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- **Treatment of Suspected or Confirmed Infection with Enterobacterales or Acinetobacter spp. Resistant to Carbapenems**
  - **Surgical Prophylaxis in the Context of Colonisation with such organisms.**
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APRIL 2019

## Scope

This document is intended to support those who must manage or give advice on antimicrobial management of people with suspected or confirmed infection with carbapenem-resistant Enterobacterales and *Acinetobacter spp.* This document does not apply to *Pseudomonas spp.*, *Burkholderia spp.* or *Stenotrophomonas spp.* It addresses both empiric therapy for suspected CPE infection and targeted therapy after a pathogen has been identified.

Antimicrobial therapy is only one element of the care of people with suspected or confirmed infection. Guidance on screening for sepsis and the management of sepsis and septic shock are available at <https://www.hse.ie/eng/about/who/cspd/ncps/sepsis/>

The guidance is based on best available evidence as of December 2018. Given the rapidity with which new evidence and therapies are emerging, the approach to treatment is likely to evolve over time. This document is therefore intended to guide Consultant Microbiologists and Infectious Disease Physicians who have the expertise to integrate emerging evidence into their decision making. The document will need to be reviewed regularly.

Those managing CPE infection are encouraged to retain a record of experience with the use of this guideline and where possible to share anonymised information with the Antimicrobial Resistance and Infection Control Division of HPSC etc to inform future revision of the guidance. Note the HPSC enhanced surveillance for CPE blood stream infection process and Appendix 1 of this document.

This document provides a framework to support a generally consistent approach to treatment. Given the complexity of clinical situations and antimicrobial susceptibility patterns, treatment must be tailored to individual patients. This document is not intended to restrict the appropriate application of clinical judgement.

Many infections in those colonised with carbapenem-resistant organisms/CPE will be considered unlikely to be CPE related on clinical grounds. Examples include many soft tissue infections. This guidance does not apply to those situations. Similarly many surgical procedures performed on patients with carbapenem-resistant organisms/CPE will be at sites where carbapenem resistant organisms/CPE is not likely to be associated with surgical site infection. This guidance does not apply to those situations.

CPE infection may be suspected in a setting where a person has clinical features of infection and is known to be colonised with CPE. It may also be appropriate to suspect CPE infection in some cases where the person is not known to be colonised with CPE but is at high risk of CPE colonisation for example because they are a CPE Contact.

CPE infection may be considered confirmed when CPE is detected in a clinical sample of body fluid or tissue in the context of relevant clinical evidence of infection. Detection of CPE in a sample such as urine, sputum or wound swab does not of itself confirm infection.

All of the doses and treatment recommendations in the document are based on managing infections in adults: dosing and potential contraindications may be different in children.

## Table of Contents

Scope .....	1
Abbreviations and Glossary of Terms .....	5
Background .....	6
Note on the use of carbapenem for treatment of carbapenem-resistant Enterobacterales.....	6
Note on Combination Therapy.....	7
Recommendations in accordance with the Start Smart, then Focus Care Bundle .....	7
Key principles of management .....	7
Initial evaluation and investigations .....	8
Empiric antimicrobial therapy .....	9
Directed antimicrobial therapy (carbapenem resistance/CPE confirmed) .....	10
De-escalation of antimicrobial therapy (carbapenem resistance/CPE becomes unlikely) .....	11
Examples of approaches to antimicrobial treatment.....	11
New agents in the pipeline .....	14
Appendix 1.....	15
Appendix 2.....	17
Appendix 3.....	21
References .....	44

## Abbreviations and Glossary of Terms

**AMRO** = Antimicrobial-Resistant Organism

**ED** = Emergency Department

**ESBL** = Extended Spectrum Beta-lactamase

**IPC** = Infection Prevention and Control

**Isolation** = Isolation refers to accommodation of one person in a single room

**Person/People** = the terms person/people are generally used in this document and are in general interchangeable with the terms client, service user or patient.

**CPE** = Carbapenemase Producing Enterobacterales\* The following in alphabetical order are some of the more common carbapenemase enzymes. There are a number of other carbapenemase enzymes.

**IMP** = Imipenemase

**KPC** = Klebsiella pneumoniae carbapenemase

**NDM** = New Delhi metallo-beta-lactamase

**OXA** = Oxacillinase-type carbapenemase (OXA-48 is the most common variant)

**VIM** = Verona Integron-encoded metallo-beta-lactamase

\***Enterobacterales** is a new term encompassing all those genera of bacteria formerly encompassed by the term *Enterobacteriaceae*. The term *Enterobacteriaceae* now encompasses a more limited number of genera.

## Background

Acquired carbapenem resistance poses a very significant challenge in the treatment of life threatening Gram-negative infection.

The pandemic spread of highly mobile genetic elements encoding for carbapenemase enzymes enables Enterobacterales to become Carbapenemase Producing Enterobacterales (CPE). The dissemination of CPE has been a key driver of emerging carbapenem-resistance globally and the control of CPE is a major public health challenge. Acquired resistance to carbapenems may also be related to mechanisms other than carbapenemase production, for example loss of porin channels, or increased efflux of the antibiotic. In relation to therapeutics for an individual patient it is the pattern of resistance rather than the mechanism that is most important therefore this advice relates to management of carbapenem resistant Enterobacterales regardless of the mechanism and may also be relevant to management of certain other taxa with acquired carbapenem resistance including *Acinetobacter spp.*

### Note on the use of carbapenem for treatment of carbapenem-resistant Enterobacterales

Antimicrobial susceptibility test (AST) interpretation guidelines have historically advised discounting *in vitro* susceptibility test measurements in the presence of certain specific resistance mechanisms. For example, avoidance of cephalosporins and beta-lactam/beta-lactamase inhibitor combinations was often recommended in the treatment of ESBL producing Enterobacterales even when such isolates had minimum inhibitory concentrations within the susceptible range. In recent years, following downward revision of the interpretive breakpoints, AST guidelines have generally advised that if an isolate tests susceptible to an agent then the agent may be used regardless of detection of any gene or mechanism associated with resistance. This approach, however, should take note of a recent paper which suggested that a particular beta-lactam/beta-lactamase inhibitor combination (piperacillin/tazobactam) may be less effective than meropenem for the

treatment of patients with ceftriaxone-resistant *E. coli* or *Klebsiella pneumoniae* bloodstream infection [1].

By applying that AST interpretation principle to CPE, carbapenems are used to treat CPE isolates that test susceptible to a carbapenem by EUCAST criteria (for example meropenem MIC of less than or equal to 2 mg/L). For isolates that are non-susceptible but not resistant by EUCAST criteria (meropenem MIC of less than or equal to 8 mg/L), the addition of meropenem to a combination of other agents is an appropriate option.

### Note on Combination Therapy

Combination therapy is widely recommended and widely used in the treatment of severe infection related to carbapenem-resistant organisms and CPE. Combination therapy is generally recommended in what follows in this document. However, in the INCREMENT study combination therapy was only associated with improved survival among patients with a high probability of death as measured by the INCREMENT-CPE mortality score. This scoring tool can be used to assist in selecting patients for whom monotherapy may be appropriate [2]. Also of note, a recent study of colistin compared with colistin plus meropenem failed to show added value from the combination [3, 4].

## Recommendations in accordance with the Start Smart, then Focus Care Bundle

For additional information on Start Smart then Focus see <https://www.rcpi.ie/news/publication/start-smart-then-focus-an-antibiotic-care-bundle-for-hospitals>

### Key principles of management

1. A Consultant Microbiologist or Infectious Disease Physician should be consulted early in relation to people with suspected or confirmed severe infection with carbapenem resistant Enterobacterales or *Acinetobacter spp.*

2. Generally such patients should be managed in a hospital with an on-site Consultant Microbiologist or Infectious Disease Physician to manage or to consult on treatment and diagnostics. This may not be appropriate for all patients, in particular for those where the priority is comfort, rather than intervention and active management.
3. There should be input from an Antimicrobial Pharmacist in relation to antibiotic therapy, particularly given the role of pharmacokinetic (PK)/pharmacodynamic (PD) considerations in the likely success of therapy and the fact that these infections frequently occur in patients who are already receiving multiple other medications, who are usually critically ill, and who may have altered drug kinetics.
4. Every effort should be made to ensure early and effective source control is achieved, in the setting where the focus of infection is amenable to drainage, debridement, or removal.

### Initial evaluation and investigations

1. As with all patients with severe infection, diagnostic samples, including blood cultures, should be collected before initiation of antimicrobial therapy if at all possible. In addition to diagnostic samples rectal swabs for testing for CPE should also be submitted if they have not been submitted in the previous 7 days. This should be done even in patients with known CPE colonisation as the patient may have acquired additional CPE (for example acquisition of NDM in addition to pre-existing KPC) or the susceptibility of the CPE they carry may have changed in a way that may impact on treatment.
2. In patients with suspected infection with carbapenem resistant Enterobacterales, any Gram-negative bacilli cultured from blood, or other normally sterile body site, should be directly subjected to rapid testing for carbapenemase (gene) direct from blood cultures if possible. If this is not possible a test for carbapenemase should be performed as soon as colonies are available on solid media (enzyme or gene). Suitable rapid methods may include lateral flow or molecular methods.

3. In patients with suspected infection with carbapenem-resistant Enterobacterales, direct provisional susceptibility testing should be performed on any Gram-negative bacilli cultured from blood.
4. All first isolates of CPE from bloodstream or other normally sterile body site should be submitted to the national reference laboratory. This should be done even if previous colonisation isolates were submitted. Testing for susceptibility to colistin and ceftazidime-avibactam should be requested (where relevant).

### Empiric antimicrobial therapy

1. Treatment and treatment response should be discussed at least daily with a Consultant Microbiologist or Infectious Disease Physician until the patient's condition has stabilised.
2. Where the infecting organism is not identified and treatment is therefore empiric inclusion of a broad spectrum beta-lactam or carbapenem may be appropriate even when the suspected infecting organism is resistant to beta-lactams and carbapenems. This is because the infecting organism may, in fact, be a beta-lactam or carbapenem susceptible organism and in that case an appropriate beta-lactam may be the preferred approach to treatment.
3. Given the current evidence suspected or confirmed severe infection with carbapenem resistant Enterobacterales or *Acinetobacter* spp. should generally be treated in the first instance with a combination of at least two antimicrobial agents likely to be effective. The choice of antimicrobial agents should take account of the type of carbapenemase (if known) and the most recent susceptibility test result of the CPE isolate from that person (if known). In people in septic shock, the addition of a third antimicrobial is often appropriate.
4. Where no susceptibility testing/results are available to guide treatment, for initial empiric therapy of infection for a person known or suspected to be colonised with a KPC or OXA-like carbapenemase, a combination of ceftazidime-avibactam with tigecycline and colistin may be appropriate. If there is concern regarding co-infection

with resistant Gram-positive bacteria vancomycin or other suitable agent may also be required.

5. Where no susceptibility testing/results are available to guide treatment, for initial empiric therapy of infection for a person known or suspected to be colonised with an organism containing an NDM/VIM/IMP carbapenemase, a combination of colistin, tigecycline and fosfomycin may be appropriate. If there is concern regarding co-infection with resistant Gram-positive bacteria, vancomycin or other suitable agent may also be required.

### Directed antimicrobial therapy (carbapenem resistance/CPE confirmed)

1. Where isolates have tested susceptible to one or more carbapenems by a validated and reliable method carbapenems may be included in treatment regimens, regardless of resistance genes /enzymes detected in the organism unless the patient is intolerant of carbapenems.
2. Where isolates have tested susceptible to an aminoglycoside and there is no specific contraindication to their use an aminoglycoside should generally be used for at least the first 48 hours in patients who are in septic shock due to infection with carbapenem resistant Enterobacterales or *Acinetobacter spp.*
3. De-escalation to monotherapy should be considered within 48 hours or if the patient is improving. Antimicrobial susceptibility test results should be used to guide de-escalation.
4. The requirement for continuation of antimicrobial agents or combinations of antimicrobial agents with significant nephrotoxic potential should be reviewed daily. Where relevant antimicrobial blood levels should be measured at appropriate intervals and considered in making decisions on treatment.
5. For treatment of carbapenem-resistant organisms with confirmed antimicrobial susceptibility the combination of agents chosen should generally favour agents with the greatest evidence /experience of efficacy for treatment of Gram-negative infection such as beta-lactams, carbapenems and aminoglycosides.

6. In circumstances where CPE is repeatedly isolated from a patient during treatment for CPE infection, susceptibility testing of the new isolate should be performed if the interval between samples cultured positive for CPE is 5 days or more. In some cases testing at more frequent intervals may be required.

### **De-escalation of antimicrobial therapy (carbapenem resistance/CPE becomes unlikely)**

When a specific pathogen that is not a carbapenem-resistant organism/CPE is identified from blood culture or another relevant site, the antimicrobial treatment should generally be modified to target the identified organism based on its susceptibility. The patient should generally not be continued on a regimen directed towards treatment of a carbapenem-resistant organism after this point, even if the patient is known to be colonised with CPE.

### **Examples of approaches to antimicrobial treatment**

A priority in a person with septic shock is the rapid administration of an antimicrobial agent(s) likely to be effective. The following general questions should be considered in relation to choice of treatment but incomplete information should not unduly delay initiation of treatment. The potential scenarios outlined attempt to provide advice in a specific set of circumstances. However, all treatment decisions should take account of the individual person's circumstances and needs.

- Does the patient have a history of drug allergy (document allergy type: minor (rash only) or major (anaphylaxis, angioedema))?
- Does the patient have any contraindications to individual antimicrobials?
- Is the patient receiving concomitant medications likely to interact with individual antimicrobials?
- Does the patient have organ dysfunction (e.g. renal or hepatic impairment) requiring adjusting of dose/frequency of individual antimicrobials?

- Are there other factors relating to PK/PD that need to be considered to maximise efficacy and minimise toxicity for individual antimicrobials?

<b>No identified pathogen but suspect KPC or OXA carbapenemase based on known colonisation or exposure, susceptibility of isolate not accessible</b>	
Patient with septic shock	Ceftazidime-avibactam plus tigecycline plus colistin
Patient with septic shock, with a clear history of anaphylaxis to penicillin /cephalosporin	Tigecycline plus colistin plus fosfomycin. [Addition of a carbapenem* may be appropriate, if benefit outweighs risk, and is directed towards the possibility of infection with a susceptible organism]
Patient with severe infection but not septic shock.	Ceftazidime-avibactam plus tigecycline
Patient with sepsis but not septic shock with a clear history of anaphylaxis to penicillin /cephalosporin	Tigecycline plus colistin
<b>Identified pathogen as KPC or OXA carbapenemase, susceptibility of isolate available</b>	
Patient with septic shock	Aminoglycoside (whichever agent is susceptible) plus one of: meropenem [if susceptible] or ceftazidime-avibactam
Patient with septic shock, with a clear history of anaphylaxis to penicillin /cephalosporin	Tigecycline plus aminoglycoside. [If tests susceptible, use of a carbapenem* may be appropriate instead of tigecycline if benefit outweighs risk]
Patient with severe infection but not septic shock.	Meropenem [if susceptible] or ceftazidime-avibactam. <b>Note caution with the use of ceftazidime-avibactam alone if the isolate is a KPC-3 producer.</b>
Patient with severe infection but not septic shock and with a clear history of anaphylaxis to penicillin /cephalosporin	Tigecycline plus colistin. [Use of a carbapenem* as a single agent may be appropriate if the isolated tests

	susceptible and the benefit outweighs the risk]
<b>No identified pathogen but suspect NDM/VIM/IMP carbapenemase based on known colonisation, susceptibility of isolate not accessible</b>	
Patient with severe infection including those with septic shock. This example is equally applicable to patients with a clear history of anaphylaxis to penicillin /cephalosporin.	Tigecycline plus colistin plus fosfomycin. [Addition of a carbapenem* may be appropriately directed towards the possibility of infection with a susceptible organism]
<b>Identified pathogen as NDM/VIM/IMP carbapenemase, susceptibility of isolate available</b>	
Patient with severe infection including those with septic shock. This example is equally applicable to patients with a clear history of anaphylaxis to penicillin /cephalosporin.	Colistin plus tigecycline <u>OR</u> aminoglycoside plus tigecycline (choice of agent based on susceptibility test).

**\*Caution: the use of carbapenems in penicillin / cephalosporin allergy is recommended in guidelines. Both prospective and retrospective studies have found low cross-reactivity rates between carbapenems and penicillins, with the likely risk as being less than 1%. [5]**

Reviews of the literature and microbiology data in Appendices 2, 3 & 4 have informed the choices detailed in the examples. A monograph for each of the individual antibiotics is included in Appendix 3 to assist in prescribing these agents. Appendix 3 also includes monographs for some of the newer antibiotics: meropenem-vaborbactam, plazomicin (licensed by US FDA but not commercially available until early 2019), eravacycline (licensed by US FDA but not commercially available until early 2019)

## New agents in the pipeline

Other agents in the pipeline but not approved are: imipenem-relebactam, cefiderocol, aztreonam-avibactam, cefepime-zidebactam. Cefiderocol, a new siderophore cephalosporin, appears the most promising, with activity against KPC, NDM, VIM, IMP & OXA carbapenemase producers and carbapenem resistant *A. baumannii*.

## Appendix 1

**Table 1: Template to record experience of the treatment of an individual patient with a carbapenem resistant bloodstream infection – please submit this template to [hcainternational.lead@hse.ie](mailto:hcainternational.lead@hse.ie).**

Amended EARS-Net/Enhanced Bacteraemia Surveillance (Source HPSC website)			
		<i>Circle items that apply</i>	
PART OF CORE DATA	Same as each EARSS-Net isolate	EARS-Net Laboratory Code	
		EARS-Net Hospital Code	
		Patient number	
		Specimen number	
		Specimen date (dd/mm/yyyy)	
		Organism & CPE type & AST results	
		Date of admission (dd/mm/yyyy)	
LEVEL 1		Probable contaminant	Y   N   <i>(do not complete the rest of form if 'Y')</i>
		Healthcare-association	This Hospital   Other Hospital   Long Stay Facility   Community   Unknown
	Device	Device (catheter)-associated	Y   N
		Type of device	PVC   CVC   CVC-PICC   Dialysis Catheter   Urinary Catheter   Other
	Implant	Implant-associated	Y   N
		Type of implant (free text)	
	Procedure	Procedure-associated	Y   N
		Name of procedure (free text)	
	Any additional information (free text)		
LEVEL 2		Source organ site (one from list):	Respiratory   Gastrointestinal   Hepatobiliary   Bone and joint   Head and neck   Central nervous system   Urinary tract   Genital tract   Skin/Soft tissue – surgical wound   Skin/Soft tissue–other   Cardiovascular   Other   Unknown
		Further information on source	
		Neutropaenia	Y   N
		Acquired in critical care	Y   N
		Outcome	Discharged   Died   Still in Hospital   Unknown
		Date of discharge or death (dd/mm/yyyy)	

		Antibiotic exposure including doses & durations (free text list)	
HSE-HPSC	EARS-Net Enhanced V5		April-19
	amendments to form		

## Appendix 2

### Literature review of combination therapy versus monotherapy.

Until more robust evidence is available combination therapy is recommended as empiric therapy and monotherapy should only be considered when susceptibility results are available to support this approach and the patient is clinically stable.

- A meta-analysis of studies to the end of 2015 demonstrated that compared with carbapenem susceptible Enterobacterales, infection with carbapenem resistant Enterobacterales was associated with a significantly higher risk of overall mortality (OR, 3.39; 95% confidence interval [CI], 2.35-4.89. Monotherapy (vs. combination therapy) for carbapenem-resistant Enterobacterales infections was also associated with higher mortality (OR, 2.19; 95% CI, 1.00-4.80). The overall findings across the included studies indicate that the differences in mortality between people with infections due to carbapenem-resistant and carbapenem-susceptible Enterobacterales are possibly due to the treatment- or organism-related factors rather than differences in study population baseline characteristics. [6]
  - Seven studies included in the analysis compared monotherapy with combination therapy for carbapenem-resistant Enterobacterales; 5 were retrospective and 2 were case-control. Four of the studies included people with bloodstream infections, and 3 studies included people with a mix of infection types attributed to carbapenem resistant Enterobacterales.
  - Monotherapy in people with bloodstream infection led to a further increased mortality risk. Those treated with monotherapy were 3.8 times more likely to die compared with those people receiving combination therapy.
  - The treatment-related factors as a reason for increased mortality include: increased risk for delayed administration of an active antibiotic, optimal treatment remains undefined and often involves use of agents with a greater propensity for adverse effect, i.e. tigecycline, colistin, gentamicin and amikacin.

- This meta-analysis was conducted before the availability of ceftazidime-avibactam and meropenem-vaborbactam.
- In 2014 Falagas *et al.* [7] reported on 20 studies involving 692 people. Studies up to early 2013 were included.
  - Fifteen studies reported on CPE, five others were on carbapenem-resistant Enterobacterales.
  - In 8 out of 20 studies, the total or majority (>50% of the included infections) of the included infections were bloodstream infections. Pneumonia and urinary tract Infection were the most common infections among the remaining 12 studies.
  - Eight studies reported data on KPCs, five others on MBLs and OXA-producing *Klebsiella* spp.
  - Methodological issues with the studies precluded a meta-analysis
  - The following conclusions were made on the data:
    - Among critically ill people with bloodstream infection due to carbapenemase-producing *Klebsiella* spp., a combination antibiotic treatment may result in lower mortality than monotherapy
    - Tigecycline in combination with colistin, carbapenem in combination with colistin, and tigecycline in combination with gentamicin were the commonly administered antibiotic treatment regimens among the included studies and might result in lower mortality than other combinations of antibiotics. An effectiveness similar to that of the aforementioned combinations was observed among patients treated with monotherapy with colistin, tigecycline and carbapenems. However, the data were from studies often including fewer than 50 people.
    - There were few cases of successful treatment of bloodstream infection with gentamicin monotherapy
- In the INCREMENT study (2017) combination therapy was only associated with improved survival among people with a high probability of death as measured by the INCREMENT-CPE mortality score [2]

- The cohort was 480 people with blood stream infection due to CPE
  - Of 437 people, 69 had infection with OXA-48-, 329 with KPC- and 39 with MBL-producers
- This study could not make estimations of efficacy of particular combinations [2]
- Active antimicrobials should be administered as soon as possible. Consider relevant aspects of the HSE sepsis management Sepsis 6 bundle [8].
- Although the ideal is administration of active antimicrobial agents as soon as possible there is evidence of benefit if active antimicrobial agents are given within 3-5 days of onset of infection [2]
- In most trials targeting CPE, combination therapies have included the use of (i) colistin and a carbapenem; (ii) colistin and tigecycline, or colistin and fosfomycin; or (iii) double carbapenem therapy. [9]
- Laboratory (*in vitro*) studies suggest that dual carbapenem combinations might work against carbapenemase-producing strains. Significant synergy was reported when using imipenem and another carbapenem [9]
- Ertapenem and doripenem together have been reported to have enhanced activity compared to either agent alone against KPC-producing *K. pneumoniae*.
- The phenomenon of increased activity in studies of two carbapenems may be because ertapenem is “trapped” by KPC more readily and acts as an “inhibitor” due its low turnover, which frees doripenem to act on penicillin binding proteins [10]
- An earlier systematic review highlighted that the lowest failure rate was observed in the group treated with a carbapenem-containing antimicrobial combination [10]
- Recommendations from professional groups and well-respected guidelines vary between monotherapy and combination therapy as shown in Table 1 below.
- Antibiotics with generally reliable activity against carbapenem-resistant organisms and CPE of all classes, typically include tigecycline, colistin and fosfomycin. There are, however, important concerns regarding the limited efficacy of these options because of their pharmacologic characteristics. There are also reports of increasing resistance, selection of resistance when used as monotherapy against carbapenem-resistant Enterobacterales and concerns regarding toxicity and adverse events. The

risk of emergence of resistance is a further reason for the use of combination therapy when these agents are used. [10]

**Table 1: Recommendations from professional groups and well-respected guidelines for the treatment of CPE.**

Carbapenemase type	KPC	Metallo-beta-lactamases (MBL) (NDM, VIM, IMP)	OXA-48
BSAC [11]	Colistin & meropenem (if unknown/S in past)	Fosfomycin & colistin	Aztreonam. ( <i>note many such isolates are resistant to aztreonam by an independent mechanism</i> ).
	Consider addition of tigecycline to above	Consider tigecycline	Ceftazidime ( <i>note many such isolates are resistant to ceftazidime by an independent mechanism</i> ).
	Ceftazidime-avibactam & meropenem		Ceftazidime-avibactam
Sanford Guide [12]	Ceftazidime-avibactam	Colistin	Colistin
	Meropenem-vaborbactam	Aminoglycoside if susceptible	
	Colistin		
John Hopkins [13]	Gentamicin	Aztreonam (for IMP & VIM)	No recommendation
	Tigecycline	Tigecycline	
	Colistin	Colistin	

## Appendix 3

### Individual monographs for antimicrobial agents with activity against carbapenem resistant bacteria with a literature review of their place in therapy and recommendations on dosing

Optimising dosing strategies to give the highest drug exposure according to PK/PD parameters is recommended. The tables below provide information on how this can be achieved. Please note that some recommendations reflect dosing strategies not covered by the product license.

1. Aminoglycosides & plazomicin
2. Aztreonam
3. Carbapenems – ertapenem, meropenem, meropenem-vaborbactam
4. Ceftazidime
5. Ceftazidime-avibactam
6. Colisitin
7. Co-trimoxazole
8. Eravacycline
9. Fosfomicin
10. Tigecycline

## Aminoglycosides

Aminoglycosides	
Place in therapy	<ul style="list-style-type: none"> <li>• Could use gentamicin in combinations for urinary, intra-abdominal and bloodstream infections due to gentamicin-susceptible CPE including KPC-producing <i>Klebsiella</i> spp [11].</li> <li>• NDM-1 producing organisms frequently carry resistance to aminoglycosides [14].</li> <li>• Case reports most frequently cite amikacin as a treatment option [14].</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• This guideline recommends standard optimal once daily regimens based on local guidelines for both gentamicin &amp; amikacin.</li> <li>• Note: use dose determining weight in obesity [15].</li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Concentration dependent killing [12]</li> <li>• Cmax : MIC <math>\geq</math> 10 [16]</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Monitor for ototoxicity in any patients receiving aminoglycoside for more than 3 days [13].             <ul style="list-style-type: none"> <li>○ Vestibular toxicity monitoring: check baseline visual acuity using a Snellen pocket card. After 3 days of treatment have patient shake head (side to side) while reading a line, Early sign of ototoxicity if patient loses 2 lines of visual acuity. Check Romberg sign.</li> <li>○ Cochlear toxicity monitoring: audiology test.</li> </ul> </li> <li>• Monitor for nephrotoxicity, reviewing other potential nephrotoxins on a daily basis.</li> <li>• Routine stock in most hospitals.</li> </ul>

### Plazomicin – a new aminoglycoside

#### Place in therapy

- Plazomicin is a semi-synthetic aminoglycoside derived from sisomicin [12].
- Approved by US FDA June 2018 [3], supply not available in Ireland until early 2019.
- Most aminoglycoside modifying enzymes (AMEs) do not affect plazomicin, as this drug is structurally modified to prevent inactivation by plasmid-borne AMEs [17].
- It has potent activity *in vitro* against MDR Enterobacterales, including against aminoglycoside-resistant carbapenem resistant Enterobacterales that encode AMEs [17].
- However, **plazomicin is not active against strains with 16S ribosomal RNA methyltransferases that confer pan-aminoglycoside resistance [17]. Significant numbers of NDMs seem to carry this resistance.**
- Plazomicin has potent activity against MDR Enterobacterales with multiple AMEs in several species that renders these organisms non-susceptible to amikacin, tobramycin, and gentamicin [17]. In this same laboratory study, by both checkerboard and time-kill analyses, plazomicin clearly exhibits synergy when combined with piperacillin/tazobactam and ceftazidime against MDR Enterobacterales. Clear evidence of synergy was not exhibited for plazomicin in combination with other agents. Antagonism was not observed with any combination [17].
- It may be an option for NDM carbapenemase producers based on a Brazilian *in vitro* study of CPEs [18], however, other studies are disputing its activity against NDM carbapenemase producers.
- In an *in vitro* study of *K. pneumoniae* carrying VIM-1 carbapenemase synergy was observed when plazomicin was combined with meropenem, colistin or fosfomycin against both isolates, whilst the combination with tigecycline resulted in indifference. Antagonism was not observed for any of the

	<p>combinations tested [19].</p> <ul style="list-style-type: none"> <li>• Significantly improved activity was seen in OXA-producing <i>A. baumannii</i> isolates compared with other aminoglycosides [20].</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• Adult usual dose: 15 mg/kg IV every 24 hours [12].</li> <li>• Dose adjustment for renal impairment [12]. <ul style="list-style-type: none"> <li>○ Creatinine Clearance <math>\geq 30</math> to <math>&lt; 60</math>: 10 mg/kg IV every 24 hours.</li> <li>○ Creatinine Clearance <math>\geq 15</math> to <math>&lt; 30</math>: 10 mg/kg IV every 48 hours.</li> <li>○ Renal replacement therapies or Creatinine Clearance of less than 15: no information currently available.</li> </ul> </li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• 24 hour AUC/MIC [12].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Therapeutic drug monitoring required.</li> <li>• Although plazomicin may be associated with nephrotoxicity and neurologic side effects, based on available data, rates appear to be lower than for other aminoglycosides.</li> <li>• Currently not included in the list of assays available from the Antimicrobial Reference Laboratory North Bristol NHS Trust <a href="http://www.bcare.nbt.nhs.uk/services/clinical-antimicrobial-assays">http://www.bcare.nbt.nhs.uk/services/clinical-antimicrobial-assays</a></li> <li>• Should be available to purchase in 2019.</li> </ul>

Aztreonam	
Place in therapy	<ul style="list-style-type: none"> <li>• Use aztreonam for MBL- or OXA-48 producing strains if they are not resistant to this agent by other mechanisms [11] Aztreonam is not hydrolysed by MBL alone. It is readily hydrolysed by a number of other beta-lactamases and carbapenemases [20].               <ul style="list-style-type: none"> <li>○ Data from the CPE national reference laboratory service for Ireland indicate 79% and 44% of MBL- or OXA-48 respectively co-produce ESBL and/orAmpC.</li> </ul> </li> <li>• <b>No activity against KPC producing Enterobacterales [14].</b></li> <li>• A new pipeline agent aztreonam-avibactam has shown superior <i>in vitro</i> activity compared with aztreonam against ESBL-, class C B-lactamase- MBL- and KPC carbapenemases-producing strains of Enterobacterales [20].               <ul style="list-style-type: none"> <li>○ Until this agent becomes available a number of clinical observations have now been published evaluating aztreonam combined with ceftazidime-avibactam. These have shown successful outcomes in a small numbers of patients with infections due to NDM-producing Enterobacterales. [20] .</li> </ul> </li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• Life-threatening or other severe infections give 2g every 6 – 8 hours [14].</li> <li>• Dose adjustment for renal impairment: consult usual references.</li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Time above MIC.</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Routine stock in most hospitals.</li> </ul>

## Carbapenems

- Applying the AST interpretation principle to carbapenem-resistant isolates that test susceptible to a carbapenem by EUCAST criteria (meropenem MIC of less than or equal to 2 mg/L, ertapenem MIC of less than or equal to 0.5mg/L), they can be treated with meropenem / ertapenem respectively. For isolates that are non-susceptible but non-resistant by EUCAST criteria (meropenem MIC of less than or equal to 8 mg/L, ertapenem MIC of less than or equal to 1 mg/L) the addition of meropenem / ertapenem respectively to a combination of other agents is an appropriate option.
- Based on a meta-analysis it appears that extended or continuous infusion of carbapenems is at least as successful as intermittent dosing. It has been reported that there is reduced mortality among patients treated with extended or continuous infusion of carbapenems or piperacillin-tazobactam (pooled data) as compared to standard intermittent therapy regimens. The results were similar for extended and continuous regimens when considered separately. There was a mortality benefit with piperacillin-tazobactam but not with carbapenems [21]. Prescribers may choose to use an extended or continuous infusion to optimise the time above MIC for isolates with raised MICs that are not in the resistant range.
- Imipenem/cilastatin is not licensed in Ireland. It is not detailed as there is unlikely to be a reason to use over meropenem.
- Doripenem is not detailed as supply cannot be sourced, it has been withdrawn in many countries.

Ertapenem	
Place in therapy	<ul style="list-style-type: none"> <li>• Of the licensed carbapenems, ertapenem is the most susceptible to carbapenemases produced by <i>Klebsiella</i> spp. and other aerobic Gram-negative bacilli [12].</li> <li>• See General Carbapenems comments above .</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• 1g every 24 hours.</li> <li>• A study demonstrated the same serum-free concentrations with both intermittent infusion (at 1h, 12h &amp; 24h) as continuous infusion with a 1g dose in 24 hours [22].</li> <li>• If BMI is greater than 40 consider alternative agents as adequate levels may not be achieved [12].</li> <li>• Dose adjustment for renal impairment: consult usual references.</li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Time dependent killing [12].</li> <li>• 40%-50% time above the MIC, higher time above MIC targets (at least 75% time above the MIC) may be more appropriate in patients who are critically ill or who are immunocompromised to increase the chance of clinical response [16].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Seizures have infrequently been reported during treatment with carbapenems. Caution should be exercised with higher doses or if part of double carbapenem cover [16].</li> <li>• Carbapenems dramatically reduce valproate concentrations and seizures have been reported. Avoid concurrent use.</li> <li>• Routine stock in most hospitals.</li> </ul>

Meropenem															
Place in therapy	<ul style="list-style-type: none"> <li>• See General Carbapenems comments above.</li> </ul>														
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• Intermittent infusion: 1-2g every 8 hours [14].</li> <li>• Extended infusion: 2g every 8 hours administered as extended infusion over 3 hours [12], 4 hours [16] or 8 hours [14].</li> <li>• Dose adjustment for renal impairment: consult usual references</li> <li>• Extended Infusion [12].               <ul style="list-style-type: none"> <li>○ Stability data for 4 hours at temp of 25°C.</li> <li>○ Initial 1g loading dose then:</li> <li>○ Creatinine clearance more than 50 mL/min: 2g (over 3 hours) every 8 hours.</li> <li>○ Creatinine clearance 30-49 mL/min: 1g (over 3 hours) every 8 hours.</li> <li>○ Creatinine clearance 10-29 mL/min: 1g (over 3 hours) every 12 hours.</li> </ul> </li> <li>• Continuous Infusion [23,24] – standard dose and higher dose.</li> </ul>														
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	After the first 48 hours creatinine clearance less than or equal to 20ml/min	2g over 8 hours 2 times in 24h	
	WFI = water for injection; NS = sodium chloride 0.9%		
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Time dependent killing [12].</li> <li>• 40%-50% time above MIC, higher time above MIC targets (at least 75% time above MIC) may be more appropriate in patients who are critically ill or who are immunocompromised to increase the chance of clinical response [16].</li> <li>• Recent PK studies in critically ill patients suggest that plasma concentrations above the MIC are more likely to be achieved when meropenem is administered via extended or continuous infusion when compared to intermittent infusion [13].</li> </ul>		
Practical issues	<ul style="list-style-type: none"> <li>• Seizures have infrequently been reported during treatment with carbapenems; caution should be exercised with higher doses or if part of double carbapenem cover [16].</li> <li>• Carbapenems dramatically reduce valproate concentrations and seizures have been reported. Avoid concurrent use.</li> <li>• Routine stock in most hospitals.</li> </ul>		

Meropenem-vaborbactam	
Place in therapy	<ul style="list-style-type: none"> <li>• Vaborbactam is a first-in-class, boronic acid pharmacophore, serine beta-lactamase inhibitor.</li> <li>• Approved in August 2017 by US FDA.</li> <li>• Has activity <i>in vitro</i> against KPC producing CPE [25].</li> <li>• Meropenem-vaborbactam was very active against KPC-producers, and 99.5% of these isolates were inhibited by less than or equal to 4/8 mg/L. The single resistant isolate was shown to harbour an outer membrane porin alteration.</li> <li>• Meropenem-vaborbactam was active against contemporary carbapenem resistant Enterobacterales and wild-type Enterobacterales collected worldwide and this combination demonstrated enhanced activity compared with meropenem and most comparator agents against carbapenem resistant Enterobacterales and KPC-producers [26].</li> <li>• Meropenem-vaborbactam has limited activity against MBL-producing isolates (including 49 NDM-, 1 IMP-64- and 2 VIM-producers) and/or oxacillinases (47 OXA-48/-232) that were detected mainly in European countries.</li> <li>• <i>In vitro</i> it is more active against KPCs than ceftazidime-avibactam [13].</li> <li>• It has reduced activity against KPC-producing <i>K. pneumoniae</i> isolates with diminished expression of the porin genes <i>ompK35</i> and <i>ompK36</i>.</li> <li>• Little effect on <i>A. baumannii</i> containing OXA-type carbapenemases was observed [20].</li> <li>• Meropenem-vaborbactam was evaluated for the treatment of carbapenem resistant Enterobacterales infections (Tango II study) in adult patients and resulted in higher cure rates at both the end of treatment and through a test of cure compared to best available therapy (64% vs. 33%, <math>p=0.04</math> and 16% vs. 4%, <math>p=0.04</math>).</li> <li>• Best available therapy included: carbapenem, aminoglycoside,</li> </ul>

	<p>polymyxin B, colistin, tigecycline, or ceftazidime-avibactam (monotherapy only). Study was stopped early due to superiority of meropenem-vaborbactam [13].</p>
Optimal administration & dosing [12,13]	<ul style="list-style-type: none"> <li>• Meropenem-vaborbactam 4g (meropenem 2g + vaborbactam 2g) IV every 8 hours.</li> <li>• Each dose infused over 3 hours.</li> <li>• Dose adjustment for renal impairment. <ul style="list-style-type: none"> <li>○ eGFR 30-49: Meropenem 1g + vaborbactam 1g IV every 8 hours.</li> <li>○ eGFR 15-29: Meropenem 1g + vaborbactam 1g IV every 12 hours.</li> <li>○ eGFR less than 15: Meropenem 0.5g + vaborbactam 0.5g IV every 12 hours.</li> <li>○ Haemodialysis: As for eGFR less than 15 (administer doses after dialysis).</li> <li>○ Continuous renal replacement therapy: no information currently available.</li> </ul> </li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Time dependent killing [12].</li> <li>• As for meropenem. <ul style="list-style-type: none"> <li>○ 40%-50% time above MIC, higher time above MIC targets (at least 75% time above MIC) may be more appropriate in patients who are critically ill or who are immunocompromised to increase the chance of clinical response [16].</li> </ul> </li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Meropenem-vaborbactam is generally well tolerated, with a tolerability profile generally similar to that of piperacillin/tazobactam.</li> <li>• Seizures have infrequently been reported during treatment with carbapenems, caution should be exercised with higher doses or if part of double carbapenem cover [16].</li> <li>• Carbapenems dramatically reduce valproate concentrations and seizures have been reported. Avoid concurrent use.</li> <li>• Unlicensed in Ireland, not stocked by any wholesaler in Ireland. Available from the US with a lead time of at least one week.</li> </ul>

<b>Ceftazidime</b>	
Place in therapy	<ul style="list-style-type: none"> <li>• Effective against some OXA-48 carbapenemase producers, principally those that do not co-produce ESBLs or AmpC enzymes [11].</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• Severe infections or meningitis: 2g every 8 hours (max 8g/day)</li> <li>• Dose adjustment for renal impairment: consult usual references</li> <li>• Continuous Infusion Dose [12].               <ul style="list-style-type: none"> <li>○ Initial dose of 15 mg/kg IV infused over 30 min, then immediately start continuous infusion:</li> <li>○ Creatinine clearance greater than 60 mL/min use 6g IV over 24 hours.</li> <li>○ Creatinine clearance 31-50 mL/min use 4g IV over 24 hours.</li> <li>○ Creatinine clearance 11-29 mL/min use 2g IV over 24 hours.</li> <li>○ Creatinine clearance less than 11 &amp; Continuous renal replacement therapy: no information currently available for continuous infusion.</li> <li>○ Formulation: 3g in 250ml sodium chloride 0.9% given over 12 hours [27].</li> </ul> </li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Time dependent killing [12].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Routine stock in most hospitals.</li> </ul>

Ceftazidime-avibactam	
Place in therapy	<ul style="list-style-type: none"> <li>• Has no inhibitory activity against the MBLs [11].</li> <li>• Has activity against KPC-2 producing isolates, MICs are higher for KPC-3 producing isolates.</li> <li>• KPC-3 producing <i>Klebsiella</i> spp. are vulnerable to mutations in the bla<sub>KPC-3</sub> gene causing resistance [11].</li> <li>• Has activity against most OXA-48 producers [11].</li> <li>• Consider whether ceftazidime-avibactam should be used with a carbapenem or colistin to treat infections with KPC-3 producers [11].</li> <li>• Less active against <i>Acinetobacter</i> spp [20].</li> <li>• In a study of treatment of CPE bloodstream infection in haematology patients combination treatments with ceftazidime-avibactam included: an aminoglycoside (87.5%), carbapenems (37.5%), fosfomycin (25%), tigecycline (25%) or colistin (25%) [28].</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• 2.5g (ceftazidime 2g + avibactam 0.5g) every 8 hours [12, 28].</li> <li>• Infuse all IV doses over 2 hours [12].</li> <li>• Dose adjustment for renal impairment [12, 13].               <ul style="list-style-type: none"> <li>○ Creatinine clearance 31-50: 1.25g every 8 hours.</li> <li>○ Creatinine clearance 10-30: 0.94g every 12 hours.</li> <li>○ Creatinine clearance &lt;10: 0.94g every 48 hours.</li> <li>○ Haemodialysis: 0.94g every 48 hours (give dialysis day dose after dialysis).</li> <li>○ Continuous veno-venous haemodialysis : 1.25g every 8 hours.</li> <li>○ The dose recommended above is low in comparison to the dose recommended in the Renal Drug database for ceftazidime alone.</li> <li>○ Consider referring to this reference for the ceftazidime component of ceftazidime-avibactam if the patient is on Continuous Renal Replacement Therapy (CRRT). CRRT has been identified as an independent predictor of the</li> </ul> </li> </ul>

	development of resistance with ceftazidime-avibactam [29, 30].
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Time dependent killing [12].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Due to the emergence of ceftazidime-avibactam resistance susceptibility testing should always be performed when ceftazidime-avibactam is used [31].</li> <li>• May be stock in some hospitals. Stocked by one wholesaler in Ireland.</li> </ul>

Colistin	
Place in therapy	<ul style="list-style-type: none"> <li>• Generally used in combination with other agents [11].</li> <li>• Consider colistin with aminoglycosides or tigecycline in infections with CPE strains that are susceptible to these agents but resistant to meropenem [11].</li> <li>• Give careful consideration to the use of higher dosage regimens in critically ill patients [11].</li> <li>• No difference between monotherapy or combination colistin in meta-analysis but most were <i>Acinetobacter</i> spp., no difference in dose – high or low or loading dose or not [32].</li> <li>• Monotherapy vs. combination meta-analysis – poor quality data so difficult to make assumptions [33].</li> <li>• Combination therapy with rifampicin did not improve clinical response or 30-day mortality in patients with <i>Acinetobacter</i> spp. infections [12].</li> <li>• <i>In vitro</i> and <i>in vivo</i> exposure to polymyxins results in rapid selection of resistant sub-populations. <i>In vitro</i>, minocycline prevented emergence of resistance and augmented colistin activity but no clinical trial data. Tigecycline may function similarly, but no data. [12].</li> </ul>
Optimal	<ul style="list-style-type: none"> <li>• Adult loading dose.</li> </ul>

administration & dosing [9]	Body weight	Loading Dose	Notes
	Over 50kg	9 million units (MU)	<p>▲ In obese patients (BMI&gt;30) dosing should be based on Ideal Body Weight. Use of actual body weight in these patients is associated with increased incidence of nephrotoxicity.</p> <p>▲ In critically ill patients, irrespective of body weight, a dose of 9MU should be used. The loading dose is unaffected by renal impairment.</p>
50kg or under	6 million units (MU)		
<ul style="list-style-type: none"> <li>Adult Maintenance Dose – increasing maintenance dose from 4.5 MU 12 hourly to 6 MU 12 hourly may be considered in critically ill depending on patient response and MIC – discuss with an Infection Specialist and review daily</li> </ul>			
	Creatinine Clearance (mL/min)	Dose and Frequency (based on SPC)	Starting time after loading dose
	Greater than 50	4.5 MU 12 hourly	12 hours
	30-50	3 MU 12 hourly	24 hours
	10-30	2.5 MU 12 hourly	24 hours
	Less than 10	1.75 MU 12 hourly	24 hours
	Haemodialysis	Non-HD days: 1.12 MU 12 hourly HD days: 1.5 MU 12 hourly after dialysis	No information currently available, suggest 24 hours
	Continuous veno-venous haemodialysis diafiltration	3 MU 8 hourly	8 hours

	<ul style="list-style-type: none"> <li>• The distribution of colistin to the pleural cavity, lung parenchyma, bones, and cerebrospinal fluid (CSF) is relatively poor [14].</li> <li>• Dose and administration instructions for nebulised or intrathecal colistin are available in the SmPC available at <a href="http://www.hpra.ie">www.hpra.ie</a></li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>• Area Under the Curve /MIC [16], i.e. concentration-dependent bactericidal activity [34].</li> <li>• This suggests that if levels come back low then the total daily dose should be increased and the dosage interval reduced e.g. if 6 MU 12 hourly is not achieving adequate levels consider increasing to 4.5 MU or 6 MU 8 hourly.</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Plasma levels are required and are measured at Antimicrobial Reference Laboratory North Bristol NHS Trust . Guidance on up-to-date target trough levels is available on the Antibiotic Assay Guideline Ranges document at: <a href="http://www.bcare.nbt.nhs.uk/services/clinical-antimicrobial-assays">http://www.bcare.nbt.nhs.uk/services/clinical-antimicrobial-assays</a> . Other antibiotics can interfere with the assay therefore the laboratory will require these details.</li> <li>• Monitor for signs of neurotoxicity, more common with high doses e.g. apnoea, peri-oral and peripheral paraesthesia, vertigo, headache, muscle weakness; rarely vasomotor instability, slurred speech, confusion, psychosis, visual disturbances. Some may not be apparent if the patient is ventilated in the ICU.</li> <li>• Closely monitor renal function, especially in the elderly, those receiving high intravenous doses for prolonged periods and those on concomitant nephrotoxic agents e.g. aminoglycosides [11].</li> <li>• As per SmPC, use with caution in hepatic impairment.</li> <li>• No dose adjustment for hepatic impairment suggested [12].</li> <li>• May be stock in some hospitals. Available as routine stock in wholesalers in Ireland.</li> </ul>

Co-trimoxazole	
Place in therapy	<ul style="list-style-type: none"> <li>• An agent with an option of the oral route for carbapenem-resistant organisms depending on susceptibility results.</li> <li>• May be a last-line agent in management of MDR <i>Acinetobacter baumannii</i> infections [13], use can be guided by <i>in vitro</i> testing [11].</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• Directed treatment of Gram negative infection where organism and susceptibilities known: 960mg every 12 hours [35]. As per the BNF dose can be increased to 1.44g every 12 hours in severe infections.</li> <li>• Dose adjustment for renal impairment: consult usual references</li> <li>• For critically ill patients the findings from a paper analysing PK/PD and MICs to inform dose regimens for co-trimoxazole may be of use [36].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• Risk of hyperkalemia in patients with renal insufficiency, angiotensin-converting enzyme inhibitors or blockers (ACEI, ARB) or on other potassium-sparing drugs. Due to trimethoprim component, functioning like amiloride in the distal renal tubule. [13].</li> <li>• Several cases of severe bone marrow depression (several fatal) have resulted from the concurrent use of low-dose methotrexate and co-trimoxazole.</li> <li>• Can cause myelosuppression, monitor full blood count.</li> <li>• Routine stock in most hospitals.</li> </ul>

Eravacycline	
Place in therapy	<ul style="list-style-type: none"> <li>• Approved by US FDA August 2018 for the therapy of complicated intra-abdominal infections. Supply not available in Ireland until early 2019.</li> <li>• Eravacycline is a synthetic fluocycline tetracycline antibiotic [12].</li> <li>• Eravacycline was the most potent antibiotic of those tested against <i>A. baumannii</i>, including isolates that were resistant to sulbactam, imipenem/meropenem, levofloxacin and amikacin/tobramycin [37].</li> <li>• Eravacycline and comparators were tested against carbapenem- and tigecycline-resistant Enterobacterales and <i>Acinetobacter</i> spp. isolates received at the United Kingdom's national reference laboratory. Eravacycline MICs correlated closely with those of tigecycline but mostly were around 2-fold lower [38].</li> <li>• Has activity against Enterobacterales including strains that exhibited carbapenem resistance associated with KPC, OXA and NDM production [20].</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>• 1 mg/kg IV infused over 60 min every 12 hours (increased to 1.5 mg/kg if co-administered with a strong CYP3A4 inducer) [12].</li> <li>• Dose reduction required in severe hepatic impairment [12].</li> <li>• Can be dosed orally and parenterally with oral bioavailability estimated at 28% in phase I studies [20].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>• The most common side effects with eravacycline therapy were nausea (8%) and vomiting (4%).</li> <li>• Should be available to purchase in early 2019.</li> </ul>

Fosfomycin																	
Place in therapy	<ul style="list-style-type: none"> <li>As a result of its mechanism of action (inhibition of the first stage of peptidoglycan synthesis) and safety profile, fosfomycin may be expected to show synergistic combination therapy, including in regimens containing beta-lactams and aminoglycosides [10].</li> </ul>																
Optimal administration & dosing	<ul style="list-style-type: none"> <li>Total daily doses of 12-24 grams/day IV used in 2-3 divided doses depending on the indication, with doses on the higher end of the dose range in critically ill patients for first 24-48h before de-escalating dose [13, 29]. Maximum single dose is 8g.</li> <li>Dose adjustment for renal impairment [12, 29].</li> </ul> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 30%;">Creatinine clearance (mL/min)</th> <th>Recommended dosage</th> </tr> </thead> <tbody> <tr> <td>Greater than 40</td> <td>No dose adjustment</td> </tr> <tr> <td>31–40</td> <td>Normal loading dose for 1st dose. 70% of dose in 2–3 divided doses</td> </tr> <tr> <td>21–30</td> <td>Normal loading dose for 1st dose. 60% of dose in 2–3 divided doses</td> </tr> <tr> <td>11–20</td> <td>Normal loading dose for 1st dose. 40% of dose in 2–3 divided doses</td> </tr> <tr> <td>Less than 10</td> <td>Normal loading dose for 1st dose. 20% of dose in 1-2 divided doses</td> </tr> <tr> <td>Haemodialysi</td> <td>2-4g post dialysis [29]</td> </tr> <tr> <td>Continuous veno-venous haemodialysis diafiltration</td> <td>No dose adjustment</td> </tr> </tbody> </table>	Creatinine clearance (mL/min)	Recommended dosage	Greater than 40	No dose adjustment	31–40	Normal loading dose for 1st dose. 70% of dose in 2–3 divided doses	21–30	Normal loading dose for 1st dose. 60% of dose in 2–3 divided doses	11–20	Normal loading dose for 1st dose. 40% of dose in 2–3 divided doses	Less than 10	Normal loading dose for 1st dose. 20% of dose in 1-2 divided doses	Haemodialysi	2-4g post dialysis [29]	Continuous veno-venous haemodialysis diafiltration	No dose adjustment
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PK/PD characteristics	<ul style="list-style-type: none"> <li>Unclear if time dependent or concentration dependent killing [16].</li> <li>60%-70% time above the MIC.</li> </ul>																
Practical issues	<ul style="list-style-type: none"> <li>Generally well tolerated with minimal toxicity [39].</li> <li>Licensed in Ireland. May be stocked in some hospitals. Available as stock in wholesaler in Ireland.</li> </ul>																

Tigecycline	
Place in therapy	<ul style="list-style-type: none"> <li>• The role of tigecycline remains uncertain in the treatment of infections due to MDR GNB [11].</li> <li>• Majority of evidence is for use is in combination with other agents [14].</li> <li>• A low achievable serum concentration makes treatment of bloodstream infection problematic [13]. However, due to limited options for carbapenem-resistant organisms, it is used in this context in combinations with other agents.</li> <li>• There are published reports of a higher risk of death among patients receiving tigecycline compared to other antibacterial drugs, the greatest increase in mortality was observed in patients with ventilator-associated pneumonia, a review by the FDA suggested the increased mortality was associated with progression of disease, its bacteriostatic nature and suboptimal dosing [10].</li> <li>• Should not be used for urinary tract infections due to poor urine drug concentrations [16].</li> <li>• For therapy of CPE infections, tigecycline combination therapy and high-dose regimens may be more effective than monotherapy and standard-dose regimens, respectively [40]. <ul style="list-style-type: none"> <li>○ 21 studies included in this meta-analysis.</li> <li>○ 15 studies related to CPE, <i>Klebsiella</i> spp. being the main pathogen and bloodstream infection the most common manifestation.</li> <li>○ 30-day mortality was significantly lower in the combination group than the monotherapy. Moreover, the 30-day mortality in the triple tigecycline-containing combinations group was significantly lower than that in the dual combinations group.</li> <li>○ Tigecycline combined with colistin, carbapenems or aminoglycosides were the most common combinations regimens used. However the study could not assess</li> </ul> </li> </ul>

	<p>which combination might be the best choice.</p> <ul style="list-style-type: none"> <li>○ The meta-analysis showed that with pooled data from 2 studies, the ICU mortality was significantly lower in high-dose groups than in standard-dose groups. Conversely, pooled analysis from 2 further studies showed no difference between the 2 groups in terms of 30-day mortality. High –dose = 200mg stat then 100mg every 12 hours, standard dose = 100mg stat then 50mg every 12 hours.</li> </ul>
Optimal administration & dosing	<ul style="list-style-type: none"> <li>● Use higher than licensed dosing, such as 100mg twice daily, for infections due to MDR GNB in critical care [11].</li> <li>● Tigecycline regimens: 150 mg load and then 75 mg every 12 hours vs. 200 mg load and then 100 mg every 12 hours. Higher dose achieved best serum levels and superior in efficacy to lower tigecycline dose but also had the highest frequency of GI side effects [12].</li> </ul>
PK/PD characteristics	<ul style="list-style-type: none"> <li>● Time dependent killing [12].</li> <li>● Area under the curve : MIC 1 [16].</li> </ul>
Practical issues	<ul style="list-style-type: none"> <li>● Owing to the increased adverse effects associated with unlicensed high doses the following advice is recommended: [14]. <ul style="list-style-type: none"> <li>○ Prescription of anti-emetic medication.</li> <li>○ Weekly monitoring of liver function tests.</li> <li>○ Weekly monitoring of platelet counts.</li> </ul> </li> <li>● May be stock in some hospitals. Available as routine stock in wholesalers in Ireland.</li> </ul>

**Tables 2 & 3: Antibiogram of CPE isolates from National CPE Reference Laboratory Service (January to September 2018 data).**

<b>CPE isolates tested by Microbroth Dilution by the National CPE Reference Laboratory Service</b>											
Class:		Ceftaz- avibactam number susceptible	% Suscept.	Colistin number susceptible	% Suscept.	Ceftol-Tazo number susceptible	% Suscept.	Meropenem number susceptible	% Suscept.	Pip-tazo number susceptible	% Suscept.
A	<b>KPC (n=44)</b>	44	100%	44	100%	3	7%	9 (n=20)	45%	1	2%
B	<b>VIM (n=13)</b>	0	0%	13	100%	0	0%	4 (n=5)	75%	0	0%
	<b>NDM (n=19)</b>	1	5%	18	95%	0	0%	3 (n=14)	21%	0	0%
	<b>IMP (n=10)</b>	0	0%	10	100%	0	0%	8 (n=10)	80%	6	60%
D	<b>OXA-48 (n=198)</b>	198	100%	196	99%	103	52%	159 (n=164)	96%	0	0%

### CPE isolates tested by Minimum Inhibitory Concentration by the National CPE Reference Laboratory Service

Class:		Fosfomycin number susceptible	% Suscept.	Tigicycline number susceptible	% Suscept.	Amikacin number susceptible	% Suscept.	Gentamicin number susceptible	% Suscept.	Co-trim number susceptible	% Suscept.	Aztreonam number susceptible	% Suscept.
<b>B</b>	<b>VIM</b>	9 (n=9)	100%	6 (n=9)	67%	9 (n=9)	100%	2 (n=9)	22%	3 (n=9)	33%	2 (n=9)	22%
<b>D</b>	<b>OXA -48</b>	35 (n=36)	97%	30 (n=36)	83%	35 (n=35)	100%	25(n=34)	74%	23(n=36)	64%	21 (n=36)	58%

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