Clinical Microbiology and Infection 25 (2019) 203–209

Contents lists available at ScienceDirect

Clinical Microbiology and Infection

journal homepage: www.clinicalmicrobiologyandinfection.com

Original article

Colonization and infection due to carbapenemase-producing *Enterobacteriaceae* in liver and lung transplant recipients and donor-derived transmission: a prospective cohort study conducted in Italy

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ARTICLE INFO

Article history:
Received 31 January 2018
Received in revised form
5 March 2018
Accepted 1 May 2018
Available online 22 May 2018

Editor: A. Kalil

Keywords:
Colonization
CPE
Donor–recipient transmission
Infection
Solid organ transplant

ABSTRACT

Objectives: A prospective cohort study was conducted in Italy in order to describe the microbiologic aspects of colonization/infection by carbapenemase-producing *Enterobacteriaceae* (CPE) in donors and recipients of lung and liver transplants and the possible CPE transmission from donors to recipients.
Methods: Between 15 January 2014 and 14 January 2015, all recipients of solid organ transplants (SOT) at ten lung and eight liver transplantation centres and the corresponding donors were enrolled. Screening cultures to detect CPE were performed in donors, and screening and clinical cultures in recipients with a 28-day microbiologic follow-up after receipt of SOT. Detection of carbapenemase genes by PCR, genotyping by multilocus sequence typing, and pulsed-field gel electrophoresis and whole-genome sequencing were performed.
Results: Of 588 screened donors, 3.4% were colonized with CPE. Of the liver first transplant recipients ($n = 521$), 2.5% were colonized before receipt of SOT and 5% acquired CPE during follow-up. CPE colonization was higher in lung first transplant recipients ($n = 111$, 2.7% before SOT and 14.4% after SOT). CPE infections occurred in 1.9% and 5.3% of liver or lung recipients, respectively. CPE isolates were mostly *Klebsiella pneumoniae* carbapenemase (KPC)-producing *K. pneumoniae* belonging to CG258. Three events of donor–recipient CPE transmission, confirmed by whole-genome sequencing and/or pulsed-field gel electrophoresis, occurred in lung recipients: two involving *K. pneumoniae* sequence type 512 and one Verona integron-encoded metallo-β-lactamase (VIM)-producing *Enterobacter aerogenes*.
Conclusions: This study showed a low risk of donor–recipient CPE transmission, indicating that donor CPE colonization does not necessarily represent a contraindication for donation unless colonization regards the organ to be transplanted. Donor and recipient screening remains essential to prevent CPE transmission and cross-infection in transplantation centres. **G. Errico, Clin Microbiol Infect 2019;25:203**

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https://doi.org/10.1016/j.cmi.2018.05.003
1198-743X/

Introduction

Carbapenem-resistant *Enterobacteriaceae* (CRE) have become endemic in several areas of the globe and represent a public health threat due to their multidrug-resistant phenotype [1,2]. CRE infections are problematic to treat because available therapeutic options are extremely limited; therefore, associated mortality is high, ranging from 24% to 70%, depending on the study population [3,4], the type of infection and the characteristics of the microorganism [5].

Although different mechanisms can confer resistance to carbapenems in *Enterobacteriaceae,* such as reduction of outer membrane permeability or overexpression of β-lactamases, the most common is production of carbapenemases, enzymes capable of hydrolyzing carbapenem antibiotics [6]. Carbapenemase-producing *Enterobacteriaceae* (CPE) can contain different types of carbapenemases, according to the species of the microorganism or the geographical area. CPE are present in many European countries, although with different prevalence, and they are often extensively or pan-drug resistant, according to the EuSCAPE study [7]. CPE are prone to colonize patients, especially their intestinal tract, and colonization leads to infection in a significant proportion of patients [3].

In Italy, a dramatic increase of carbapenem-resistant *K. pneumoniae* occurred starting from 2010, when resistance rate jumped from 1% to 15% in bacteraemia, reaching 33% in 2014–2015 [8]. The spread of carbapenem-resistant *K. pneumoniae* in Italy is largely due to clonal expansion of strains producing the *Klebsiella pneumoniae* carbapenemase (KPC)-type carbapenemase belonging to clonal group (CG) 258 [9,10].

In the first month after receipt of solid organ transplant (SOT), recipients are particularly susceptible to infections, especially to infections due to multidrug-resistant organisms (MDRO), because of immunosuppressive therapies, broad-spectrum antimicrobials and prolonged hospital stay [11]. MDRO can be acquired before or after receipt of SOT or, in rare cases, can be transmitted to recipients from colonized or infected donors [12,13]. Results of a national study on the incidence of infections due to carbapenem-resistant Gram-negative bacteria among Italian recipients of SOT showed that a large proportion (15.7%) of infections was due to CRE and in particular to *Klebsiella* spp. In this study, the mortality rate was ten times higher for CRE-infected recipients than for those noninfected and also depended on the type of graft and length of hospital stay [12].

The present study, which is part of a wider research project on MDRO infections and colonization in SOTs, funded by the Italian Ministry of Health and coordinated by the Italian Authority for Organ transplant (Centro Nazionale Trapianti) [14], aimed to describe the prevalence and the microbiologic aspects of colonization and infections due to CPE and to assess the transmission of CPE from donors to recipients.

Materials and methods

Setting and participants

All the lung transplantation units operating in Italy ($n = 10$) and the eight liver transplant units that were located in the same transplantation centres (TCs) (performing approximately 50% of the liver transplantations carried out in Italy annually) participated in the study. All lung and liver recipients who underwent transplantation in the participating TCs between 15 January 2014 and 14 January 2015 and the corresponding donors were enrolled.

Ethics statement

The study was approved by the ethics committee of the Istituto Superiore di Sanità (version protocol 2, 26 September 2013) and by the local ethics committee of each TC. At the time of enrollment, patients were required to sign an informed consent that included the acceptance of the transplantation procedures, and of the collection and management of data for epidemiologic and scientific purposes. Patient data were anonymized.

Study design

This was a cohort study with 28 days' microbiologic follow-up after receipt of SOT; data were prospectively collected from donors and recipients and entered in an *ad hoc* web-based system.

Screening cultures of the utilized donors and screening or clinical cultures of the recipients were performed in order to identify isolates of *Enterobacteriaceae* that had reduced susceptibility or were resistant to carbapenems (isolates exhibiting meropenem MIC $\geq$0.5 mg/L) that, for the purpose of this study, were defined as CRE. Screening of donors included cultures of blood, urine, bronchoalveolar lavage (BAL) and rectal swab obtained before organ recovery and culture of the organ-preservation solution (OPS). Organ recipients were screened at day 0 before receipt of SOT and at days 7, 14, 21 and 28 after receipt of SOT with rectal swab, cultures of urine and, only for lung recipients, of BAL.

Identification of CPE and characterization of resistance mechanism

CRE isolation, identification and *in vitro* susceptibility tests were performed by the microbiology laboratories of the TCs according to a shared protocol. CRE isolates were sent to the coordinating laboratory at Istituto Superiore di Sanità and to three other reference laboratories, where further phenotypic and molecular characterization were carried out.

Carbapenemase production was detected using the modified Hodge test and the synergy test (disc diffusion method) [15]. The identification of the genes responsible for carbapenemase production (bla_{KPC}, bla_{VIM}, bla_{IMP}, bla_{NDM} and bla_{OXA-48}) and their variants was carried out by PCR and sequencing [16]. If a carbapenemase gene was detected, the CRE isolate was defined as confirmed CPE. A CRE isolate that was not available for molecular confirmation but was obtained from a recipient who was colonized or infected with a confirmed CPE at any time during the study was defined as probable CPE.

Clonal relatedness

KPC-producing *K. pneumoniae* (KPC–*K. pneumoniae*) isolates were submitted to genotyping. One isolate for each patient (from rectal swab whenever available) was analysed by multilocus sequence typing (MLST) [17]. Sequence types (STs) were assigned at the Institute Pasteur MLST website (http://bigsdb.pasteur.fr/klebsiella/klebsiella.html).

In case of suspected donor–recipient transmission events, additional isolates from different samples or infection sites were submitted to MLST [17] and to pulsed-field gel electrophoresis (PFGE) [18].

Whole-genome sequencing

Whole-genome sequencing (WGS) was conducted on KPC–*K. pneumoniae* obtained from probable donor–recipients transmission events. Genomic DNA was sequenced using the 454 GS Junior (Roche Life Science, Indianapolis, IN, USA) system. Sequencing was performed using the Roche 454 Titanium Kit, and raw reads were *de novo* assembled using Newbler 3.0 software. A core genome single-nucleotide polymorphism phylogeny was generated by Parsnp software [19] using the complete genome of

strain NJST258_1 (accession no. NZ_CP006923.1) as reference and the draft genomes of 48 KPC–*K. pneumoniae* strains belonging to ST258 and ST512 isolated in Italy [20,21]. The phylogenetic tree was edited and visualized by FigTree 1.4.3 software (http://tree.bio.ed.ac.uk/software/figtree/). Assembled genomes were screened for antimicrobial resistance, virulence and capsular genes against bacterial genome sequence database (BIGSdb; (http://bigsdb.web.pasteur.fr). Plasmid incompatibility (Inc) types were assessed using PlasmidFinder (https://cge.cbs.dtu.dk/services/PlasmidFinder/).

Results

Between 15 January 2014 and 14 January 2015, a total of 571 liver transplant recipients (523 first transplant and 48 repeat transplant recipients) and 119 lung transplant recipients (113 first transplant and 6 repeat transplant recipients) were enrolled. The corresponding liver and/or lung donors numbered 606.

Isolation of CPE from donors

Screening cultures were performed in 588 (97.0%) of 606 donors, and screening of OPS was performed in 541 donors. CPE were obtained from 20 donors (16 liver, two lung, and two liver and lung donors), representing the 3.4% of the screened donors; all isolates were KPC–*K. pneumoniae* with only one exception (*Enterobacter aerogenes* producing VIM) (Table 1). CPE were obtained mostly from rectal swabs and in two donors also from blood and/or OPS.

Isolation of CPE from liver transplant recipients

Overall, 521 (99.6%) of 523 first liver transplant recipients and all 48 repeat liver transplant recipients had at least one screening culture performed. The percentage of screened recipients was higher than 90% at any time point of follow-up, with only two exceptions when it was >85% (Supplementary Table S1A). Thirteen (2.5%) first transplant and three (6.2%) repeat transplant recipients had at least one culture positive for CPE at day 0 before receipt of SOT. During microbiologic follow-up, 26 (5.0%) additional first transplant and 2 (4.1%) repeat transplant recipients became screening positive for CPE. Overall, 41 (93.1%) of 44 recipients who screened positive for CPE harboured KPC–*K. pneumoniae* (Table 2).

During the 28-day follow-up, infections due to CPE were observed in ten (1.9%) first transplant and in five (10.4%) repeat transplant recipients, all caused by KPC–*K. pneumoniae* (Table 2). Overall, 12 (29.2%) of 41 of the liver transplant recipients who were colonized with confirmed or probable KPC–*K. pneumoniae* developed an infection due to this microorganism (data not shown).

Colonization or infection cases occurred in all eight liver transplantation units participating in the study, without any apparent place or time clustering.

Table 1
Characteristics of liver and/or lung donors and CPE isolates

Characteristic	Value	CPE species and type of carbapenemase (*n*)
No. of donors	606	
Retrieved organ		
Liver	495 (81.7%)	
Lungs	20 (3.3%)	
Liver and lungs	91 (15.0%)	
Age (years), median (range)	58 (0–90)	
Male gender	308 (50.8%)	
Donors with screening tests (cultures of blood, BAL, urine, rectal swab and OPS)		
With at least one source cultured	588 (97.0%)	
With OPS cultured[a]	541 (89.3%)	
With confirmed CPE[b]	20 (3.4%)	KPC–*Klebsiella pneumoniae* (19); VIM–*Enterobacter aerogenes* (1)

BAL, bronchoalveolar lavage; CP, carbapenemase-producing; CPE, carbapenemase-producing *Enterobacteriaceae;* CRE, carbapenem-resistant *Enterobacteriaceae;* KPC, *Klebsiella pneumoniae* carbapenemase; OPS, organ-preservation solution; VIM, Verona integron-encoded metallo-β-lactamase.

[a] Two cultures positive for KPC–*K. pneumoniae* and non-CP *E. aerogenes,* respectively.

[b] Six additional patients were colonized with CRE: two non-CPE (one each *K. pneumoniae* and *E. aerogenes*) and four not tested.

Isolation of CPE from lung transplant recipients

Of 113 first lung transplant recipients, 111 (98.2%) had at least one screening culture performed. The percentage of screened recipients was higher than 95% at any time point of follow-up (Supplementary Table S1B). Three recipients (2.7%) were found to be CPE positive at day 0 before receipt of SOT, and 16 additional recipients (14.4%) became positive during follow-up. All isolates were available for characterization (Table 3); 17 of 19 screening isolates were KPC–*K. pneumoniae.* CPE infections occurred in six recipients, all caused by KPC–*K. pneumoniae.* Of the lung recipients colonized with KPC–*K. pneumoniae,* five (29.4%) of 17 developed a KPC–*K. pneumoniae* infection. No screening or clinical cultures positive for CPE were obtained from the six lung repeat transplant recipients. CPE colonization or infection cases occurred in six of the ten lung transplantation units enrolled onto the study.

Characterization of CPE

Overall, 93% of the available CRE ($n = 95$) obtained from donors and recipients were CPE and 85% ($n = 81$) were KPC–*K. pneumoniae.* The rest of the CPE isolates belonged to different species or carried a different carbapenemase gene (Tables 1–3). The results of the genotypic characterization performed for KPC–*K. pneumoniae* isolates are shown in Supplementary Table S2. The majority of the isolates both from donors and recipients belonged to CG258, in particular to ST258 and to ST512, a single-locus variant of ST258. The remaining 13 isolates belonged to seven other STs, the most common being ST101.

Donor–recipient CPE transmission

Three events of probable CPE donor–recipient transmission were observed, all occurring in lung transplant recipients in three different TCs. Transmission occurred from three out of four lung donors positive for CPE. Two cases involved transmission of KPC–*K. pneumoniae* belonging to ST512. In both cases the recipients were negative at time 0 but colonization or infection developed after receipt of SOT. In the first event, KPC–*K. pneumoniae* was obtained from the donor's rectal swab, BAL and blood, as well as from the OPS and subsequently from the recipient screening cultures (rectal swab and BAL) collected after receipt of SOT (Table 4). In the second event, KPC–*K. pneumoniae* was isolated from the donor's rectal swab and bronchial secretion as well as from clinical cultures (BAL and surgical-site swab) of the recipient, who developed pneumonia and surgical-site infection after receipt of SOT (Table 4). PFGE analysis showed that the donor's and the recipient's isolates exhibited identical and distinctive restriction pattern for each transmission episode (pulsotype A1 and A2, respectively) (Table 4, Supplementary Fig. S1).

Three isolates for each of the two events were submitted to WGS (Table 4). A phylogenetic tree constructed on the basis of the core genome single-nucleotide polymorphism analysis of 55 genomes of

Table 2
Characteristics, risk factors and outcomes of liver transplant recipients and CPE isolates

Characteristic	First transplant		Repeat transplant	
	Value	CPE species and type of carbapenemase (*n*)	Value	CPE species and type of carbapenemase (*n*)
No. of recipients	523		48	
Age (years), median (range)	54 (0–72)		48 (0–69)	
Male gender	385 (73.6%)		27 (56.2%)	
Mean MELD score	18.1		24	
Recipients with screening tests (cultures of rectal swab and urine)				
With at least one source cultured	521 (99.6%)		48 (100.0%)	
With confirmed or probable CPE before receipt of SOT[a]	13 (2.5%)	KPC-*Klebsiella pneumoniae* (12); VIM–*Klebsiella oxytoca* (1)	3 (6.2%)	KPC–*K. pneumoniae* (2); KPC-*K. oxytoca* (1)
With confirmed CPE after receipt of SOT (negative before receipt of SOT)[b]	26 (5.0%)	KPC–*K. pneumoniae* (25); VIM–*K. pneumoniae* (1)	2 (4.1%)	KPC–*K. pneumoniae* (2)
Recipients with infection caused by confirmed or probable CPE[c]	10 (1.9%)	KPC–*K. pneumoniae* (10)	5 (10.4%)	KPC–*K. pneumoniae* (5)
Type of infection				
Bacteraemia	4		4	
Pneumonia	5		2	
Abdominal infection[d]	5		2	
Urinary tract infection	3		1	
Intravascular catheter insertion site infection	3		0	
CPE transmission from donor to recipient	0 (0%)		0 (0%)	
Death at day 28 (all causes)	12 (2.3%)		7 (14.6%)	

CP, carbapenemase-producing; CPE, carbapenemase-producing *Enterobacteriaceae*; CRE, carbapenem-resistant *Enterobacteriaceae;* KPC, *Klebsiella pneumoniae* carbapenemase; MELD, Model for End Stage Liver Disease; SOT, solid organ transplant; VIM, Verona integron-encoded metallo-β-lactamase.
[a] For first transplant, two additional patients were colonized with CRE (one non-CP *K. pneumoniae,* one not tested). For repeat transplant, two additional patients were colonized with CRE (one non-CP *K. pneumoniae,* one not tested).
[b] For first transplant, five additional patients colonized with CRE (one non-CP *K. pneumoniae* and one non-CP *Enterobacter aerogenes;* three not tested). For repeat transplant, one additional patient colonized with CRE (non-CP *K. pneumoniae*).
[c] For first transplant, three additional patients with CRE infection without further testing.
[d] Includes peritonitis, surgical-site and biliary tract infections.

Table 3
Characteristics, risk factors and outcomes of lung transplant recipients and CPE isolates

Characteristic	First transplant		Repeat transplant
	Value	CPE species and type of carbapenemase (*n*)	Value
No. of recipients	113		6
Age (years), median (range)	48 (7–67)		33.5 (21–63)
Male gender	64 (56.6%)		2 (33.3%)
Recipients with screening tests (cultures of BAL, urine and rectal swab)			
With at least one source cultured	111 (98.2%)		6 (100.0%)
With confirmed CPE before receipt of SOT[a]	3 (2.7%)	KPC-*Klebsiella pneumoniae* (2); VIM–*Enterobacter aerogenes* (1)	0 (0%)
With confirmed CPE after receipt of SOT (negative before receipt of SOT)	16 (14.4%)	KPC–*K. pneumoniae* (15); VIM–*Enterobacter cloacae* (1)	0 (0%)
Recipients with infection caused by confirmed CPE	6 (5.3%)	KPC–*K. pneumoniae* (6)	0 (0%)
Type of infection			
Pneumonia	3		0
Bacteraemia	3		0
Surgical-site infection	2		0
Urinary tract infection	1		0
CPE transmission from donor to recipient	3 (2.7%)		0 (0%)
Death at day 28 (all causes)	12 (10.6%)		1 (16.7%)

CP, carbapenemase-producing; CPE, carbapenemase-producing *Enterobacteriaceae;* CRE, carbapenem-resistant *Enterobacteriaceae;* KPC, *Klebsiella pneumoniae* carbapenemase; SOT, solid organ transplant.
BAL, bronchoalveolar lavage; VIM, Verona integron-encoded metallo-β-lactamase.
[a] For first transplant, one additional patient was colonized with CRE (non-CP *Enterobacter cloacae*).

KPC–*K. pneumoniae* showed that the isolates from each event clustered into different monophyletic groups on the tree (Fig. 1), thus confirming the donor–recipient transmission. Features of the genomes of the isolates related to the two transmission events are shown in Supplementary Table S3.

In the third event, the donor was colonized with *E. aerogenes* carrying VIM, and the recipient had a bronchial secretion culture yielding the same microorganism after receipt of SOT. No other samples were available for this patient. Because an uncommon CPE was involved, the transmission hypothesis appeared probable and was confirmed by PFGE (pulsotype B in Table 4 and Supplementary Fig. S1).

The recipients involved in the first two events (KPC–*K. pneumoniae* transmission) were alive at day 28 of follow-up; the recipient involved in the third event died at day 9 of early transplant failure.

Table 4
Genotyping characteristics of isolates obtained from three events of CPE donor–recipient transmission

Characteristic	Isolate source (code)[a]	Duration of follow-up (days)	Species	Type of carbapenemase	MLST	PFGE
Event 1						
Donor 1	Rectal swab (CNTD86)		*Klebsiella pneumoniae*	KPC-3	ST512	Pulsotype A1
	Blood (CNTD87)[a]					
	BAL (CNTD88)[a]					
	OPS (CNTD92)					
Recipient 1	Rectal swab (CNTD93)	7	*K. pneumoniae*	KPC-3	ST512	Pulsotype A1
	BAL (CNTD94)[a]	7				
	BAL (CNTD100)	28				
Event 2						
Donor 2	Rectal swab (CNTD53)		*K. pneumoniae*	KPC-3	ST512	Pulsotype A2
	Bronchial secretion (CNTD42)[a]					
Recipient 2	BAL (CNTD43)[a]	7	*K. pneumoniae*	KPC-3	ST512	Pulsotype A2
	Surgical-site swab (CNTD46)[a]	14				
	Surgical-site swab (CNTD51)	21				
Event 3						
Donor 3	Rectal swab (CNTD116)		*Enterobacter aerogenes*	VIM	NA	Pulsotype B
Recipient 3	Bronchial secretion (CNTD172)	0	*E. aerogenes*	VIM	NA	Pulsotype B

CPE, carbapenemase-producing *Enterobacteriaceae*; KPC, *Klebsiella pneumoniae* carbapenemase; MLST, multilocus sequence typing; NA, not applicable; OPS, organ-preservation solution; PFGE, pulsed-field gel electrophoresis; ST, sequence type; VIM, Verona integron-encoded metallo-β-lactamase.
[a] Isolates submitted to whole-genome sequencing.

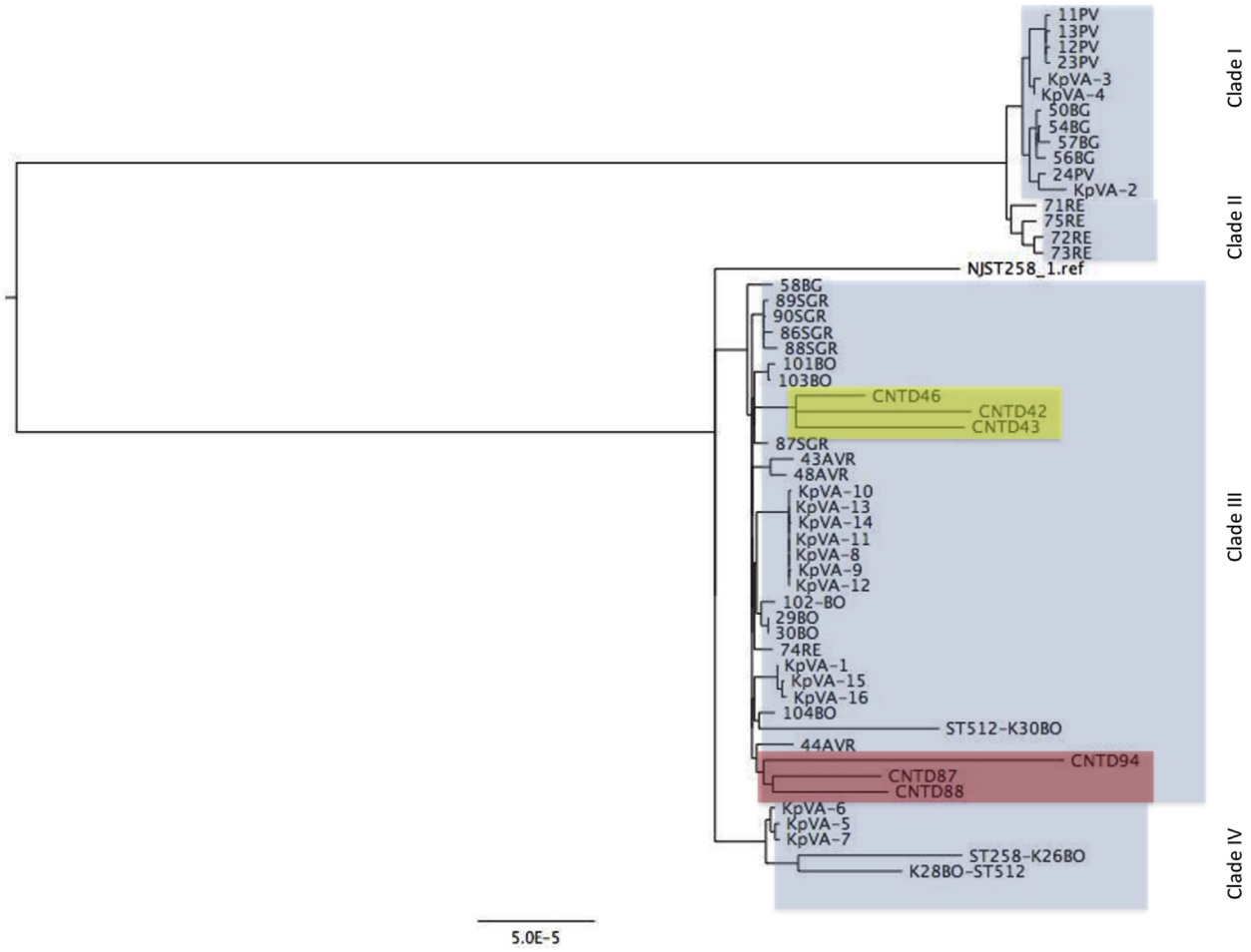

Fig. 1. Maximum likelihood phylogenetic tree based on single- nucleotide polymorphism in the core genomes of ST258 and ST512 KPC- *K. pneumoniae* strains isolated in Italy. Strains associated with the first donor-recipient transmission event are highlighted in red, while strains associated with the second event are highlighted in yellow. The four different clades within Italian isolates are indicated.

Discussion

Although recipients of SOT are particularly at risk for infections and CPE are endemic in Italy, few studies have investigated the presence of CPE and CPE transmission from donors to recipients in our country. This cohort study showed that a noticeable percentage of patients undergoing transplantation (2.5% and 2.7% for liver and lung first transplant recipients, respectively) were already

colonized with CPE before receipt of SOT. Patients undergoing repeat liver transplantation had a higher rate of colonization (6.2%), probably as a result of the longer hospital stay as well as the complex treatments and procedures received. These figures reflect the high frequency of asymptomatic rectal carriage among hospital patients. A recent study carried out in a tertiary-care hospital in North Italy showed that 3.9% of all inpatients were colonized with CPE [22].

A higher percentage of patients became colonized with CPE after transplantation during the hospital stay, specifically an additional 5% and 14.4% of patients who received liver or lung transplants, respectively. This can be ascribed to the inherent susceptibility to colonization and infection of SOT recipients in the early period after transplantation [11], but it also highlights the circulation of CPE and the risk for cross-contamination in TCs.

Infections due to CPE were diagnosed in 1.9% and 5.3% of liver or lung recipients, respectively, and in 10.4% of repeat liver transplant recipients. Most patients who developed CPE infections had been previously shown to be CPE carriers. Another study in Italian recipients of SOT revealed that 16% of the recipients had an episode of infection due to a Gram-negative microorganism, a large proportion being carbapenem-resistant *Klebsiella* spp. [12].

As shown in previous reports, donor–recipient transmission of CRE can occur and can involve multiple recipients, with variable outcomes [23–26]. In our study, transmission of CPE from donors to recipients was demonstrated only in three lung recipients, representing 2.7% of all lung recipients enrolled onto this study. In two of these events, KPC–*K. pneumoniae* belonging to ST512 was involved. Because this is the most common KPC–*K. pneumoniae* clone recovered in Italy according to this and other studies [10], the demonstration of transmission required the application of a finer typing method, such as WGS, to allow the unequivocal assignment of the isolates involved in each event into a single cluster. The third event was due to transmission of VIM–*E. aerogenes*, a strain isolated only in this occurrence throughout our study.

Other cases of CPE transmission from donor to lung or liver recipients were documented in Italy. Transmission of carbapenem-resistant *K. pneumoniae* from the same donor to one lung and two liver transplant recipients who developed infection or colonization was reported [25]. Giani et al. [26] described a likely transmission of OXA-48–producing *K. pneumoniae* from a single donor to two recipients of kidney and liver, respectively. The OXA-48–*K. pneumoniae* was isolated from the kidney preservation fluid.

Our study confirms that in the setting of SOT, the large majority of CPE colonizing or infecting patients are represented by KPC–*K. pneumoniae* belonging to CG258. However, other non-CG258 STs were detected in our study, confirming a polyclonal evolution of KPC–*K. pneumoniae* in Italy [10,27].

Our results showed a low risk of CPE transmission from donor to recipient in liver transplantation because no case of transmission was observed in our study. Conversely, all three events of CPE transmission occurred in lung transplantation; in two of these cases, donor colonization was present at the level of the transplant organ (BAL or bronchial secretion), while in the third event BAL colonization was not reported.

In accordance with updated Italian recommendations, these data suggest that CPE colonization is not necessarily to be considered a contraindication for organ donation [23,24] unless colonization regards the organ to be transplanted (http://www.trapiantipiemonte.it/pdf/Linee/ProtocolloIdoneitaDonatore2017.pdf; http://www.trapiantipiemonte.it/pdf/Linee/AllegatiProtIdoneitaDonatore2017.pdf).

The microbiologic screening of donors and recipients for the presence of CPE remains essential to prevent transmission via the transplant organ, the emergence of infections in recipients and cross-infection in TCs.

Acknowledgements

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Transparency declaration

This study was endorsed by the Italian National Transplant Center (CNT) and was supported by a grant from the Italian Ministry of Health (CCM 2012) 'Prevenzione della diffusione di infezioni sostenute da microrganismi multiresistenti (MDR) in ambito trapiantologico e analisi del rischio.' All authors report no conflicts of interest relevant to this article.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.cmi.2018.05.003.

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