Chief Scientific Adviser's
Science Report

Issue four: Antimicrobial resistance in the food supply chain

Food Standards Agency
food.gov.uk

"In this CSA report, we look at a global problem – antimicrobial resistance. This is a complex health issue which government departments are working together to address. The spread of bacteria that are resistant to one or more antibiotics, is of great concern."

Professor Guy Poppy,
FSA Chief Scientific Adviser

'These resistant microbes can be present in our environment, in our livestock, in our food, and in us. Antimicrobial resistance threatens the effective treatment of an increasing range of infections. It has been estimated that the global impact of AMR could be 10 million deaths annually by 2050, and cost up to US $100 trillion in cumulative lost economic output. The FSA works to protect consumer interests in relation to food. As part of that mandate, the role that food plays in the problem of antimicrobial resistance is of concern. In particular because food may carry antimicrobial resistance genes that may then spread to other bacteria in the human gut.

'While the problem of antimicrobial resistance cannot be eliminated, its development can be slowed. A holistic approach is needed to tackle the problem throughout the food supply chain. As this report will explain, we need to understand how a whole range of practices, such as animal husbandry, food handling or how we irrigate our crops, might affect the spread of antimicrobial resistance to our food, and ultimately to us.'

'This report explains the science behind this intricate problem, and presents the latest findings that indicate the role that food plays in the problem of antimicrobial resistance.

'As this is a global problem, it requires global answers. This is why the FSA is working closely with governments, industry and other key stakeholders, both within the UK and across the world. The report argues that each individual aspect of the problem of antimicrobial resistance cannot be treated in isolation. Therefore, a high level of collaboration is essential, underpinned by robust and up-to-date scientific evidence.'

'With such complex problems, it further emphasises the role that technology can play in helping us manage these issues. As such, this report also briefly touches upon the tremendous advances that are being made in what's known as the Internet of Things. The Internet of Things is a network of devices that communicate in order to relay data. The report will explain, and provide examples of, how such an emerging technology can be of critical use to food safety and security.'

Introduction

In this report, we introduce antimicrobial resistance (AMR) and its global impact. We explain the role that the FSA plays in tackling the problem of AMR, through its research and engagement activities.

What is an antimicrobial?

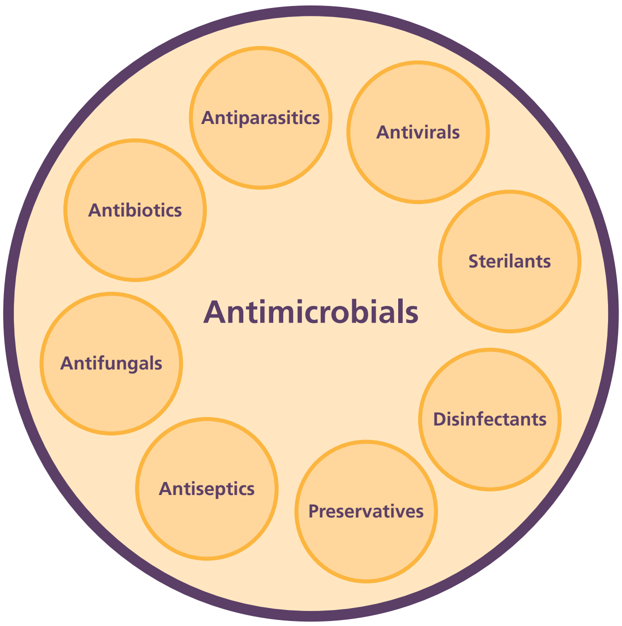
The term **antimicrobial** includes any substance that kills or stops the growth of **microbes**. They are used in a wide range of settings, and are thought to have varying impacts on antimicrobial resistance.

Microbes (or microorganisms) are microscopic organisms, which include bacteria, viruses, fungi, and parasites.

AMR, antimicrobial resistance, or resistance the ability of a microbe to withstand the effects of one or more antimicrobials.

AMR genes short pieces of DNA that cause microbes to have antimicrobial resistance.

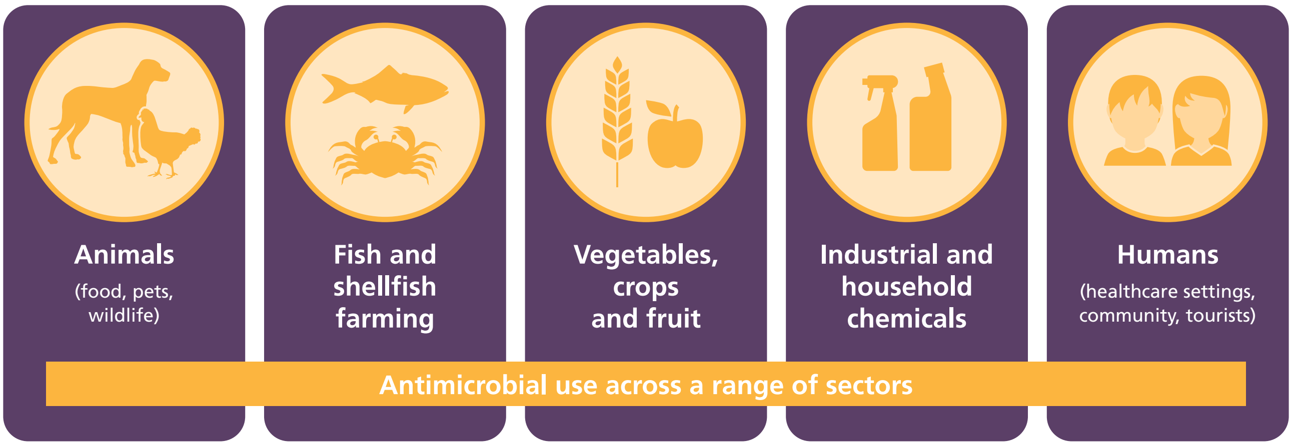
Types of antimicrobials



What is an antibiotic?

Antibiotics are a type of antimicrobial. An antibiotic is a drug used to treat bacterial infections in both humans and animals. They have no effect on viral or fungal infections. Examples of antibiotics include penicillin, tetracyclines, meticillin and colistin. The use and misuse of antibiotics is a major factor in the development and spread of AMR in bacteria. It is less clear whether other types of antimicrobials also make a contribution.

Sectors impacted by antimicrobial use



What is AMR?

AMR is the ability of a microbe to withstand the effects of antimicrobials to which it would normally be susceptible. This means that antimicrobials become ineffective. To have this ability, the microbe must have antimicrobial resistance genes (AMR genes). Microbes may be resistant to just one antimicrobial or to many (multi-resistant) depending on which AMR genes they have. This can make infections by these microbes difficult to treat, causing infections to persist.

Multi-resistant – bacteria resistant to more than one category of antibiotics.

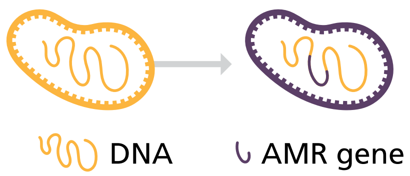
How does AMR develop?

Resistance can develop via two mechanisms. Firstly, by random mutations (changes to DNA), as it is copied during bacterial replication. Secondly, AMR genes can be exchanged between bacteria, even of different types. This means that the number of different types of bacteria that have AMR genes increases.

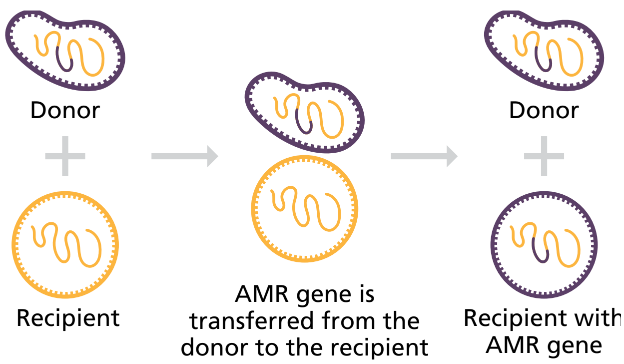
How does AMR spread?

AMR spreads primarily through the use and misuse of antimicrobials in humans and animals. The food chain contributes to the spread of AMR bacteria. As AMR microbes are found in soil, water and in human or animal excrement, food can become contaminated with AMR microbes. Food can also be contaminated during handling and processing.

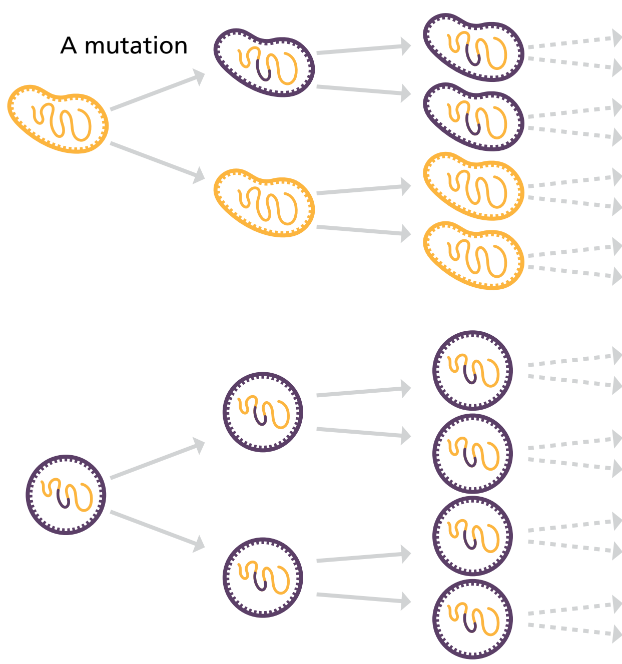
Mutation



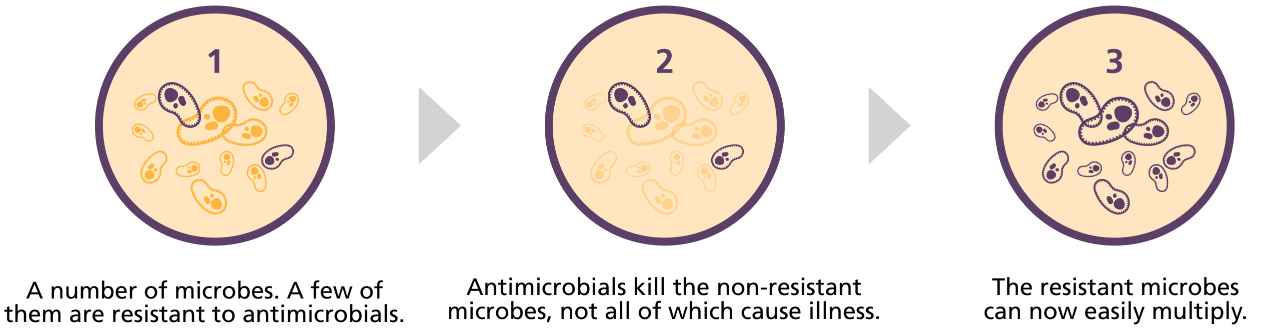
Genes can be transferred between different types of bacteria



Replication of bacteria with antimicrobial resistance spreads AMR genes further



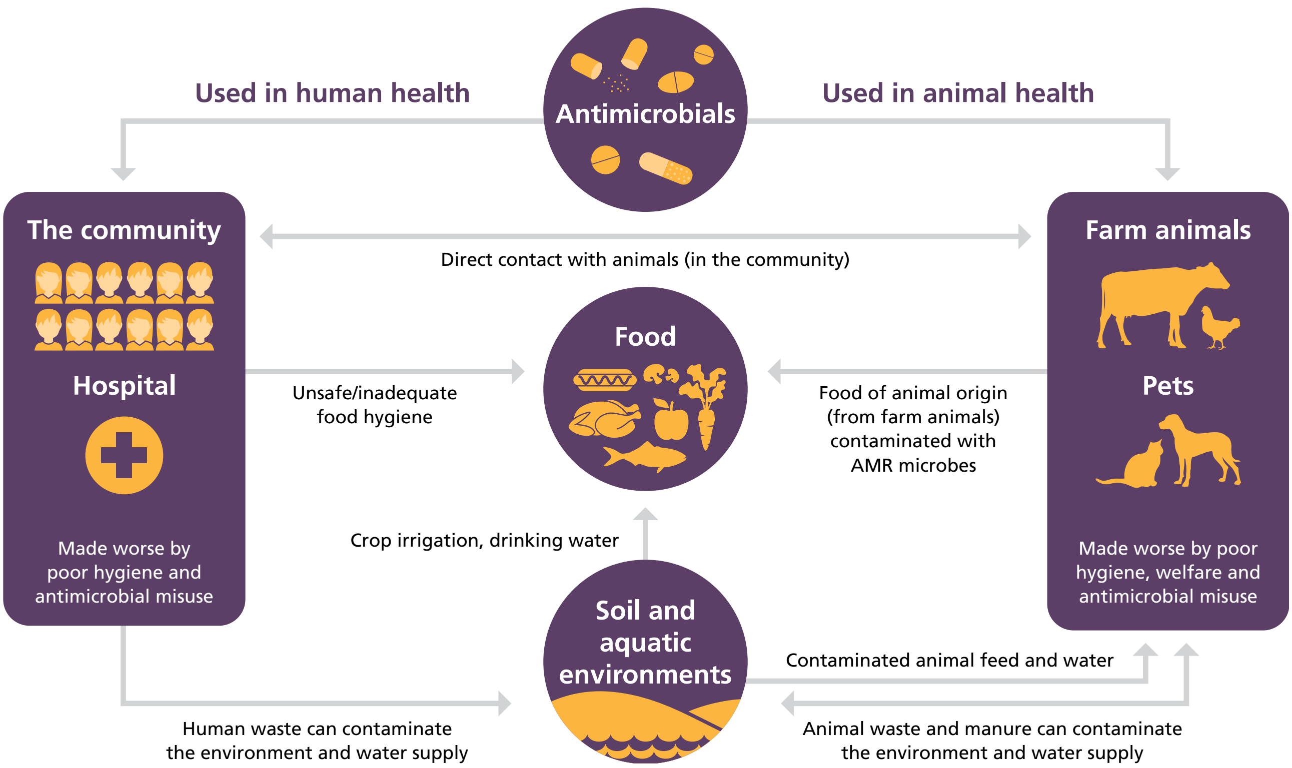
How antimicrobials speed up the spread of AMR microbes



How can antibiotic resistance spread through food?

AMR microbes can be spread via food in several ways:

- Faecal contamination when the animal is slaughtered could transfer AMR microbes to meat and meat products.
- Products that come from plants, but also shellfish, can become contaminated if the water used to grow them is contaminated with sources of AMR microbes, such as human and/or animal faeces.
- Food may be contaminated by AMR microbes in the environment. Such contamination may occur up to the point of consumption.
- When food is handled, AMR bacteria can spread from one type of food to another. This is called cross-contamination.



How are people exposed to AMR microbes?

People can be exposed to AMR microbes in the same way they are exposed to normal microbes. This can happen through a number of routes such as from person-to-person, and from sources that have become contaminated (animals, the environment, water, and food).

Food is important in the problem of AMR, because pathogenic and non-pathogenic microbes in food may carry AMR genes that can be spread to other bacteria in the human gut.

Pathogenic is the ability to cause disease in humans and animals.

Food of animal origin – Foods such as meat, milk, eggs, cheese and yoghurt.

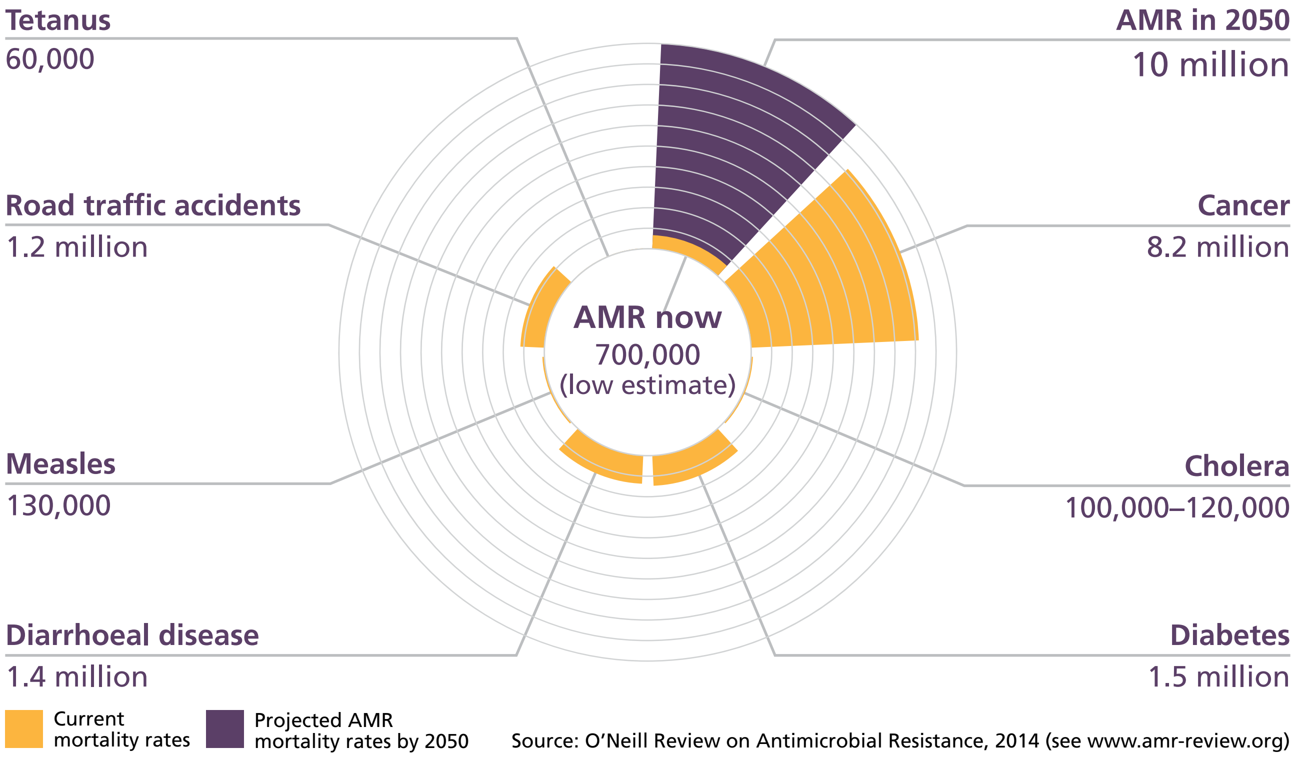
MRSA (Meticillin resistant *Staphylococcus aureus*) are strains of *S. aureus* that are resistant to a range of antibiotics, including meticillin.

What are the consequences of AMR to public health?

Infections caused by AMR microbes are unlikely to respond to standard treatments resulting in prolonged illness and a greater risk to health.

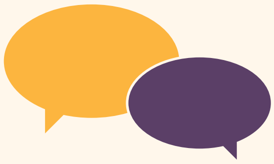
For example, MRSA (Meticillin-resistant *Staphylococcus aureus*) is estimated to cause 64% more deaths than infections caused by a non-resistant strain of the bacteria. AMR microbes are also more likely to be passed on to other people because those infected are sick for longer. The O'Neill Review estimated that the global impact of AMR could be 10 million deaths annually by 2050, and cost up to US $100 trillion in cumulative lost economic output. The nature of this global problem emphasises the challenge that the UK faces when tackling AMR in the food supply chain.

Deaths attributed to AMR every year compared to other major causes



Source: O'Neill Review on Antimicrobial Resistance, 2014 (see www.amr-review.org)

How can we reduce our exposure to AMR microbes in food?



Consumer advice

The FSA continues to promote the 4Cs (cleaning, avoiding cross-contamination, cooking and chilling) in its food hygiene messaging to both industry and consumers.

Thorough cooking is crucial as it can destroy bacteria that may be present in the foodstuff including those that are AMR.

The FSA 4Cs

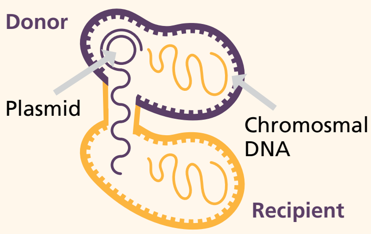
The risk to public health from AMR microbes in food can be reduced in similar ways to that of non-AMR microbes in food. It is important that good hygiene practices are in place to minimise the risk of spreading AMR microbes. Therefore, the FSA promotes the 4Cs (see image above). Greater awareness and practice of good hygiene by food businesses and consumers will reduce exposure. For example, fruits and vegetables should be washed thoroughly and/or peeled if they are to be consumed raw, unless otherwise indicated. Also, consumer demand for burgers cooked 'rare', and for lightly cooked pork and poultry products may increase the risk of exposure to AMR microbes.

Most cases of food poisoning, such as those caused by *Salmonella* and *Campylobacter* get better by themselves, and antimicrobials are not used for treatment. Serious infections with these bacteria are uncommon but are treated with antibiotics.

The spread of colistin resistance genes

What is colistin?

Colistin is an antibiotic that became available for clinical use in 1959. Colistin has fallen out of favour due to its side-effects but remains one of the antibiotics of last resort for people with multi-resistant infections caused by certain species of bacteria.



The plasmid that contains the *mcr-1* gene is copied to the recipient cell. Afterwards, both bacteria have the gene.

Enterobacteriaceae a family of bacteria that includes, along with harmless species, the pathogens *Salmonella, Escherichia coli, Klebsiella* and *Shigella.*

Why is colistin resistance important?

In 2015, a new colistin resistance gene (*mcr-1*) was found in several types of bacteria from raw meat and people. The gene is found on a circular piece of DNA called a plasmid, which is able to transfer between one bacterium and another (see figure). This is important because it is more likely to spread to other bacteria (including different types) than genes located on chromosomes. In January 2016, an *E. coli* strain that was resistant to colistin, and to another group of antibiotics of last resort (carbapenems), was discovered in chicken meat on sale in China. This finding is of concern as the spread of bacteria with this combination of resistances to many critically-important antibiotics increases the risks of un-treatable infections in people.

Since its discovery, occurrence of the *mcr-1* colistin resistance gene has been reported in *E. coli*, *Salmonella*, and *Klebsiella* throughout the world, including several European countries. It has been found in people, pigs, poultry and other raw foods. The Animal and Plant Health Agency (APHA) found the gene in *Salmonella* and *E. coli* in pigs on a British farm in late 2015. In June 2016, a second plasmid-based colistin resistance gene (*mcr-2*) was found in Belgian piglets and calves.

What is the risk to public health of the colistin resistance gene?

Following a risk assessment based on the data available in early 2016, the FSA considers the risks to human health via the food supply chain to be very low in the short-term (with varying levels of uncertainty). Public Health England (PHE) also considers the immediate risk to public health to be very low. The long-term risk of the spread of the gene is currently unquantified. Although data are still limited, they suggest that the gene is still rare in the UK.

The European Centre for Disease Prevention and Control published a rapid risk assessment on plasmid-mediated colistin resistance in Enterobacteriaceae in June 2016. This sets out a range of actions to reduce the risks and spread of plasmid-mediated colistin resistance. It is essential to recognise the importance of good hygiene practices in meat production, and in the handling and cooking of meat in order to minimise the risk.

What else is the FSA and the rest of Government doing to tackle colistin resistance?

Along with the rest of the EU, the FSA is carrying out a survey on AMR *E. coli* in raw retail pork, beef and poultry meat in the UK. From 2016, testing for colistin resistance has also been included. We are keeping a close eye on the situation and continue to review the risk as more data emerge.

PHE identified 15 isolates with the *mcr-1* gene (12 *Salmonella* and 3 *E. coli*) from people and food products with the gene (out of 24,000 samples screened). The APHA and Veterinary Medicines Directorate screened samples collected from pigs as part of UK surveillance programmes. The European Medicines Agency has published a series of recommendations to reduce the use of colistin in animal husbandry in EU Member States.

AMR in the food supply chain

Current knowledge

There is published evidence that AMR bacteria are found in the food supply chain and therefore present a potential route of exposure for humans.

In 1999, the FSA's Advisory Committee on the Microbiological Safety of Food (ACMSF) published a report on AMR in relation to food safety. This in-depth review assessed the risks to people from resistant bacteria entering any part of the food supply chain. The ACMSF found that there were AMR bacteria in the food supply chain and therefore people might be exposed to them. They were particularly concerned about a strain of *Salmonella* (*S. typhimurium* DT104) that was resistant to multiple categories of antibiotics. At the time, this type of *Salmonella* was the second most common in UK food.

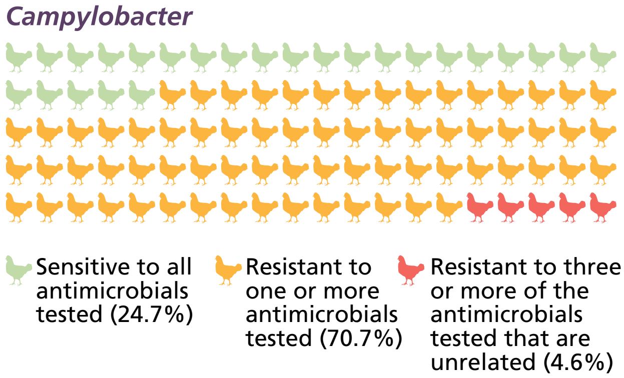
The EU collects and reports current data from Member States on the levels of AMR found in food, humans, and animals. In 2011, the European Food Safety Authority (EFSA) published a Scientific Opinion on two particularly important kinds of antibiotic resistance in *Salmonella* and *E. coli*. Specifically, they looked at the risks to public health of strains that produce one of two enzymes (called ESBL and AmpC) in food and food-producing animals. They found that the resistant types of *Salmonella* and *E. coli* have been reported ever more often, both in Europe and globally, since 2000. Importantly, they found some indirect evidence of people being infected with these types of AMR bacteria by food. Poultry and poultry products were most frequently reported to contain these resistant bacteria.

ESBL (Extended spectrum beta lactamases) and **AmpC beta-lactamases** are bacterial enzymes that confer resistance to several different penicillin-like antibiotic categories.

Isolate – a single type of microbe separated from a sample containing a mixture of types of microbes.

Sensitive – the antimicrobial is effective at killing or inhibiting the microbe.

Resistance of *Campylobacter*



The FSA commissioned a UK-wide survey between February 2014 and February 2015 to determine how much *Campylobacter* there was on fresh, whole, UK-produced chicken on sale to the public. A subset of *Campylobacter* isolates from this survey were also tested for their resistance to five classes of antibiotics. The high levels of resistance found (see graphic above) are of particular concern, given that *Campylobacter* was found in 73% of the retail chicken samples tested. It is important to recognise that there has been a downward trend in *Campylobacter* levels – it was present on 50% of chicken samples in 2015-16.

Antibiotic usage in the poultry industry has reduced by 44% between 2012 and 2015.

With around 5% of isolates showing multi-resistance, and with 900 million chickens produced in 2014, there could potentially be millions of chickens with multi-resistant *Campylobacter*. The poultry industry is taking active steps to address these issues. For example, in 2011 the British Poultry Council formed an Antibiotic Stewardship Scheme that advocates responsible use of antibiotics. Data collected by this scheme shows that overall antibiotic usage in the poultry industry has reduced by 44% between 2012 and 2015.

Evidence gaps

Although there is evidence of the presence of AMR bacteria in retail foods, it is not yet clear what contribution food makes to the overall problem of AMR. Significant evidence gaps include the contribution of: different foods of both animal and non-animal origin; different types of antimicrobials; people who handle food in processing and catering settings; and the importance of AMR microbes in foods imported into the UK, as opposed to food produced in the UK. Further data are needed on the prevalence, levels, and movement of resistant microbes and genes throughout the food supply chain.

Most work has focussed on pathogens, however little is known about the contribution of non-pathogenic microbes. Non-pathogenic microbes are important as they could transfer AMR genes to pathogenic microbes.

Challenges

There are a number of complicating factors that make controlling AMR in the food supply chain particularly challenging. For one, the reduction of AMR is highly dependent on controlling the use of antibiotics in food animals and humans.

Ecology is the branch of biology dealing with the relationships and interactions between living things and their surroundings, including other organisms.

In order to minimise the risk to public health from AMR in the food supply chain, we need to know where AMR infections in people are coming from. Crucially, we need to determine if changing levels of AMR in foodborne bacteria are also seen in bacteria that cause infections in people. This is complicated by four further challenges:

- People can be infected with AMR bacteria through multiple routes, not just food. It is not easy to tell if the infection came from food or elsewhere.
- The complex nature of the global food supply chain makes it difficult to trace the source of foods contaminated with AMR microbes.
- The transfer of AMR genes between bacteria further complicates identifying the source.
- The knowledge on the ecology and transfer of AMR genes and microbes throughout the food chain is incomplete.

FSA science on AMR

Research

We actively fund research to fill gaps in our knowledge, underpin risk assessment of AMR in the food chain and inform risk management and policy decisions.

The FSA has published a study that successfully developed a method to detect ESBL-producing Enterobacteriaceae in meat and thus provide us with the means to carry out future surveys.

The FSA has commissioned the Royal Veterinary College to carry out a systematic review on the occurrence of AMR bacteria in food at retail. The review will provide a comprehensive description of the current state of knowledge with regard to the type of AMR bacteria that consumers could be exposed to. The review is also likely to identify knowledge gaps to guide future research, supported by the FSA (or others). The review, together with other evidence, will inform AMR policy and discussions the FSA has with other departments. We anticipate publishing the final report in Autumn 2016.

Recent FSA funded research highlighted that some uses of recycled waste and waste derived products (in agriculture and food production) have the potential to spread AMR. AMR microbes or residues of antimicrobials could be present in these materials.

Data gathering

Testing for AMR bacteria has previously been included within FSA's retail food surveys investigating major foodborne pathogens on red meats and chicken. We are continuing to gather UK AMR surveillance data in retail foods which will help to form a baseline.

The FSA are carrying out a survey of *Campylobacter* contamination in fresh, whole, UK-produced chicken at retail sale. We have collected data on the resistance of a subset of these *Campylobacter* samples to a range of antimicrobials.

The European Commission have set-up a 7-year mandatory surveillance in Member States for specific pathogens within slaughterhouse environments, led in the UK by the VMD. The FSA is leading on an additional component of this survey by collecting data on several types of AMR in *E. coli* in analysing raw retail beef, pork and poultry in the UK. A proportion of the meats tested will include non-UK meats.

The Department of Health has funded a three-year project with Public Health England (PHE), which aims to establish where ESBL–producing *E. coli* is found and the threat posed to animal and public health in the UK. FSA are financially supporting a component within this study that is quantifying ESBL–producing *E. coli* in 400 raw meats and 400 fresh produce (fruit and vegetable) samples. This study is likely to report in late 2016.

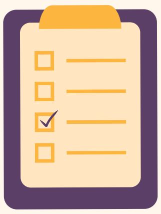
AMR microbes on fresh produce

The majority of UK data on AMR Microbes in food has focussed on raw meat samples. However, one area that is currently lacking in UK data is the levels and types of AMR bacteria found in fresh produce (salads, fruit and vegetables). The presence of AMR microbes could be a cause for concern as some fresh produce are consumed raw and microbes are not always removed by washing.

The lack of UK AMR data on fresh produce is likely to be highlighted as an evidence gap in the FSA systematic review on the occurrence of AMR in food at retail sale. The FSA is dealing with this using the surveillance approach described above. The EFSA's Scientific Opinion on Carbapenem (a class of antibiotics) resistance in food animal ecosystems also recommended additional AMR monitoring in imported food (including fresh produce) from countries outside the EU. Recent studies from Mozambique and Pakistan have found evidence of carbapenem resistance in bacteria found in samples of fresh produce.

In 2016, a paper reported the finding of ESBL–producing Enterobacteriaceae on fresh produce. Six percent of the samples analysed (7 out of 119) were contaminated with these bacteria. Further characterisation of the ESBL–encoding genes in the samples revealed that these genes were similar to those found in strains of the Enterobacteriaceae in people. The study concluded that raw vegetables could be a potential source of resistance genes for the bacterial strains found in humans.

Risk assessment



Microbiological risk assessments (along with microbiological risk management) play a core part in ensuring the food that people consume is safe. The FSA provides risk assessments on AMR issues of potential public health significance in the food chain.

Microbiological risk assessment is a scientific approach used to estimate the risk from microbiological hazards in terms of public health. We work closely with VMD, the Department of Health, Defra, APHA and PHE when an AMR incident occurs in livestock and foods that may represent a risk to public health. This includes first discoveries of MRSA in poultry and pigs, and the colistin *mcr-1* resistance gene in pigs in the UK.

ACMSF sub-group on AMR

The FSA's Advisory Committee on the Microbiological Safety of Food (ACMSF) has established a sub-group on AMR. It assesses the risks to humans from foodborne transmission of AMR microbes and provides advice to the FSA.

The ACMSF sub group on AMR has recently considered a draft microbiological risk assessment on MRSA in the UK food chain, with a focus on a particular type of MRSA that has been associated with food producing animals. They continue to be consulted on the FSA's risk assessments on colistin resistance (*mcr-1* and *mcr-2*).

Our response

People have a right to be protected from unacceptable risks in food, whether those risks are about the safety of food today, or the food choices available to them in the future. Although the immediate food safety risk from AMR in food is very low, the risks to the sustainability of food production systems and to future public health more widely are very high.

The Government response to Lord O'Neill's Review on AMR was published earlier this month. It restates the commitment of the Government to work nationally and internationally to take concrete steps to meet the significant threat that AMR poses to global health, prosperity and security.

A collaborative approach involving government and industry will be essential to tackle the economic, developmental, human and animal health challenges involved. The FSA is committed to playing its part in this collaborative approach.

Defra is leading work to reduce antibiotic use in livestock and fish farmed for food to an average of 50mg/kg by 2018, which would be a drop of around a fifth from 2014.

Capacity building that encompasses food security, effective regulation, professional training and collection of reliable data is important for ensuring responsible use of antibiotics in agriculture.

Lord O'Neill made 29 recommendations in his report, and the Government has set out its response to each of these. Three of these are particularly relevant to the role and work of the FSA. Recommendation 3.3 calls on UN agencies for human and animal health and for food and agriculture to bring together a global group of experts to help everyone agree those antibiotics that should be banned or restricted from use in agriculture.

Codex recently agreed the setting up of an AMR Task Force. As a preliminary step in this work, the UK will be hosting a working group, which the FSA will co-chair with Australia and the USA. The working group will help define the scope of the AMR Task Force's work, and the terms of reference for the science provided to the Task Force by the relevant UN agencies. We are already working with others across government to prepare for this meeting, to be held before the end of 2016.

Codex (Codex Alimentarius) is an inter-governmental body jointly administered by the Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO). Codex develops harmonised, science-based food standards to protect consumer health and promote fair practices in international food trade.

Recommendation 3.4 calls on major food producers, retailers and regulators to agree standards for 'responsible use' in agriculture, as a basis for labelling or certification schemes. The FSA believes that consumers are able to engage with complex food issues if they are given the right support and opportunities to do so. We also believe that providing greater transparency on anti-biotic use will incentivise rapid and comprehensive improvement, support innovation and reward responsible businesses.

We will support work across Government to encourage food manufacturers, assurance scheme and retailers to develop standards for the responsible use of antibiotics in poultry, pig and dairy sectors and incorporate these into standards for assurance scheme standards. This work should also set clear expectations about the information on usage of antibiotics that industry should publish as open data, to support development of new tools and applications that support consumers in taking greater responsibility for the food decisions they make and their impacts.

Recommendation 4 calls for improved surveillance. Earlier in this report we've talked about some of the scientific studies that we and others have funded to look at AMR in food. This data is limited at present. As one of our corporate objectives for this year we are developing a new strategic approach to surveillance, and we will apply this approach to surveillance for AMR in food.

Our Government partnerships

The FSA are represented on several cross-government working groups on AMR. These groups provide a useful forum for the FSA and other Government Departments. Officials share and discuss the findings on recent AMR research and surveillance data and the impact to public health.

- Department of Health led 'High Level AMR Steering Group' considers the UK Government's strategy and action plans for AMR as a whole.
- Defra led 'Antimicrobial Resistance Co-ordination' (DARC) Group. Co-ordinates, advises and reviews VMD activities on antimicrobial usage in animals and antimicrobial resistance (AMR) in microbes from feeding stuffs, animals and food.
- Department of Health led 'Advisory Committee on Antimicrobial Resistance and Healthcare Associated Infection' (ARHAI) (observers).

We are developing a new strategic approach to surveillance.

Conclusion

In summary, this report has shown that AMR is a developing and global problem that cuts across multiple domains and so requires a collaborative solution that engages with governments, industry, academia and the public. The FSA, in collaboration with its partners, has been working to fully establish the link between the food we eat and the problem of AMR. The FSA is taking steps to reduce the risk to consumers from AMR microbes in food.

These include:

- Working with industry as they develop action plans to reduce the levels of AMR in food;
- independent surveillance of AMR levels in food; and;
- working with consumers to raise awareness of the issue of AMR, and provide practical advice.

The science that the FSA commissions and utilises is crucial in achieving these goals.

Also of interest: The internet of food things

The Internet of Things has considerable potential for assisting with food safety and, to a lesser extent, food security.

The Internet of Things is a network created from everyday objects, which have the ability to communicate with other devices. The idea is that this would enable advanced services, similar to those designed using internet-connected computers and smartphones. Industry analysts estimate that the number of internet-connected objects could increase from 14 billion today, to somewhere between 20 and 100 billion by 2020. The technology is still emerging, yet there are a few examples of this idea in practice.

An example application of the Internet of Things to the food supply chain is a pilot project that used data loggers to monitor the actual temperature of sandwiches. The data loggers located in the sandwich sent their data to an app, which informed the shop owner of any significant breaches of temperature control. This project formed part of a research initiative commissioned by the FSA and 'IT as a Utility Network+' (ITaaU) to explore how the Internet of Things can be applied to the food supply chain.

As part of this initiative, a review was conducted of published research on the Internet of Things related to food safety and security. This concluded that the most significant impact could be in the area of transport, logistics and storage of food. Sensors can be stored in packaging that measure the temperature, humidity and even chemical composition within the packaging. When combined with a radio-frequency identification tag, this could allow a non-destructive way to monitor the food's integrity, via a tag-reader located metres away from the package. This technology could simplify tracking and tracing throughout highly complex food supply-chains. Several such systems are commercially available.

For the consumer, there could be benefits to trust, health, nutrition, identification of safety issues, and supporting personal responsibility for food decisions. A demonstrator project within the FSA/ITaaU's initiative showed how a network of sensors enabled tenants of an allotment to conduct communal experiments. This allowed the tenants to understand how growing conditions varied across the allotment.

Another FSA/ITaaU project used a system of sensors installed in a commercial kitchen to generate a record of compliance with food safety protocols. Using systems such as those developed by these projects and, crucially, the data they generate, leads to the prospect of improved food safety via automated processes throughout the food supply chain. The FSA is currently considering the implications and applications of this technology.

Acknowledgments

With thanks for the contributions of Bobby Kainth, Kirsten Stone, Fraeya Whiffin, Javier Dominguez, Steve Wearne and David Self. Thanks also to colleagues from ACMSF, APHA, DH, FSA, PHE, and VMD for their helpful suggestions. With reference to the "Also of interest" section, we would like to thank the Information Knowledge Management team for their input.

Further Reading

AMR in general

O'Neill, (2014), *Antimicrobial Resistance: Tackling a crisis for the health and wealth of nations*, amr-review.org/

Verraes C et al., (2013) *Antimicrobial resistance in the food chain: a review. Int J Environ Res Public Health.* DOI:10.3390/ijerph10072643.

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Colistin

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