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Antimicrobial/antibiotic resistance is the phenomenon where infectious bacteria or fungi become resistant to an antibiotic, otherwise known as a drug meant to target and kill bacteria/fungi. Bacteria and fungi become resistant to antibiotics, not humans or animals. Antibiotic resistance can affect anyone at any stage of life. Additionally, it is a growing problem in several vital industries such as healthcare, veterinary services, and agriculture. The CDC reports that at least 2.8 million people in the US are infected with antibiotic resistant bacteria each year and more than 35,000 people die from such infections each year. The threat of antibiotic resistance to deadly infections is a potential threat to human existence. For instance, scientists like Professor Graham from Newcastle University and Professor Collignon from Australian National University predict it will be the underlying cause of the next global pandemic if resistance continues to increase at its current rate. By delving into this topic through extensive research and providing visualizations, we hope to raise awareness and motivate readers to do the same.

Although it is understood as a critical problem, the development of antibiotic resistance occurs naturally and has existed since the first antibiotic--Penicillin--was discovered in 1928 by Alexander Flemming. However, the increasing misuse and/or overuse of antibiotics combined with a lack of infection prevention and control has greatly accelerated this natural occurrence--turning it into a deadly threat. One common misuse of antibiotics happens when one fails to complete a full course of antibiotics or simply stops taking them once they feel better. Feeling better does not equate to the defeat of all the bacteria causing the infection, and the remaining bacteria are likely those that are more resilient to the antibiotic. Not taking the full course of antibiotics creates an ideal environment for remaining bacteria to develop resistance. Once bacteria or fungi develop the ability to withstand exposure to the drugs designed to kill them, they multiply to create identically resistant bacteria/fungi. These germs are invisible to the naked eye and can easily be transferred from one living thing to another. Some antibiotic resistant germs can even directly pass on their acquired resistance to other germs which then multiply and continue the cycle. These resistant germs can transfer across countries and can infect not only humans but animals, soil, water, and other aspects of our environment.

Over the course of this paper, we will highlight six dangerous pathogens that have shown increasing amounts of resistance to antibiotics. Salmonella, which is commonly known for causing foodborne infections, has become increasingly antibiotic-resistant over the past few decades, infecting cold and warm-blooded animals as well as our food and water supply. Escherichia coli (E. Coli) can cause life-threatening bloodstream infections or more common ones such as urinary tract infections and its resistance to antibiotics is rapidly becoming more prevalent. Streptococcus pneumoniae is a bacteria responsible for most cases of community-acquired pneumonia and is regarded as an extracellular bacteria meaning it is free to grow and travel throughout various tissues of the body instead of staying in one spot. Staphylococcus aureus is known to cause staph infections but can also infect the bloodstream, lungs, bones, and joints. Neisseria gonorrhoeae is a bacteria that causes the common STD called gonorrhea which infects the reproductive tract of women and the urethra in both women and men. Acinetobacter is a group of bacteria that are most commonly found in soil or water and can cause infections in the blood, urinary tract, and lungs.

We will also focus on five major classes of antibiotics: Penicillins, Fluoroquinolones, Carbapenems, Cephalosporins, and Macrolides. These classes contain the most commonly used antibiotics such as Amoxicillin. Furthermore, the CDC recognizes that Carbapenem resistant bacteria is an urgent threat. Penicillins were the first kind of antibiotics used and Penicillin G was discovered by accident in 1928. Penicillins can be used to treat a broad range of infections including gonorrhea, staph, urinary, and respiratory infections. Another important aspect to these antibiotics is that Macrolides are unique since they work to suppress the growth of bacteria instead of killing them which means there will be less resistance overall to them.

We ultimately used data collected from the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO). The CDC compiles the latest national death and infection estimates, which highlight the ongoing threat of antibiotic resistance in the United States, into an annual Antibiotic Resistance Threats Report. Their report presently contains eighteen antibiotic resistant bacteria and fungi, categorized based on their level of concern to human health-- urgent, serious, and concerning. Additionally, the CDC reports statistics to the WHO, where they compile data into a system called Global Antimicrobial Resistance Surveillance System (GLASS). On global terms, GLASS is able to provide a standardized approach to the continued collection, analysis, and sharing of data on antimicrobial resistance. Unfortunately even among promising data, there were some limitations to the data sets we chose. For instance, not all countries are reporting data on their levels of AMR to the WHO, and therefore they cannot be incorporated into GLASS, which left missing values in our data set. A major country we were hoping to find data for was China. We felt the nature of their population size and healthcare system would help add to our investigation, but no data was proven to be reliable. We also would have liked to find global data for the trend over time of AMR. With the CDC’s data however, we were able to analyze this for the United States.

In order for the data to be in a more presentable format, we had to clean it to make it workable. We updated several column heading variables as well as refined the number of variables we wanted to work with so as to not overcomplicate our final goal of spreading awareness to the general public. Some data points were not accessible to us, so we had to adjust for this by manually creating some of our own tables. For example, not all geographic data was present, so we had to manually enter latitude and longitude values in order to be able to fulfill our idea for creating heat map visualizations.

With the data we collected and cleaned, we were able to produce eight different visualizations. The first visualization provides more of an overview of the presence of antibiotic resistance in different countries around the world. Because the data we collected was missing information from a lot of countries, this particular global heat map of percent resistance appears to have a lot of missing information. Also in relation to the world, we have a visualization that demonstrates the prevalence of each of the different pathogens throughout the world titled Number of Pathogens in the World 2018. We also have graphs depicting the amount of resistance per antibiotic and bacteria. We have a few heat maps specific to the United States including the amount of antibiotic resistant E. Coli per state and the amount of antibiotics prescribed per 1000 people.

Continued through our analysis, for the United States, antibiotic resistance appears to be lower among the southeastern portion of the country. We speculate that the reason for this is because the number of prescribed antibiotics in the southeastern states is higher than any other part of the country which allows a variety of antibiotics to be distributed and counteract different bacteria. If we look at the world map, we can confirm this speculation since the percent of resistance is extremely low in the United States. Now on a global level, points of interest include Russia, India, the Middle East, and parts of Africa. In general, the regions with lower levels of resistance are the United States, Canada, Australia, and much of Europe. It appears that the locations where people have greater access to antibiotics show lower levels of antibiotic resistance among pathogens. This does not mean AMR is not still an issue in these countries though. Bacteria know no boundaries and can make their way around the globe as easily as us.

As listed by the CDC, the pathogens that are of most concern at the present time include Carbapenem-resistant Acinetobacter, drug-resistant Candida auris, Clostridioides difficile, Carbapenem-resistant Enterobacteriaceae, and drug-resistant Neisseria gonorrhoeae. The antibiotics used to fight these bacteria are becoming less effective the more we use them over time. This is worrisome with having two of the most dangerous pathogens both resistant to the major drug class of Carbapenems. A multitude of these germs are resistant to multiple drug classes, which indicates even more of a threat. Even Penicillin, the oldest antibiotic, has only shown an increase in its rate among pathogenic resistance since the time it was discovered nearly a century ago.

While there are many factors at play which contribute to the global rise of antibiotic resistance, a major one worth bringing attention to is the agricultural industry. This is due to its environmental component coupled with the direct correlation to our food supply. With the increasing amount of agriculture present in our world, there is also a rise in antibiotic use among this community. Farmers use antibiotics on their livestock to prevent illnesses that would kill off their products. This is seen especially in large scale factory farming where they have to utilize as much of the given space as possible. This creates close quarters for living arrangements among the animals. With this, fecal matter among other things becomes increasingly transmissible. Runoff from farming communities can leech bacteria as well as leftover antibiotics into our surrounding environment. The more bacteria and antibiotics that are present in our natural environment, the more resistance will come about because they are under the right conditions to adapt and survive. However, without using antibiotics on livestock, the animal’s health is not ensured and could therefore break the food supply chain. For the population to continue our current eating habits, we need antibiotics. If we do not have antibiotics that work against the bacteria potentially harming the livestock, this is a serious issue. We would have liked to incorporate more of this information into our visualizations and presentation, but could not find a workable data set to partner with what we had.

It is also important to recognize that the same types of bacteria do not always cause the same types of infections in our bodies once contracted. For instance, the E. Coli bacterium is able to cause both urinary tract infections and traveler’s diarrhea. It depends on which strain is present, so it is important to be able to distinguish between the types so that the proper antibiotic(s) can be used to treat the infection. There is no one antibiotic that is versatile enough to cover all infections, and many times now multiple antibiotics need to be implemented into someone’s treatment plan. This is because some bacteria have developed enough resistance that one single antibiotic will not make a dent. It is also misunderstood by much of the public the difference between bacteria and viruses, and they need to be aware that antibiotics will do nothing in terms of stopping their infections if they have a viral infection. Antibiotics are designed to kill bacteria, thus also killing the “good” bacteria inside us like the ones that promote a healthy gut and digestion. If someone were suffering a viral infection and misused antibiotics in an attempt to treat themselves, they would only be hindering their own immune systems, in turn making it harder to fight off the initial infection. As observed through our data, antibiotics are becoming increasingly accessible to people, even over the counter. This allows for more error among antibiotic usage if sick people are not being evaluated by a medical professional before starting a course of treatment. It is clear by observing the yearly trend data for the number of prescriptions given annually in the United States that there is an increase in the rate year after year. This indicates the number of antibiotic resistant infections is also increasing.

Overall, antibiotic resistance is a major health crisis both globally and locally. The progressive growth of these bacteria and the infections they cause is a huge concern and we are reaching a point where it may be impossible to treat some infections. There are many factors contributing to the aggressive incline of these antibiotics. It’s difficult to pinpoint the exact factors that are most important to combat antibiotic resistance as they all work together to accelerate the issue. However, we are in dire need of some major and quick changes. First, we need to implement strategies that work to combat the spread of infection throughout health care settings because of the concerning prevalence of acinetobacter infections in hospital settings.

Vaccines are also extremely important in the process of combating antibiotic resistance. WHO estimates that if every child in the US were to receive a vaccination that protects against *Streptococcus pneumoniae,*  approximately 11 million days of antibiotic use each person would experience in life would be prevented. Additionally, vaccines that prevent viruses such as the flu are helpful in the sense that less cases of flu would allow for less over-prescribing of antibiotics. Furthermore, recognizing new threats or newly resistant bacteria and working quickly to prevent its spread is vital in combating this global health crisis. Lastly, as the goal of this paper, we need to expand the knowledge of antibiotic resistance and we need to reach a wider audience that will be motivated to take proper action in combating it.

With all of this information, there is still much more research to be done regarding the somewhat broad topic of antibiotic resistance. First off, our data is limited in that we have more specific data to the US and less information on the countries around the world. It is extremely important to understand that antibiotic resistance is a global problem and not just specific to the US. In fact, the less developed countries have much higher levels of antibiotic resistance than developed countries like the US and most in Europe. This poses challenges as not all countries report their data to the WHO, in fact, only about 73 countries out of 197 report data. Not only is this an issue in potential future research but also an issue in combating antibiotic resistance because we are unsure of areas that may need extra assistance.

There are several rich domains for future research including the dual health crises of COVID-19 and antibiotic resistance. With people not going to the doctor as often for minor symptoms, antibiotics are more easily prescribed over telehealth appointments and are often the first resort instead of testing for COVID-- this was especially true at the beginning of the pandemic. Our data also needs to be expanded to include the presence of antibiotic resistance in agriculture and how resistant pathogens are transferred from animal/plant to humans in order to present the full picture of AR in our environment. It may also be helpful to explore what plans are in place by the WHO to address antibiotic resistance and what has worked with plans and what has not been helpful. There also needs to be attention drawn to the development of new antibiotics and how effective these antibiotics are in treating resistant pathogens. On the topic of solutions specifically, future research may include alternatives to antibiotics and what kinds of alternatives exist, and which are effective. The importance of this topic and action needed to be taken cannot be emphasized enough and as the prominent species on this planet, it is our responsibility to spread awareness and push for action.

Resources

<https://arpsp.cdc.gov/profile/antibiotic-use?tab=outpatient-antibiotic-use>

<https://antibioticresistance2018.carrd.co/>