were represented by a single isolate each.

Only hospital vancomycin-resistant E. faecalis isolates carried esp gene, excluding clonal type VRE-G.

During 2013, from 10 patients were recovered E. faecalis producing invasive productions and 4/10 of them showed high-level gentamicin resistance. Regarding food of animal origin, E. faecalis was isolated from different samples: minced meat for hamburgers, 5; regional handmade “salame”, 2; sheep cheese, 4; cow cheese, 3. HLGR E. faecalis (3/14) were recovered from minced meat for hamburgers elaborated in ET4 (2/3) and “salame” (1/3), manufactured in ET1. Those isolates were recovered in different seasons: summer (January) and fall (April).

All E. faecalis isolates expressing high-level gentamicin resistance carried the aac(6′)-Ie-aph(2″)-Ia gene. None showed multiple antimicrobial resistance. Determined MICs were: gentamicin > 500 μg/mL; streptomycin ≤ 500 μg/mL; ampicillin ≤ 2.0 μg/mL; linezolid ≤ 2.0 μg/mL; ciprofloxacin ≤ 0.5 - ≥ 8.0 μg/mL; vancomycin ≤ 1.0 μg/mL and teicoplanin ≤ 0.5 μg/mL.

Most of the clinical HLGR E. faecalis carried cylA gene; were recovered from blood (n=2) and abdominal puncture fluid (n=1). In food enterococci, cylA was detected in minced meat isolates (n=2) from ET4.

**Figure 2: SmaI-PFGE patterns in high level gentamicin resistant Enterococcus faecalis isolates** (Lane 1: E. faecalis HRSRG16 (human); Lane 2: E. faecalis HRSRG215 (human); Lane 3: E. faecalis HRSRG291 (human); Lane 4: E. faecalis HRSRG304 (human); Lane 5: E. faecalis CEBRG72 (food); Lane 6: E. faecalis CEBRG82 (food); Lane 7: E. faecalis CEBRG87 (food); Lane 8: lambda ladder).

SmaI-PFGE (Figure 2) showed that seven HLGR E. faecalis isolates were differentiated in four clonal types: EFA-A, EFA-B, EFA-C and EFA-D. Clone A was represented by four isolates, two from UCI’s patients HRSRG215 and HRSRG304 in the same period, isolated from blood and abdominal puncture fluid, respectively, and two from food, in minced meat from the same industrial plant (ET4) and period. Clones B (hemoculture), C (hemoculture) and D (handmade “salame”) included one isolate each. Moreover, cylA gene was detected in pulsotypes EFA-A and EFA-B (Table 2).

**Discussion**

In the present study, vanA E. faecium was recovered from handmade “salame” and cheese. Previously, Barbosa et al. [40] did not detect vancomycin resistance in E. faecium isolated from traditional fermented meat products. Recently, Ribeiro et al. [41] found vanA E. faecium isolated from a traditional Portuguese dry fermented sausage. Therefore, the presence of vanA E. faecium is variable according to each analyzed geographic region.

Worldwide, VanA phenotype is linked to most of the human cases of vancomycin resistant enterococci, and is mainly carried by E. faecium. Spread of vancomycin-resistant E. faecium is a major global issue due to its persistence in hospital environment, limited therapeutic alternatives, and plasmidic vanA transfer [42].

Vancomycin-resistant E. faecium are the second most common cause of nosocomial infections in the US [43]. In Europe, vancomycin-resistant E. faecium prevalence is variable, ranging from less than 1% in France and Sweden to higher than 20% in Greece, Ireland, Portugal and the United Kingdom [44].

In Argentina, vancomycin-resistant E. faecium infections have been reported since 1998. In different hospitals predominance of one epidemic clone carrying vanA has been observed, with an increased incidence of vancomycin-resistant E. faecium clonal spread [24]. In 2014, according to the Antimicrobial Resistance Surveillance Network WHONET-Argentina (89 Microbiology Laboratories), clinical E. faecium showed a high rate (61%) of vancomycin resistance (www.antimicrobianos.com.ar).

In the current study, one pulso-type (VRE-B) was observed in two patients and in the mattress of another one, suggesting strain dissemination between patients and the environment. Kalocheretis et al. [45] detected vancomycin-resistant E. faecium transmission through a contaminated environment in different hospitals areas.

It should be noted that as a result of appearance of invasive infections at ICU-HMRS, surveillance of vancomycin-resistant E. faecium carriage in patients was started.

It is important to highlight that food vancomycin-resistant E. faecium isolates were susceptible to ampicillin and ciprofloxacin, but those of hospital origin were resistant to both antimicrobials. Ampicillin and, frequently, fluoroquinolone resistance are phenotypic markers for differentiating hospital and community vancomycin-resistant E. faecium [46].

In this research, only hospital E. faecium strains carried esp gene, also reported by Willems & Bontem [20]. According to Willems et al. [47], emergence of E. faecium ST-17 lineage in hospital settings started with adaptive changes, acquiring ampicillin resistance and a novel putative pathogenicity island, linked to esp gene. In CC17 strains, esp gene brings advantages in the adaptation to the hospital environment. Furthermore, the strong linkage between ampicillin and ciprofloxacin resistant E. faecium and CC17 has been widely accepted [48].
Table 2: Source and Smal-PFGE of enterococcal isolates.

<table>
<thead>
<tr>
<th>Isolate</th>
<th>Source</th>
<th>Sample</th>
<th>cylA/esp†</th>
<th>HLGR/VR*</th>
<th>Smal-PFGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. faecium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VREf-HRSER456</td>
<td>Clinical, ICU††</td>
<td>Abdominal puncture fluid ‡</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-C</td>
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<tr>
<td>VREf-HRSER457</td>
<td>Clinical, ICU, ID</td>
<td>Hemoculture</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-C</td>
</tr>
<tr>
<td>VREf-HRSER458</td>
<td>Clinical, ICU, ID</td>
<td>Hemoculture</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-A</td>
</tr>
<tr>
<td>VREf-HRSER459</td>
<td>ICU, Environment</td>
<td>Mattress</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-B</td>
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<tr>
<td>VREf-HRSER460</td>
<td>Clinical, ICU, RC§</td>
<td>Rectal swab</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-B</td>
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<tr>
<td>VREf-HRSER461</td>
<td>Clinical, ICU, ID</td>
<td>Hemoculture</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-B</td>
</tr>
<tr>
<td>VREf-HRSER462</td>
<td>Clinical, ICU, ID</td>
<td>Rectal swab</td>
<td>+/-</td>
<td>+/-</td>
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</tr>
<tr>
<td>VREf-HRSER501</td>
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<td>VREf-HRSER503</td>
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</tr>
<tr>
<td>VREf-HRSER509</td>
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<tr>
<td>VREf-CEBER95</td>
<td>Food, ET1§§</td>
<td>“salame”</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-D1</td>
</tr>
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<td>VREf-CEBER180</td>
<td>Food, ET3</td>
<td>Sheep cheese</td>
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<td>+/-</td>
<td>VREf-D2</td>
</tr>
<tr>
<td>VREf-CEBER161</td>
<td>Food, ET5</td>
<td>Cow cheese</td>
<td>+/-</td>
<td>+/-</td>
<td>VREf-F</td>
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</table>

E. faecalis

<table>
<thead>
<tr>
<th>Isolate</th>
<th>Source</th>
<th>Sample</th>
<th>cylA/esp†</th>
<th>HLGR/VR*</th>
<th>Smal-PFGE</th>
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<tbody>
<tr>
<td>EFA-HRSRG16</td>
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<td>EFA-HRSRG215</td>
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<tr>
<td>EFA-HRSRG304</td>
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<td>Abdominal puncture fluid</td>
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<td>+/-</td>
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<tr>
<td>EFA-CEBR72</td>
<td>Food, ET1</td>
<td>“salame”</td>
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<td>+/-</td>
<td>EFA-D</td>
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<tr>
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<td>Food, ET4</td>
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<td>EFA-A</td>
</tr>
<tr>
<td>EFA-CEBR87</td>
<td>Food, ET4</td>
<td>Minced meat</td>
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<td>+/-</td>
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</tr>
</tbody>
</table>

†: cylA gene, esp gene; ‡: HLGR: aac(6')-Ie- aph(2'')-Ia gene; VR: vanA gene; ††: VREf: vancomycin-resistant E. faecium; †§: ICU (Intensive Care Unit); †††: ID: Invasive disease; **: isolation date (mm/dd/yy); §§: ET: industrial plant; ††: EFA: high-level gentamicin resistant E. faecalis.

In this study, clonal complexes of vanA E. faecium were not investigated. Nevertheless, the presence of esp gene, ampicillin and ciprofloxacin resistance could suggest that clinical enterococcal isolates might belong to clonal complex 17, since its spread in Argentina has been reported (http://antimicrobianos.com.ar/2010/?cat=9).

The vanA gene is contained in Tn1546 or its derivatives, usually located on transferable plasmids. Plasmids are readily found in enterococci, and are common that clinical and commensal strains harbor a number of such elements. They comprise an important fraction of the auxiliary genome, and are responsible for much of the horizontal gene transfer that has allowed antibiotic and virulence traits to converge in hospital adapted lineages. Remarkably, different plasmid types occur in E. faecium and E. faecalis, despite their close phylogenetic relationship. The high content of plasmid and mobile genetic elements in E. faecium human lineages seems to be relevant to the emergence and persistence of their antibiotic resistance.

It is important to note that multiple drug resistance was not observed in food enterococci. Besides, it was not detected a clonal relationship between hospital-origin and food vancomycin-resistant E. faecium. Hammerum [17] considered that E. faecium isolates of animal origin are not themselves a hazard to humans, but they could act as donors of antimicrobial resistance genes to other pathogenic bacteria. The same variants of the vanA gene cluster, encoding for vancomycin resistance, have been observed in human and animal origin enterococci [49].

During 2013, in this study, in 10 patients with invasive infections, HLGR E. faecalis (40%) were detected. In Argentina, in 2014, according to WHONET Argentina, clinical HLGR E. faecalis (21.3%)
In summary, in Argentina, there has not been so far evidence regarding the clonal relationship between food and human enterococcal strains. This is the first study that showed clonal relationship between \( E. \text{faecalis} \) with high-level gentamicin resistance isolated from food and humans. \( \text{vanA} \) \( E. \text{faecium} \) strains from hospital origin belong to different clonal types than \( E. \text{faecium} \) from animal food; although, it is important to emphasize that the number of isolates tested is small. Food \( \text{vanA} \) \( E. \text{faecium} \) were not identified as a direct cause of resistant enterococci in humans, but they could pose a risk for the intra or inter genus transfer of \( \text{vanA} \) resistance determinant to human-adapted strains. 

Finally, this study demonstrated the spread of strains of \( \text{vanA} \) \( E. \text{faecium} \) and HLGR \( E. \text{faecalis} \) of different origin in the ecosystem, with potential for horizontal transfer resistance to other bacteria.

**Author's Contributions**

GP, MMDL and JB provided the samples for the study. GP, SL and CS were in charge of phenotypic characterization of isolates. AC and PG carried out molecular characterization. GD, SL and CS studied antimicrobial resistance. GD, JAB and MS analyzed results coordinated the different stages of the study. GP and JAB were responsible for an internal review of the study. GP, GD and MS were in charge of the writing of the manuscript.

**Compliance with Ethical Standards**

**Ethical approval**

Samples from human participants were obtained under Medical prescription. International and local legislation was followed. This article does not contain any studies with animals performed by any of the authors.

**References**


