Science Fair Planner

By: Mannat Sidhu

Question (Problem):

- What role can microrobots play in treating cancer, and how does their use improve patient outcomes and treatment efficacy?

Cancer diagnoses have become more common in our society. Efficient cures and treatments are unable to fully serve their purpose for such a large population. It is crucial 4to investigate alternate cures and treatments that are efficient and are guaranteed to improve patient outcomes and treatment efficacy. With our technological advancements, it is critical to further analyze different technological treatments for numerous different cancers. For my project I will be working on analyzing and researching how microrobots can be used to treat cancer. This exploration could lead to innovative solutions that not only enhance patient care but also address the diverse needs of those living with cancer. Thus, my problem is; What role can microrobots play in treating cancer, and how does their use improve patient outcomes and treatment efficacy?

Method

- Defining Scientific/Key Terms
    - Medical Microrobot
    - Chronic Diseases
    - Nanotechnology
    - Bio Medical Engineering
    - Endoscopy
    - Actuators
    - Microfabrication
    - Swarm Robotics
    - Bio-inspired design
    - Micro-manipulation
    - Deoxyribonucleic acid (DNA)
    - Cells
- Research
    - What chronic diseases can be treated using microrobots?
    - What is the process of microrobots being used in cancer treatments, and how can this process be improved?

        - Compare traditional methods of treating cancer versus microrobots.
    - What is the process of microrobots being used in blood clots, and how can this process be improved?
        - Compare traditional methods of treating blood clots versus microrobots.
    - What causes microrobots to have the ability to enter our blood cells and insert treatments?
    - How are microrobots currently being used in medicine?
        - Are these services accessible for patients to receive?
        - Are microrobots currently being used in Canada to treat chronic diseases, if they are, where?
        - How can our current methods and processes be improved?
    - Compared to traditional treatments, how efficient and effective are microrobots when it comes to treating chronic diseases?
    - What are the challenges faced in the mass production of microrobots for clinical use?
    - Pros and Cons of microrobots
    - What are the differences in microrobot applications between chronic and acute diseases?
    - What role do microrobots play in personalized medicine, and how can they be tailored to individual patients?
    - What are the potential side effects or risks associated with using microrobots in medical therapies?
    - How do microrobots navigate through the bloodstream, and what technologies are used for navigation?
    - What advancements in nanotechnology are contributing to the development of microrobots in healthcare?
    - How can machine learning and AI be integrated into microrobot technology to improve treatment outcomes?
- Data Sets
    - Using real world evidence to convey and support the importance of this process.
    - Creating graphs and analyzing the effects and progress of this technology.
    - Ensuring I have analyzed all my information is conveyed through visuals and has facts and figures.
    - Comparing the pros and cons of microrobot treatments for patients with chronic diseases.
- Now What?

    - After concluding how microrobots play a role in treating chronic diseases and whether they improve patient outcomes and treatment efficacy it, how can I apply this to our real-life world to stabilize or potentially reduce the number of lives lost due to these diseases.
    - Microrobot technology could be adapted for use in developing countries, where access to traditional medical interventions may be limited. This could involve designing cost-effective solutions that address specific health challenges prevalent in those regions.
    - Considering strategies to raise awareness about the potential of microrobots in medicine, advocating for educational programs that inform both healthcare professionals and the public about these innovations.
    - Propose areas for further research and improvement.
    - Creating a future spinoff to reflect on what I would change or do differently going forward.
- Various Sources
    - To ensure the quality of information, I am going to conduct my research using numerous different sources.
        - Trusted websites and online sources
        - Books and media texts from local libraries
        - Reaching out to someone who is credible in the field and can help answer questions and provide further insights on this topic.
            - Interview from the University of Calgary Bio Medical Engineering Department

<u>Monthly Planner</u>

October	☐ ~~Forming my problem~~ ☐ ~~Study the rubric to understand the expectations~~ ☐ ~~Complete my method~~ ☐ ~~Background Research (some basic research questions)~~ ☐ ~~Defining key terms~~ ☐ ~~Form my monthly planner~~ ☐ ~~Complete Ethics and Due Care on the CYSF platform~~
November	☐ ~~Complete lots of research, get about half of my research completed.~~ ☐ ~~Start communicating with the University of Calgary Bio-Medical Engineering Department~~
December	☐ ~~Complete all my research~~

	☒ ~~Complete about half of my data~~ ☐ Complete interview with the University of Calgary Bio-Medical Engineering Department
January	☒ ~~Complete all of my data~~ ☒ ~~Form my conclusion~~ ☒ ~~Create my future spinoff~~
February	☒ ~~Receive tri-fold from Ms. Bretner~~ ☒ ~~Complete tri-fold~~ ☐ Work on showcasing my project ☐ Practice presenting for the day of the science fair ☐ Practice answering any questions for the day of the science fair

Defining Key Terms

Medical Microrobot – They are miniature robots that are often developed for research purposes or specific uses in the biotech industry, such as diagnostics and treatments. They typically measure less than 1 millimeter. Although, this size is not fixed and can vary. It aims at non-invasive diagnosis and treatment inside the human body through miniaturized sensors and actuators.

References; [3] and [4]

Chronic Diseases – Are defined as medical conditions that last one or more years. They require ongoing medical attention and/or treatments. They typically limit activities of daily living and lifestyles. It means having to adjust to the demands of the illness and the therapy used to treat the condition. Chronic diseases are usually associated with complex causes, many risk factors, long latency periods, and functional impairment or disability. Most chronic diseases cannot be cured without medication or treatment and are generally not cured completely. Many chronic diseases can be immediately life–threatening, such as heart disease or stroke. However, some chronic diseases remain over time and need to be managed, such as diabetes. Most chronic diseases last persist through an individual's life, but are not necessarily always the cause of death, such as arthritis.

References; [5] and [6]

Nanotechnology – A technology that is executed on the scale of less than 100 nanometers, the goal is to control individual atoms and molecules. Mainly to create

computer chips or types of microscopic devices and technologies. In other words, it refers to a take on science that focuses on engineering that is devoted to designing, producing, and using structures, devices, and systems by manipulating molecules and atoms at nanoscale.

References; [7] and [8]

Bio Medical Engineering - The application of engineering principles and design concepts to medicine and biology for healthcare applications. Biomedical engineers study, design, develop and evaluate biological and medical systems and products such as artificial organs, prostheses, medical instruments and information systems. It focuses on advancements the improve human health and health care. Biomedical engineers differ from other engineering disciplines that have an influence on human health in that biomedical engineers use and apply an intimate knowledge of modern biological principles in their engineering design process.

References; [9] and [10]

Endoscopy - A procedure used in medicine to look inside the body. The endoscopy procedure uses an endoscope to examine the interior of a hollow organ or cavity of the body. Unlike many other medical imaging techniques, endoscopes are inserted directly into the organs. Most endoscopes are thin, hollow tubes that have a light on the end. Some endoscopes have a small video camera that projects pictures on a computer screen. Some endoscopes are flexible and others are firm. The different endoscopes are designed for looking at a certain part of the body.

References; [11] and [12]

Actuators - An actuator is a part of a device or machine that helps it to achieve physical movements by converting energy, often electrical, air, or hydraulic, into mechanical force. Simply put, it is the component in any machine that enables movement. Actuators are present in almost every machine around us. Common examples of actuators include electric motors, stepper motors, jackscrews, electric muscular stimulators in robots, etc.

References; [13]

Microfabrication - Microfabrication is the process of fabricating miniature structures of micrometer scales and smaller. Historically, the earliest microfabrication processes were used for integrated circuit fabrication. Microfabrication, as the name suggests, refers to the fabrication of a substrate at micron or submicron scale to design miniaturized

patterns, objects, or devices that are applicable in biophysics, pharmacology, medical biology, and nanotechnology.

Reference; [14]

Swarm Robotics - Swarm robotics is an approach to the coordination of multiple robots as a system which consist of large numbers of mostly simple physical robots. In a robot swarm, the collective behavior of the robots results from local interactions between the robots and between the robots and the environment in which they act. distributed and specialized for the tasks requiring a large area of space, e.g. large coverage. The robots in the swarm are distributed in the environment and can detect the dynamic change of the entire area, such as chemical leaks or pollution.

Reference; [15]

Bio-Inspired Design - the process of developing concepts, approaches and technologies that build and control the way nature does – offers potentially transformative solutions to these problems. Solutions to engineering problems have been inspired by biological phenomena.

Reference; [16]

Micro-manipulation - A recent effective technique for microalgal isolation that enables single-celled action and culture. Typically, this micromanipulation technique uses capillary tubes to identify cells and transfer these to aseptic water. This is a manual process that is difficult and demands precision and perfection. The micromanipulation of biological cells is playing an increasingly important role in biomedical research and applications. Many different techniques have been developed in terms of biomedical engineering.

Reference; [17]

Deoxyribonucleic acid (DNA) - Deoxyribonucleic acid is a polymer composed of two polynucleotide chains that coil around each other to form a double helix. The polymer carries genetic instructions for the development, functioning, growth and reproduction of all known organisms and many viruses. A molecule that contains the genetic code that is unique to every individual. The DNA that determines heritable traits is found in the nucleus of every single cell of our bodies. Nearly every cell in a person's body has the same DNA. Most DNA is located in the cell nucleus (where it is called nuclear DNA), but a small amount of DNA can also be found in the mitochondria (where it is called mitochondrial

DNA or mtDNA). An important property of DNA is that it can replicate or make copies of itself. Each strand of DNA in the double helix can serve as a pattern for duplicating the sequence of bases. This is critical when cells divide because each new cell needs to have an exact copy of the DNA present in the old cell.

References; [18] and [19]

Cells – The smallest unit that is able to live on its own. Cells make up all living organisms and the tissue of the body. A cell consists of 3 main parts: the cell membrane, the nucleus, and the cytoplasm. The cell membrane surrounds the cell and controls the substances that go into and out of the cell. The nucleus is a structure inside the cell that contains the nucleolus and most of the cell's DNA. It is also where most RNA is made. The cytoplasm is the fluid inside the cell. The human body has more than 30 trillion cells.

Reference; [20]

Research

What chronic diseases can be treated using microrobots?

Microrobots could be used to develop new transformative strategies for the treatment of chronic disease states such as cancer, cardiovascular disease, liver disease, respiratory diseases, and kidney disease. Additionally, they can be used to help treat tumors. Biopsy and removal of blood clots are also two possible applications for soft microrobots.

Reference; [21]

What is the process of microrobots being used in cancer treatments, and how can this process be improved?

The nanorobots improve treatment efficiency by performing advanced biomedical therapies using minimally invasive operations. Chemotherapy's harsh side effects and untargeted drug distribution necessitate new cancer treatment trials. Due to their mobility, microrobots can infiltrate tissues and reach tumor sites more quickly. Different types of microrobots, like custom-made moving bacteria, microengines powered by small bubbles, and hybrid spermbots, can be designed with complex features that are best for precise

targeting of a wide range of cancers. Due to their active motion, microrobots may improve tumor targeting across long and short distances by combining the benefits of existing nanomedicines.

Cancer cells or their microenvironments have peculiar chemical and physical properties because of genetic/epigenetic abnormalities. Tumor-associated antigens and neoantigens are the two kinds of cell surface proteins that they express. Because these are created primarily by tumor cells, neoantigens provide a distinct target advantage over tumor-associated antigens. These microrobots are made from materials like carbon and DNA. Microrobots have two main routes to target cancer cells. The first approach is straightforward, applicable to all three types of microrobots, and is based on turning them into drug-delivery vehicles capable of delivering and releasing drugs directly to cancer cells and/or the microenvironments in which they exist. In the second approach, microrobots activate or stimulate the immune system of the patient to eradicate cancer cells.

First Method – Targeted Drug Delivery:

Drugs and medication can be attached directly or as part of the larger nanocarriers depending on the class of microrobot and the nature of therapeutic material/drug used. Larger microrobots may be able to transport higher doses of drugs. However, transporting larger microrobots is difficult through the body. Factors such as imaging techniques and external guiding mechanisms adaptable to various microrobot size regimens must be considered to identify which approach is most suited for the patient. Microrobots can also be tailored to carry and deliver drugs with high spatiotemporal precision, while protecting their cargo from being diluted by body fluids. Drug-loaded microrobots have to discharge the drug at a specific spot in the body at the correct time. If the drug is delivered incorrectly severe complications may arise for the patient.

Targeted drug delivery using microrobots is an exciting approach because it allows treatments to be more effective and less harmful to healthy tissues. One of the biggest challenges in cancer treatment is that traditional methods, like chemotherapy, affect both cancerous and healthy cells, leading to side effects. With microrobots, drugs can be delivered directly to the tumor, minimizing the damage to healthy tissues. These microrobots are designed to move through the body with high precision, navigating through the bloodstream to reach specific areas where cancer cells are located. To make this possible, scientists are developing ways to coat the microrobots with special materials that help them stick to the tumor cells, almost like a key fitting into a lock. Additionally, microrobots can be equipped with sensors to identify cancer cells by recognizing unique markers or patterns found only on the surface of tumors. This ensures that the drug is only

released at the cancer site and not anywhere else in the body. The precision of this method could potentially reduce the number of treatments a patient needs and improve the overall success rate of cancer therapies. However, achieving this level of accuracy requires overcoming challenges like ensuring that the microrobots don't get trapped in smaller blood vessels or organs, which could limit their effectiveness. As research continues, it's expected that microrobots will become a powerful tool for personalized, targeted cancer treatment.

Targeted drug delivery using microrobots has the potential to treat a wide range of cancers, especially those where traditional treatments like chemotherapy are less effective or cause severe side effects.

Breast Cancer: Microrobots can deliver targeted chemotherapy or hormone therapy directly to the tumor, sparing healthy tissues like the skin and surrounding organs. This would reduce side effects such as hair loss, nausea, and fatigue. They can best be used triple negative breast cancer.

Lung cancer: Particularly non-small cell lung cancer (NSCLC), could benefit from microrobots for delivering targeted therapies to the tumor directly. Since the lungs have many blood vessels, microrobots can help avoid systemic drug exposure by precisely releasing treatment into the tumor while avoiding healthy lung tissue.

Brain Cancer (Glioblastoma): Brain tumors, especially glioblastomas, are quite difficult to treat due to the blood-brain barrier, which blocks most drugs from reaching the brain. Microrobots can potentially cross this barrier and deliver chemotherapy or immunotherapy directly to the tumor, potentially improving outcomes for patients who would otherwise have limited treatment options.

Colon Cancer: Colon cancer often spreads to lymph nodes and distant organs, making treatment challenging. Microrobots can deliver chemotherapy drugs directly to the colon tumor or even to the lymph nodes that have been affected. This localized treatment reduces the chances of side effects that would come from traditional systemic chemotherapy.

Liver Cancer: In liver cancer, especially hepatocellular carcinoma, microrobots could help deliver drugs directly to the liver, reducing the need for invasive surgery or liver transplants. Targeted drug delivery would allow for higher concentrations of drugs to reach the tumor without damaging the healthy liver tissue.

Prostate Cancer: Prostate cancer can be treated with drugs that target hormone receptors on the tumor cells. Microrobots could help deliver these hormone therapies directly to the tumor site, minimizing damage to surrounding organs like the bladder and rectum. This could lead to more effective treatment with fewer side effects.

Pancreatic Cancer: This type of cancer is known to be often undetected until it's in an advanced stage. Microrobots can help target chemotherapy or gene therapies directly to the tumor site, potentially improving survival rates in cases where traditional treatments have limited success.

Skin Cancer (Melanoma): Melanoma is an aggressive form of skin cancer that spreads rapidly. Microrobots can be used to deliver immunotherapy drugs directly to the melanoma cells, enhancing the body's immune response to fight the cancer while avoiding systemic side effects of traditional chemotherapy.

Leukemia: Leukemia, a cancer of the blood, could also benefit from targeted drug delivery. Microrobots could help deliver chemotherapy directly to the bone marrow or to the bloodstream where leukemia cells are present, reducing the risk of systemic toxicity that would occur with traditional chemotherapy.

Bladder Cancer: Microrobots could deliver drugs directly to the bladder for bladder cancer treatment, particularly for superficial cancers that have not invaded deeper tissues. This method would minimize the damage to other parts of the body and could help reduce the recurrence of the cancer.

References: [21], [22], [23], [24], [39], [40], [41], [42, [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], and [57].

Second Method – Synthetic Lethality

This method involves targeted killing of cancer cells. By exploiting genetic differences in the BRCA genes between normal and cancer cells using conventional small-molecule drugs (PARP inhibitors). Cancer cells with BRCA gene mutations (BRCA1 or BRCA2) have a weakened ability to repair DNA damage. Normal cells use BRCA to fix DNA breaks, but in cancer cells, this repair pathway is defective. As a result, these cancer cells become more reliant on another repair mechanism, the PARP (poly(ADP-ribose) polymerase) pathway. PARP inhibitors are drugs that block PARP enzymes, preventing cancer cells from repairing DNA damage. In cells with defective BRCA genes, this causes the DNA damage to accumulate, leading to cell death. This strategy is known as synthetic lethality, where inhibiting PARP leads to cancer cell death, but normal cells with functional BRCA genes

can still repair DNA and survive. PARP inhibitors, like Olaparib, have been shown to be effective in treating cancers with BRCA mutations, especially breast and ovarian cancers. The therapy selectively targets cancer cells, minimizing damage to normal cells. However, challenges like drug resistance and side effects still exist, and ongoing research aims to improve and expand this treatment approach.

Simplified Version: Synthetic lethality is a method that targets cancer cells by using their genetic weaknesses. Some cancer cells have faulty BRCA genes, which are supposed to help repair damaged DNA. In normal cells, these genes work fine, but in cancer cells, they do not. To take advantage of this, doctors use PARP inhibitors, which block another way cancer cells try to fix their damaged DNA. This makes the cancer cells accumulate too much damage and die. Normal cells can still repair their DNA, so they survive. This treatment is called synthetic lethality because it kills cancer cells without hurting normal cells. Drugs like Olaparib are used for cancers with BRCA gene problems, like breast and ovarian cancer. While this method works well, it can still have some side affects, and the cancer can sometimes become resistant to the drugs. But researchers are working on improving it.

Incorporating synthetic lethality into cancer treatment using microrobots is a promising approach that could make therapies even more targeted and efficient. Microrobots could be designed to deliver PARP inhibitors directly to cancer cells with BRCA mutations, ensuring that the drugs reach the tumor with high precision. This method could improve the effectiveness of synthetic lethality by minimizing the need for systemic drug delivery, which often leads to unwanted side effects. By navigating through the bloodstream and precisely targeting cancer cells, microrobots would avoid healthy cells and tissues, further reducing harm to the body. This targeted approach could also help with drug resistance, a major challenge in cancer treatment. If cancer cells become resistant to traditional treatments, microrobots can still deliver a combination of therapies, including PARP inhibitors and other agents, directly to the tumor, increasing the chances of successfully overcoming resistance. Additionally, microrobots could be programmed to monitor the tumor's response to treatment in real-time, making it easier to adjust therapy as needed and personalize the treatment for better outcomes. This combination of precision and adaptability could revolutionize how synthetic lethality is used to treat cancer.

Synthetic lethality is especially useful for treating cancers with specific genetic mutations that affect DNA repair mechanisms. It primarily targets cancers with BRCA1 or BRCA2 mutations.

Breast Cancer: BRCA mutations are most commonly associated with breast cancer. Women with hereditary breast cancer often have faulty BRCA1 or BRCA2 genes, making them more susceptible to treatments like Olaparib, a PARP inhibitor. This approach has been highly effective in HER2-negative breast cancers with these mutations.

Ovarian Cancer: Like breast cancer, many cases of ovarian cancer are linked to BRCA1 or BRCA2 mutations. Synthetic lethality with PARP inhibitors has been proven to be an effective treatment, especially in high-grade serous ovarian cancers, which often have these genetic mutations.

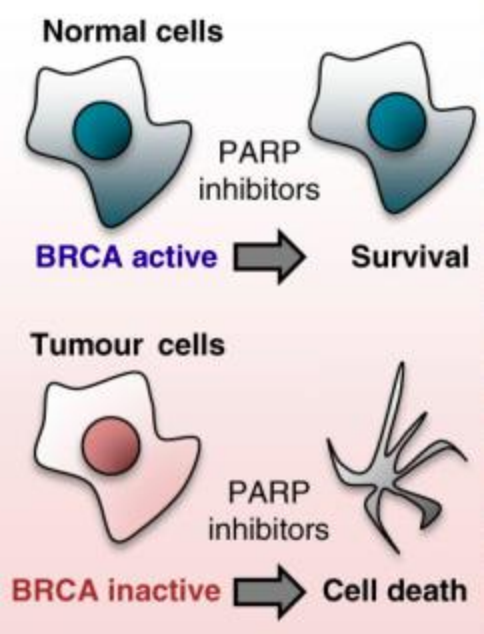
Pancreatic Cancer: In pancreatic cancer, particularly with BRCA mutations, synthetic lethality can be leveraged with PARP inhibitors to target the DNA repair defects in cancer cells. This approach is still being researched but shows promise for improving treatment outcomes. Microrobots could help deliver these therapies directly to pancreatic tumors, potentially overcoming challenges with drug delivery in this hard-to-target cancer.

Prostate Cancer: Prostate cancer with BRCA1 or BRCA2 mutations can be treated using synthetic lethality, particularly with PARP inhibitors like Olaparib, which exploit the tumor's compromised DNA repair mechanisms. These tumors are more sensitive to therapies that further inhibit DNA repair, leading to cancer cell death. Microrobots could enhance this by delivering PARP inhibitors directly to the prostate, improving treatment precision while reducing systemic side effects.

Lung Cancer: Lung cancer, especially non-small cell lung cancer (NSCLC) with DNA repair mutations, may respond well to PARP inhibitors through synthetic lethality. These inhibitors target cancer cells' weakened DNA repair systems, leading to their destruction. Using microrobots to deliver the drugs directly to lung tumors could improve effectiveness and minimize the harmful side effects of conventional therapies.

Gastric Cancer: Gastric cancer with genetic mutations, such as in BRCA1 or BRCA2, could potentially benefit from synthetic lethality treatments like PARP inhibitors that exploit the cancer's inability to repair DNA. This approach is still under investigation but offers hope for targeted therapies. Microrobots could be used to direct PARP inhibitors precisely to gastric tumors, enhancing treatment precision and minimizing systemic toxicity.

References: [21], [22], [23], [24], [39], [40], [44], [45], [46], [47], [48], [55], [56], [57], [58], [59], [60], [61], and [62]



This diagram explains the concept of synthetic lethality in cancer treatment. Synthetic lethality occurs when there is a combination of two genetic deficiencies results in cell death, while each singular deficiency is not lethal. In normal cells, BRCA (a DNA repair protein) is active and functional. However, in tumor cells with BRCA mutations, BRCA is inactive, meaning these cells already have impaired DNA repair mechanisms. When PARP inhibitors (a type of drug) are used, normal cells service because BRCA can repair DNA damage caused by PARP inhibition. However, adding PARP inhibitors to tumor cells further blocks DNA repair, leading to an accumulation of DNA damages and ultimately causing cell death. By targeting tumor cells that rely solely on PARP for DNA repair due to BRC mutations, synthetic lethality ensures selective killing of cancer cells while sparing normal cells. Microrobots enhance this approach by delivering PARP inhibitors with precision, localizing targets by using sensors to identify tumor cells, and by enhancing the efficacy by ensuring consistency and accurate treatment.

References: [21], [22], [23], [24], [39], [40], [44], [45], [46], [47], [48], [55], [56], [57], [58], [59], [60], [61], and [62]

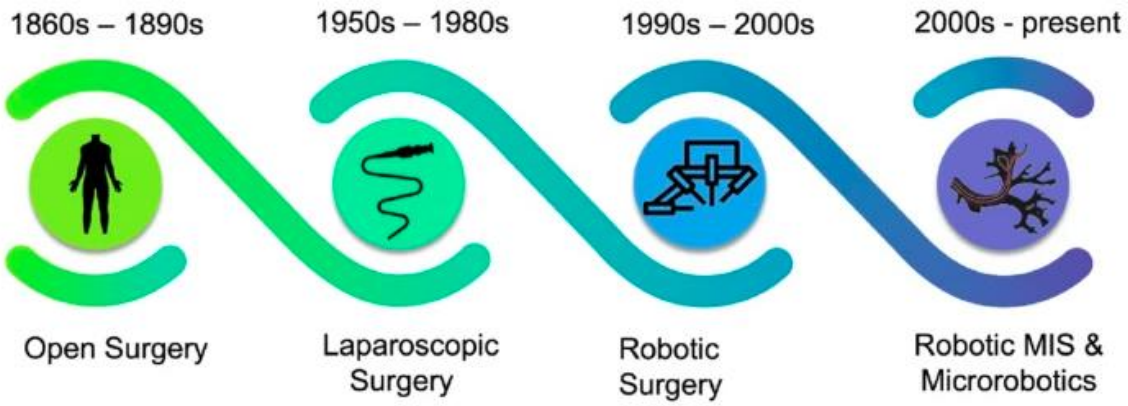
Third Method – Minimally Invasive Surgery

Minimally invasive surgery (MIS) involves using small incisions instead of large cuts, like in traditional open surgery, to reach internal organs or tissues. This method offers several advantages, such as faster recovery, lower risk of infection, less scarring, and reduced

pain for patients. In cancer treatment, microrobots improve MIS by providing greater accuracy, flexibility, and the ability to perform precise, targeted interventions that traditional surgical tools can't achieve.

Microrobots are especially useful for reaching tumors deep inside the body or in delicate areas that are hard to access with traditional surgery. Tumors in places like the pancreas, liver, lungs, brain, or spinal cord are often challenging to reach and require large, complex incisions, which increases the risk of complications. With microrobots, these procedures can be done through much smaller incisions or even via natural body openings (like the gastrointestinal tract or blood vessels), greatly reducing damage to surrounding tissue. These robots can be designed to move through body cavities, blood vessels, or the digestive system, allowing them to precisely target tumors without harming healthy tissue nearby. For example, a microrobot could travel through the bloodstream to reach a brain tumor or move through the digestive system to remove a tumor from the stomach or colon. Microrobots can also be equipped with real time imaging systems to ensure that the microrobot is receiving data from its environment in the body at the exact moment. Brain tumours are the most common form of solid cancer in children, and surgery to remove the tumour is often the first recommended course of treatment. The surgeries can be highly invasive with a long recovery process. The following types of cancers can be treated using this method: colorectal, gynecological, head and neck, pancreatic, liver, lung, prostate, kidney, colon, and cervical.

References: [40], [42], [43], [44], [45], [46], [47], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], and [72].



Compare to Traditional Methods of Cancer:

Chemotherapy in some cancer patients has limited therapeutic effects. Their efficacy is restricted due to the variability in the cancer microenvironment and drug resistance. It is difficult to treat hypoxic tumor cores using conventional chemotherapeutics. This necessitates the development of nanotechnology-based drug carriers. Cancer cells tend to grow fast, and chemo drugs kill fast-growing cells. Because these drugs travel throughout the body, they can affect normal, healthy cells that are fast-growing, too. Damage to healthy cells causes chemotherapy side effects. The normal cells most likely to be damaged by chemo are blood-forming cells in the bone marrow, hair follicles, cells in the mouth, digestive tract, and reproductive system. The use of microrobots could decrease these side effects and increase treatment efficacy. With microrobots we can transport the drug directly into the affected area and minimize side effects to other organs and cells. Additionally, microrobots allow for more customized and personalized treatments that are more precise.

References; [21], [22], [23], and [24]

Setbacks:

Microrobots can be expensive and complex to design, and they may face difficulty traveling through the blood due to its viscosity. However, their potential benefits, such as precise drug delivery and reduced harm to healthy cells, are significant. Researchers are working on improving these devices, including making them resistant to the immune system and improving their ability to deliver drugs efficiently. This causes significant setbacks in implying microrobots into our medicine. Factors such as imaging techniques and external guiding mechanisms adaptable to various microrobot size regimens must be considered to identify which approach is most suited for the patient. Drug-loaded microrobots have to discharge the drug at a specific spot in the body at the correct time. If the drug is delivered incorrectly severe complications may arise for the patient.

References; [21], [22], and [23]

<u>What is the process of microrobots being used in blood clots, and how can this process be improved?</u>

Thrombosis is the obstruction of blood flow inside a blood vessel due to the formation of a blood clot. The movement of this blood clot through the human circulatory system to the brain or lungs can cause serious cardiovascular diseases, such as myocardial infarctions and ischemic strokes. Microrobots are being engineered and researched to be used to treat blood clots. A minimally invasive potential approach for the treatment of occluded

blood vessels could be achieved by untethered microrobotic systems designed for intravascular therapy. Clearing of blood clot is achieved using a helical microrobot and rotating magnetic field. The microrobot used for treating blood clots consists of a magnetic head and helical tail. The helical tail is attached to a cylindrical magnet with axial magnetization. The tip of the helical microrobot tears the three-dimensional fibrin network of a blood clot and enables blood cells to break free.

Some key features include the locomotion mechanisms, sensing capabilities, and therapeutic payloads. The locomotion mechanisms include flagella-like structures, magnetic fields, or ciliary motion to propel the microrobots through the blood. Secondly, the sensing capabilities involve sensors that detect clots. Once the microrobot is injected into the bloodstream, the microrobots need to reach the blood clot. Some of these methods were mentioned above in the introduction for blood clots.

The steps when using microrobots to treat blood clots:

1. Navigation to the blood clot
2. Detection of the blood clot
3. Disruption of the blood clot
4. Post-treatment

Navigation to the blood clot

Magnetic Fields: The first is magnetic fields, also known as magnetic guidance. Microrobots that are designed to be magnetically responsive can be directed with the help of external magnetic fields. This guidance system typically involves embedding small magnetic particles or materials into the microrobots, allowing them to interact with external magnets placed on the surface of the skin or elsewhere on the body. By manipulating the external magnets, medical professionals can control the robots' movement and guide them precisely towards the location of a blood clot, even within the intricate network of blood vessels. The external magnets create a controlled magnetic field that applies force on the microrobots, causing them to follow specific paths or navigate around obstacles, such as blood vessel walls or curves, to reach the clot. This approach can help with precise targeting to ensure the microrobots effectively and efficiently complete their job and can help treat the illness. can be used to manipulate the robot from outside the body, ensuring that it follows the optimal route to the clot, whether it’s in larger arteries or smaller capillaries. The strength of the magnetic field can be adjusted to ensure that the microrobots are not only guided efficiently but also avoid excessive force that could cause damage to surrounding tissues or vessels.

Autonomous Navigation: Not only are microrobots controlled by magnetic fields, but some are also designed to move autonomously by responding to environmental signals. This self-navigation is completed through chemotaxis. This is where organisms move in response to specific chemical gradients. For microrobots used in blood clot treatment, this means they can be programmed to detect and respond to chemical signals released by the clot, such as proteins, enzymes, or other molecular markers found in the thrombus (the blood clot). These chemical cues trigger the robot's movement, guiding it toward the clot using its integrated propulsion mechanisms, like flagella-like structures or micro-wheels, which help propel it through the bloodstream. These robots also sense and react to other environmental factors such as temperature, pH variations, or mechanical forces. For instance, if the clot is surrounded by hypoxic conditions (areas with low oxygen levels), the microrobot could detect this environmental change and move toward the affected region. This capability allows the microrobots to locate and target blood clots with minimal need for external control, offering a more automated and hands-off approach to treatment. This reduces the need for invasive procedures while ensuring the robot reaches its target with high accuracy.

Imaging-Based Navigation: An innovative approach for guiding microrobots to blood clots involves imaging-based navigation. In this method, microrobots are equipped with imaging sensors that enable them to visualize their environment and adjust their movement accordingly. These sensors use many different advanced imaging technologies, including ultrasound, fluorescence imaging, and optical coherence tomography (OCT). Ultrasound imaging can help the microrobots detect changes in tissue density or identify the distinctive characteristics of blood clots, which often appear as anomalies or irregularities in an ultrasound scan. Fluorescence-based sensors are particularly useful in detecting specific molecules or proteins that are prevalent in clots, such as fibrin. When these sensors bind to the clot, they emit light, which serves as a signal to guide the robot directly to the target area. In addition to onboard imaging, microrobots can be synchronized with external imaging systems like Magnetic Resonance Imaging (MRI) or Computed Tomography (CT). These technologies produce detailed, high-resolution images of the body’s internal structures, which assist in guiding the microrobots with exceptional precision. When used in combination, the external imaging systems offer a continuous feedback loop, allowing medical professionals to monitor the microrobots’ progress in real-time and make adjustments to their trajectory if necessary. This real-time feedback minimizes the risk of damaging surrounding healthy tissues while ensuring the microrobots remain on track to reach and treat the clot. Moreover, adaptive imaging algorithms can be incorporated into the microrobots' systems, enabling them to adjust dynamically based on the most current scans.

References; [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], and [35]

Detection of the blood clot

Microrobots are typically designed with sensors that can detect different characteristics and elements specific to blood clots.

Mechanical Sensors: These sensors help detect physical changes or differences in the blood clot compared to the surrounding healthy blood in the bloodstream. These sensors can detect stiffness, consistency, surface texture, and hydrodynamic flow disruptions. Blood clots are denser and more rigid than the surrounding healthy blood, allowing microrobots to sense the difference in mechanical resistance as they move through the bloodstream. Specialized sensors on the microrobot measure this increased resistance when encountering a clot. The clot, composed of fibrin and trapped blood cells, is far stiffer than normal blood, which allows the robot to distinguish it based on this mechanical feedback. Additionally, the surface texture of the blood clot tends to be rough or even, unlike the smooth surface texture of blood vessels surrounding the blood clot. Microrobots use tactile sensors to detect these surface irregularities, as the robot interacts with the clot or the vascular wall. These textural differences help the microrobot determine not only the presence of a clot but also provide clues about its size and the extent of blockage. Moreover, a blood clot blocks natural blood flow in the body's bloodstream. This creates turbulence or changes in the natural blood flow. There are flow sensors that help detect these disruptions in the blood's hemodynamics. By recognizing these flow disruptions, the microrobot can pinpoint the location of the clot and accurately target the area of blockage.

Chemical Sensors: Chemical sensors enable microrobots to identify specific biochemical markers associated with blood clots. These sensors detect molecular interactions that signal the presence of a clot, often before any significant changes occur in blood flow or mechanical properties. Blood clots cause the release or increased expression of proteins, molecules, or enzymes that are either absent or found in much lower amounts in healthy blood. These include fibrin, thrombin, and plasminogen activators. Fibrin is a key protein involved in clot formation. When activated, the fibrin binds with other clotting factors to form a mesh that stabilizes the clot. Microrobots can use chemical sensors to detect fibrin or its breakdown products, which serve as reliable indicators of a clot's presence. Thrombin is an enzyme that is necessary in the formation of a blood clot, because it converts fibrinogen into fibrin. The chemical sensors are designed to detect significantly high thrombin levels, signaling that the clotting process is actively underway. When a clot

forms, plasminogen activators are often released or activated. By detecting these activators or their byproducts, microrobots can confirm the presence of a clot and even predict its resolution. When a clot forms, certain proteins on platelets or the clot's surface are exposed. For example, proteins like P-selectin or glycoprotein. Microrobots can use chemical sensors to detect these proteins as markers of clot formation. The presence or formation of a clot can also change the pH or ion concentrations. For example, clots often produce localized acidity due to metabolic byproducts and enzyme activity. Microrobots with pH-sensitive sensors can detect these shifts. Additionally, changes in ionic concentrations—such as calcium levels—are associated with clot formation, as calcium plays a crucial role in the coagulation process. Detecting these changes helps confirm the presence or progression of a clot.

Microrobots use these sensors to correctly identify and detect the blood clot before treating it. By integrating these detection mechanisms, the microrobot can differentiate between normal and abnormal conditions more effectively and increase the precision of therapeutic interventions.

Removal or Disruption of the Blood Clot

Once the microrobot locates the blood clot there are numerous different therapeutic actions to either remove or disrupt the clot. These functions aim to restore normal blood flow and prevent complications like stroke, heart attack, or pulmonary embolism.

Mechanical Disruption: One approach is for the microrobot to physically break up the clot using mechanical methods. This can be achieved through various techniques. Some microrobots are equipped with miniaturized tools or rotating mechanisms that allow them to "drill" or "cut" through the clot. By physically breaking the clot into smaller fragments, the microrobot reduces the size of the blockage, making it easier for the body’s natural processes (like fibrinolysis) to dissolve or remove the pieces. Alternatively, these smaller fragments may be removed through the bloodstream, preventing a complete obstruction. Other microrobots may use vibration or oscillatory movements to shake the clot apart. This process mechanically disrupts the structural integrity of the clot, making it less stable and easier to break down or be flushed from the circulatory system.

Dissolving Agents: For a more direct and chemical approach, some microrobots carry clot-dissolving substances that can be released at the clot site. One common method is for the microrobot to carry or produce enzymes that break down fibrin, the key structural

protein that holds the clot together. Tissue Plasminogen Activator (tPA) is one such enzyme, which works by converting plasminogen into plasmin, an enzyme that degrades fibrin. The microrobot can release tPA directly at the clot site, accelerating clot breakdown and encouraging natural clot dissolution processes. In addition to tPA, the microrobots may deliver other thrombolytic drugs or clot-busting agents that act more specifically on clot components. These drugs can be tailored to act on the molecular structure of the clot, ensuring that they target the clot directly without affecting healthy tissue.

Thermal Tactics: Heat can alter the structure of the clot, making it easier to dissolve or fragment. The first thermal technique is laser-induced heating. The lasers that are equipped onto the microrobot release a high-intensity light onto the clot. The laser energy heats the clot, causing it to soften or even melt. This localized thermal treatment weakens the clot's structure, making it easier to break apart or accelerating its dissolution through the body's natural enzymatic processes. The second technique is magnetic field induced heating. Microrobots may use magnetic nanoparticles that can be activated by an external magnetic field. These nanoparticles absorb the magnetic energy and convert it into localized heat at the clot site. The heat softens and destabilizes the clot, helping it to break down more easily.

Laser/Ultrasound Treatment: Microrobots may also use more advanced technologies to disrupt the clots such as laser and ultrasound treatments. Some microrobots are designed to use ultrasound waves to generate mechanical vibrations within the clot. These sound waves, when focused at the right frequency and intensity, can cause the clot to break apart or become loosened, facilitating its removal. Ultrasound is particularly useful for reaching deep-lying clots that are hard to access with other methods. Another method is the use of laser beams directed towards the clot. The microrobot can focus the laser on the clot either vaporize it or cause it to disintegrate. Laser treatment can be highly controlled, allowing the microrobot to target only the clot without damaging surrounding tissues.

In some cases, the microrobot can also be equipped with tools to use a combination of these techniques. For example, mechanical disruption might first fragment the clot, followed by the release of clot-dissolving agents to complete the breakdown process. Alternatively, thermal methods may be used alongside ultrasound to increase the overall efficacy of clot removal.

These advanced therapeutic functions enable microrobots to target blood clots with remarkable precision and efficiency, offering a minimally invasive alternative to traditional treatments. By disrupting or removing the clot directly, microrobots can help prevent

serious complications like organ damage, stroke, or pulmonary embolism, ultimately improving patient outcomes.

References; [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], and [35]

How can this process be improved

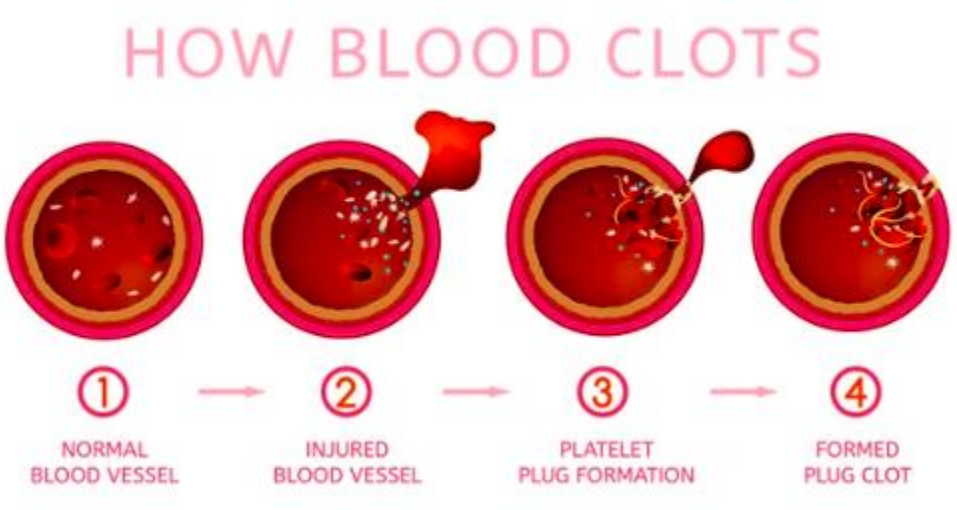
The use of microrobots for treating blood clots holds immense promise, but there are several ways the process can be enhanced to increase effectiveness, safety, and scalability. The first way that I think it can be improved is regarding precision and targeting. Microrobots typically rely on detecting changes in blood flow or specific biomarkers like fibrin or thrombin to locate clots. However, detecting smaller, early-stage clots or those in hard-to-reach areas (e.g., small capillaries or deep vein thrombosis) can be challenging. Integrating multiple types of sensors (mechanical, chemical, optical) would provide more accurate detection. For example, combining pressure sensors (detecting mechanical stiffness) with chemical sensors (detecting specific biomarkers) would significantly improve the process. Incorporating Artificial Intelligence (AI) and Machine Learning would also open new pathways for the use of microrobots to treat blood clots. AI could enable real-time analysis of sensor data, improving the ability of microrobots to distinguish between healthy tissue and blood clots even in complex regions of the body. Designing the robots to have miniaturized sensing abilities would also improve the process. Developing nano-sensors that can detect even molecular-level changes in the blood composition, would enable earlier detection of clots, which are difficult to detect using traditional imaging methods. To improve the mechanical disruption or removal of the clot, it would be beneficial to equip microrobots with adaptive mechanical tools that can adjust their intensity based on the specific type of clot they encounter. For example, the robot could automatically increase cutting force if it encounters a particularly dense or fibrin-rich clot, or use vibrational frequencies for softer, more fragile clots.

Difference between traditional methods of treating blood clots

Microrobots are designed to navigate the bloodstream with high precision, targeting specific clot locations at the microscopic level. They can be engineered to locate clots in small or hard-to-reach vessels, potentially reducing the need for invasive procedures. However, current treatments like anticoagulants (e.g., heparin or warfarin) or thrombolytic drugs (e.g., tPA) work systemically throughout the entire body. These methods can increase the risk of bleeding and may not always reach deep or small clots, especially in

areas like the brain or lungs. Another large benefit of microrobots compared to traditional methods of treating blood clots is the invasiveness. Microrobots are minimally invasive, since most designs are small enough to be injected directly into the bloodstream, potentially avoiding the need for surgical interventions. The robots can also be remotely controlled or guided to the clot, performing precise actions like breaking up the clot or delivering targeted therapy. In contrast, traditional methods like mechanical thrombectomy (a procedure to physically remove a clot) are invasive and require surgical intervention. Drugs can be administered intravenously, but they often have systemic effects and need careful monitoring. Microrobots are also more beneficial in terms of speed and effectiveness. Microrobots have the potential to act more quickly at the site of the clot, potentially resolving blockages in a matter of minutes or hours. Their ability to directly interact with the clot could result in faster and more effective removal, especially in cases where time is critical. Unlike, thrombolytic drugs which require time to break down clots, and their effectiveness is not always assured. While mechanical thrombectomy and catheter-based interventions are effective, they are time-critical procedures that depend on specialized equipment and skilled professionals. Lastly, microrobots provide the opportunity for personalized medicine. The microrobots can be programmed to deliver the most appropriate therapy based on the type, location, and severity of the clot. Personalization in traditional treatments primarily involves adjusting medication dosage or choosing between thrombolytic drugs and anticoagulants, but the level of precision is not as personalized as it would be with microrobots.

References; [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], and [38]



Real World Applications

- Children's Healthcare of Atlanta uses robots to delivering food, supplies, medication, and taking out the trash. They navigate the hospital using 3D models created by light detection and ranging, ensuring they avoid collisions with people. However, they still have no use for microrobots. Reference; [73]

- **Germany:** Researchers in Germany develop 'world's first' microrobot with potential for new cancer treatments in 2024. They have developed a microrobot which can navigate in a cell network and stimulate individual cells in a targeted manner. According to lead researcher Berna Ozkale Edelmann, professor of Nano- and Microrobotics at Technical University of Munich (TUM), the discovery has the potential for new treatment methods for patients battling cancer. We are using these microrobots to build tissues under synthetic conditions. The point is to repair damaged tissue or organs in the future based on the patient. They are made from seaweed and are about the same size as human cells. They also have the same soft consistency as cells. By incorporating nanomaterials, the microrobots can be controlled wirelessly. They can move it within the cell clusters and move it to other locations and then look at several cells in different ways. Reference; [74]

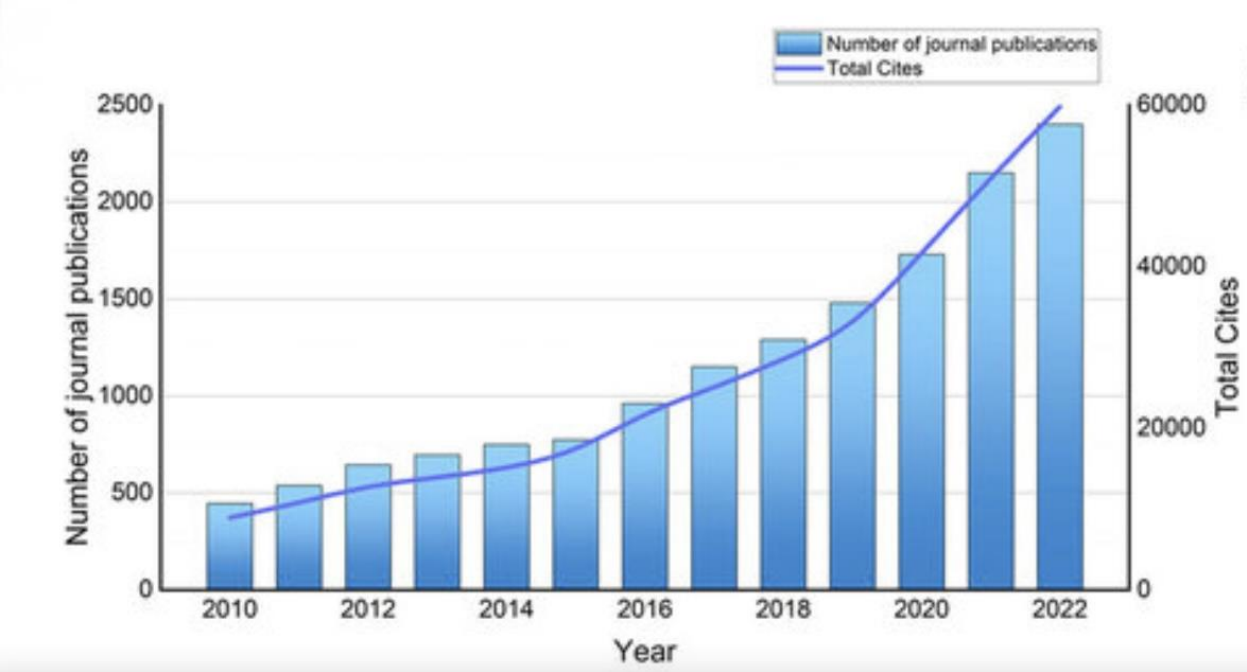
- **USA:** The University of Washington has created microrobots that could eventually serve incredible functions. They could someday be used for work in areas such as artificial pollination, search and rescue, environmental monitoring, micro-fabrication, or robotic-assisted surgery. The use for robotic assisted surgery has not been implemented yet, but they are researching. MIT has incredible technologies regarding microrobots for targeted drug delivery for cancer patients. However, they are still in research and development. These tiny machines could help deliver drugs exactly where they are needed. That would help minimize toxicity. Some such robots have made their way off the lab bench and into large animals, including pigs. There are at least four startups working on medical microrobots that could travel "untethered" inside the body. Reference; [35] and [75]

- **China:** Chinese scientists have developed many microrobots that could be used to treat cancer, blood clots, and many other diseases. However, they have not been implemented in clinical settings because they are still perfecting and testing them to ensure they are ready for patient use. They have promising technologies that they hope will be implemented in clinical settings by 2030. This innovative design enhances its ability to navigate blood vessels efficiently, even under high-flow

conditions, making it a promising tool for precision medicine, such as targeted cancer treatments. While these microrobots have demonstrated success in laboratory and animal trials, they have not yet been implemented in routine clinical practice. Ongoing research aims to further develop their capabilities for human applications in the near future. Reference; [28], [76], and [77]

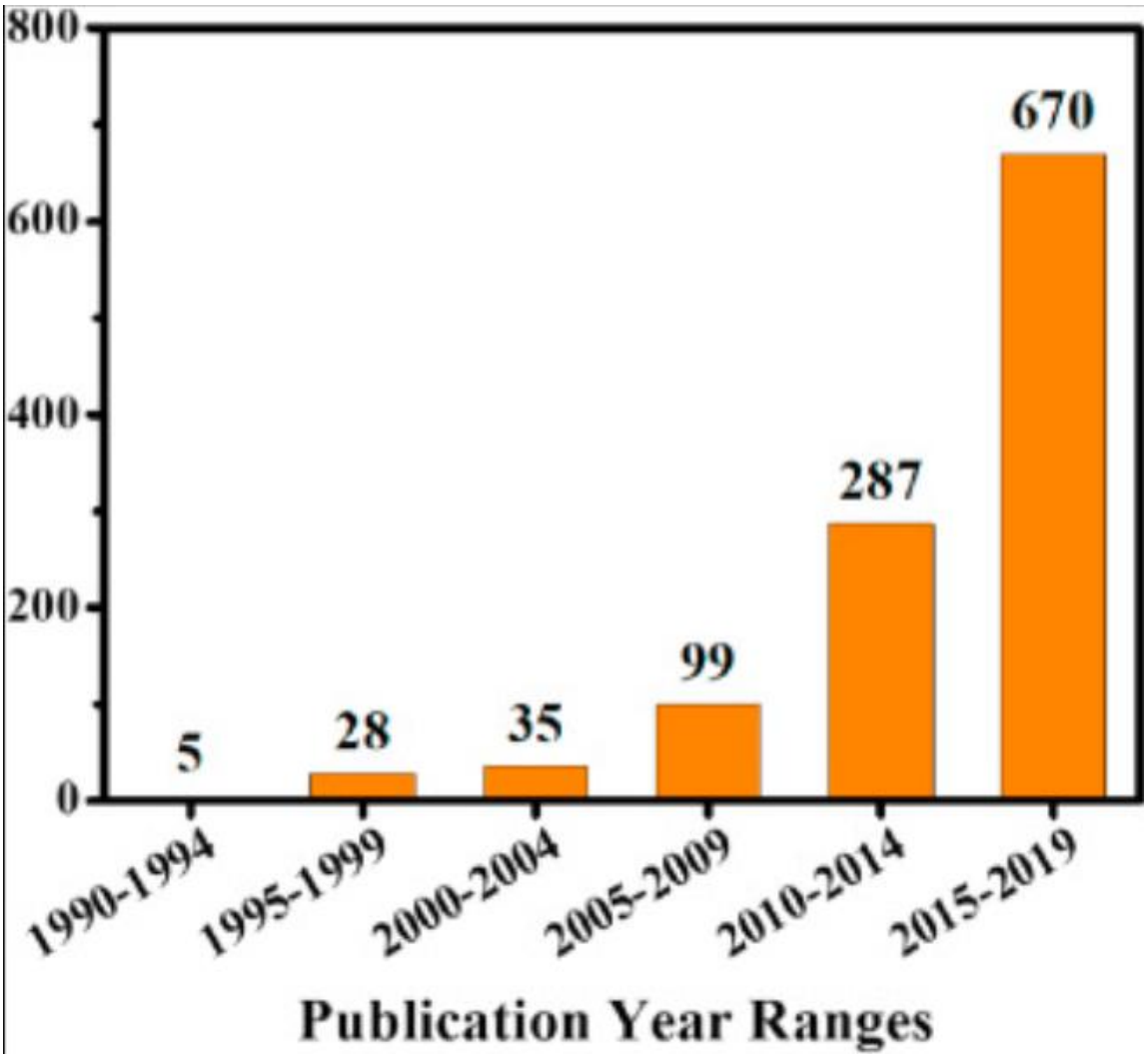
- **Canada:** In February 2024, a team led by Montreal radiologist Dr. Gilles Soulez developed a novel approach to treating liver tumors using microrobots guided by magnetic fields within an MRI device. This method allows for precise navigation of microrobots to target tumor sites, offering a promising avenue for minimally invasive cancer treatments. Researchers at the University of Waterloo, under the leadership of Dr. Hamed Shahsavan, have created tiny soft robots using plant-based materials. These biocompatible and non-toxic microrobots, measuring up to one centimeter in length, have the potential to perform medical procedures such as biopsies and cell or tissue transport in a minimally invasive manner. At Queen's University, Dr. Xian Wang's team at the Small-Scale Robotics Lab is developing microrobots designed to navigate small and hard-to-reach areas in the human body. Their research focuses on improving targeted drug delivery and advancing minimally invasive medical procedures. Meanwhile, at The Hospital for Sick Children (SickKids) in Toronto, researchers are working on magnetic microrobots with precision gripping capabilities. These tiny robotic tools have the potential to revolutionize neurosurgery by enabling minimally invasive brain procedures. References; [66], [78], [79], and [80]

Data



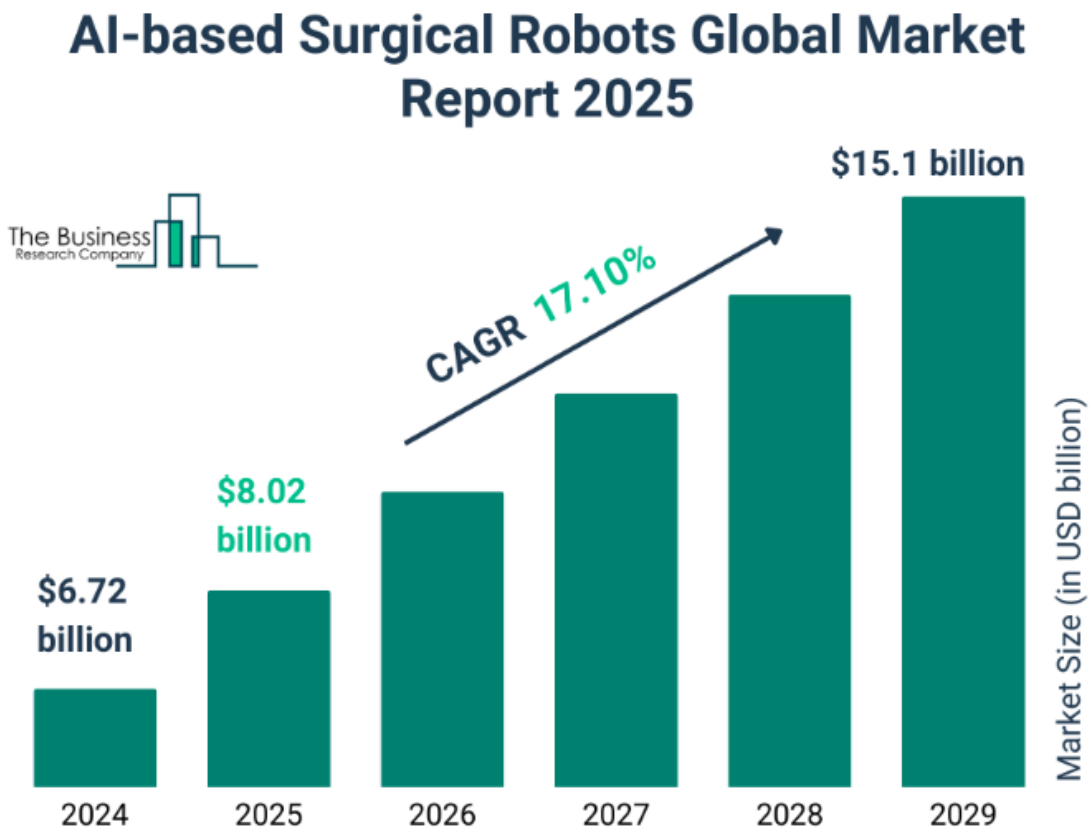
This graph shows the advancements and increases in microrobot technology over the years. In this graph it specifically shows the number of journal publications over the years and the total number of cities that have been involved in microrobot research. As we can see in the graph, microrobot research is continuously increasing in more cities each year. It highlights the steady rise in academic interest and collaboration in microrobotics over the years. The data indicates a growing global effort, with more cities contributing to advancements in the field. Overall, the graph reflects the expanding scope and significance of microrobot research worldwide.

Reference; [83]



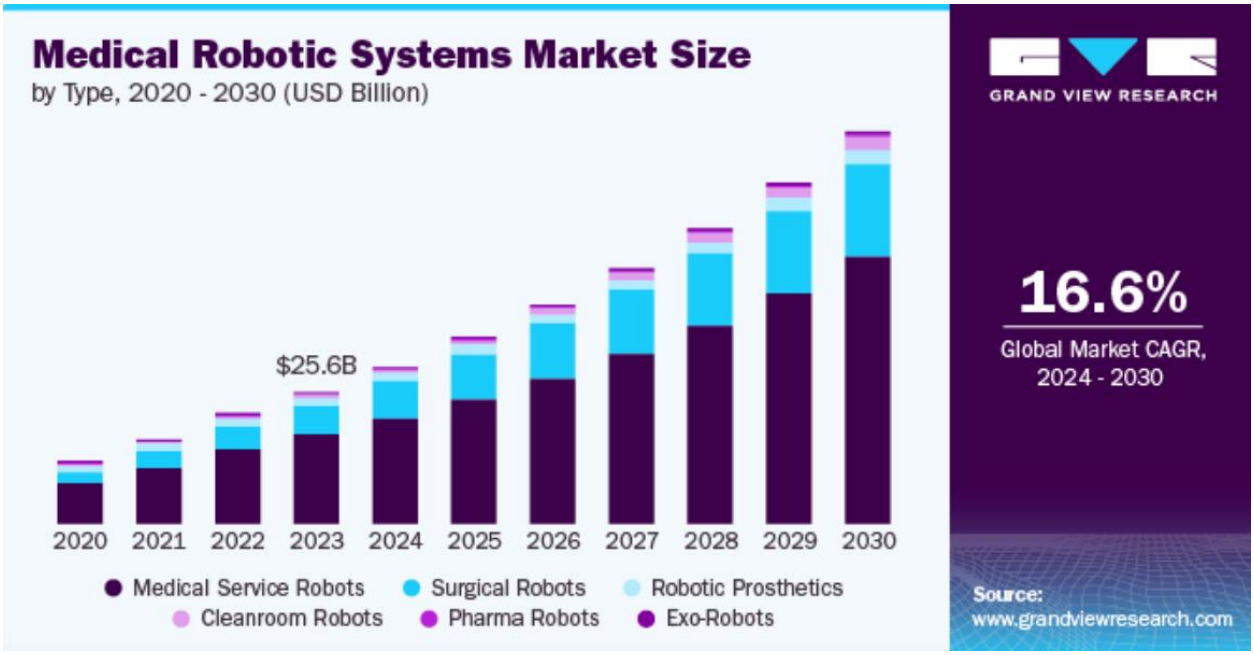
This graph shows the increase in Microrobot Biomedical Application Publications that have been made over the years in the US. We see a drastic increase in numbers in 2015-2019. In this time, the demand of microrobotic technologies for cancer patients and patients all together significantly increased, as these technologies offered new possibilities for minimally invasive procedures and targeted therapies. Technology also experienced advancement during these years, and biomedical engineering became a focus of research. The publications highlighted in this graph are scholarly articles written by researchers, professors and other experts.

Reference; [84]



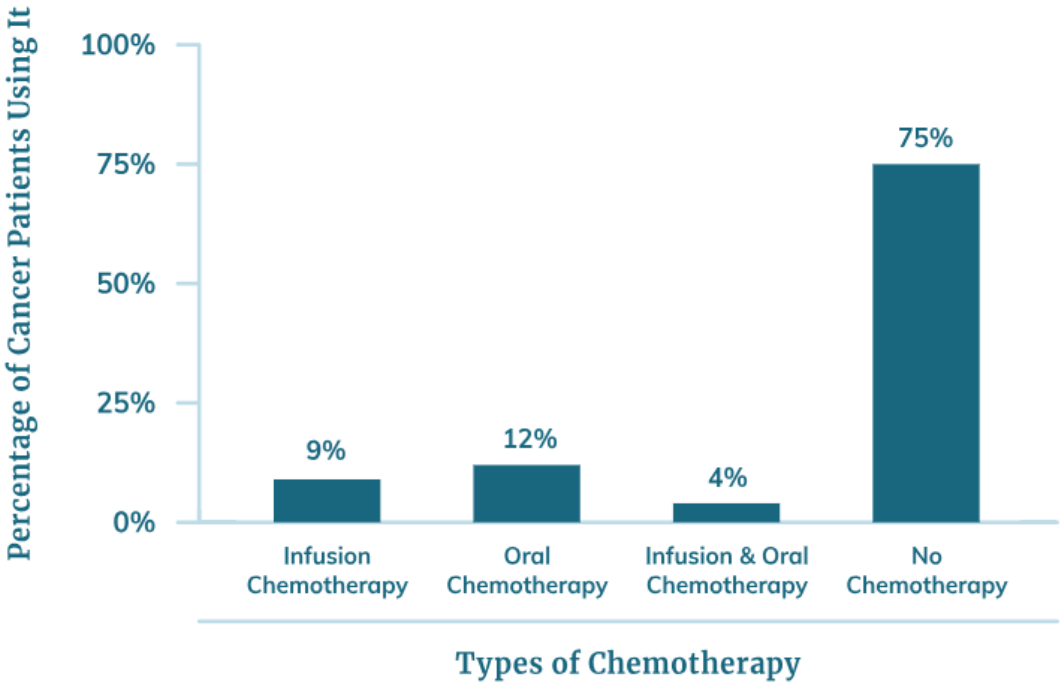
This graph shows how the AI based surgical robots market size has rapidly grown over the past few years, and how its market size is planned to continue growing at an even faster rate. It has grown from $6.72 billion in 2024 to $8.02 billion in 2025 at a compound annual growth rate (CGR) of 19.3%. The need for patient safety, increased risk of chronic diseases, and the potential benefits of minimally invasive surgery using these microrobots has caused this increase in demand and market size. The AI-based surgical robots market size is expected to see rapid growth in the next few years. It will grow to $15.1 billion in 2029 at a CAGR of 17.1%. The rising demand of AI based surgical robots in healthcare is expected to propel the growth of the AI-based surgical robot market. These robots integrate AI with robotic technology to assist or even autonomously perform surgical tasks. Currently, in 2023 according to Oliver Wayman, as US based management consulting firm, robotic surgery is used in 2% of surgeries across Europe and about 15% in the US. Some of these surgeries include neurology, urology, ENT, thoracic surgery, and colorectal surgery.

Reference; [85]



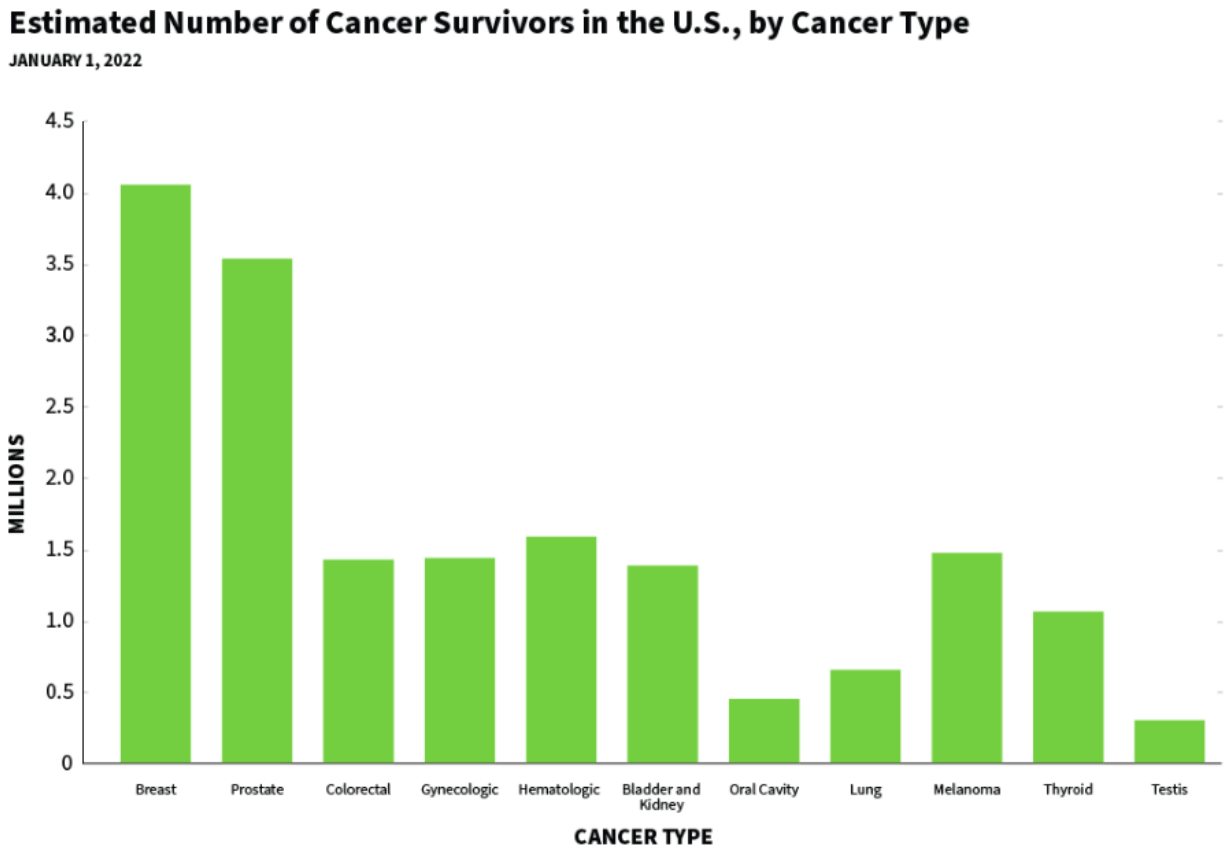
The graph illustrates the rapid growth of the Medical Robotic Systems Market from 2020 to 2030, with a projected 16.6% CAGR from 2024 to 2030. The market, valued at around $25.6 billion in 2024, is expected to expand significantly, driven by Medical Service Robots and Surgical Robots, which dominate the industry. Other segments, including Robotic Prosthetics, Pharma Robots, Cleanroom Robots, and Exo-Robots, also contribute to this growth. This trend highlights increasing adoption of robotics in healthcare, offering major opportunities for technological advancements and investment.

Reference: [86]



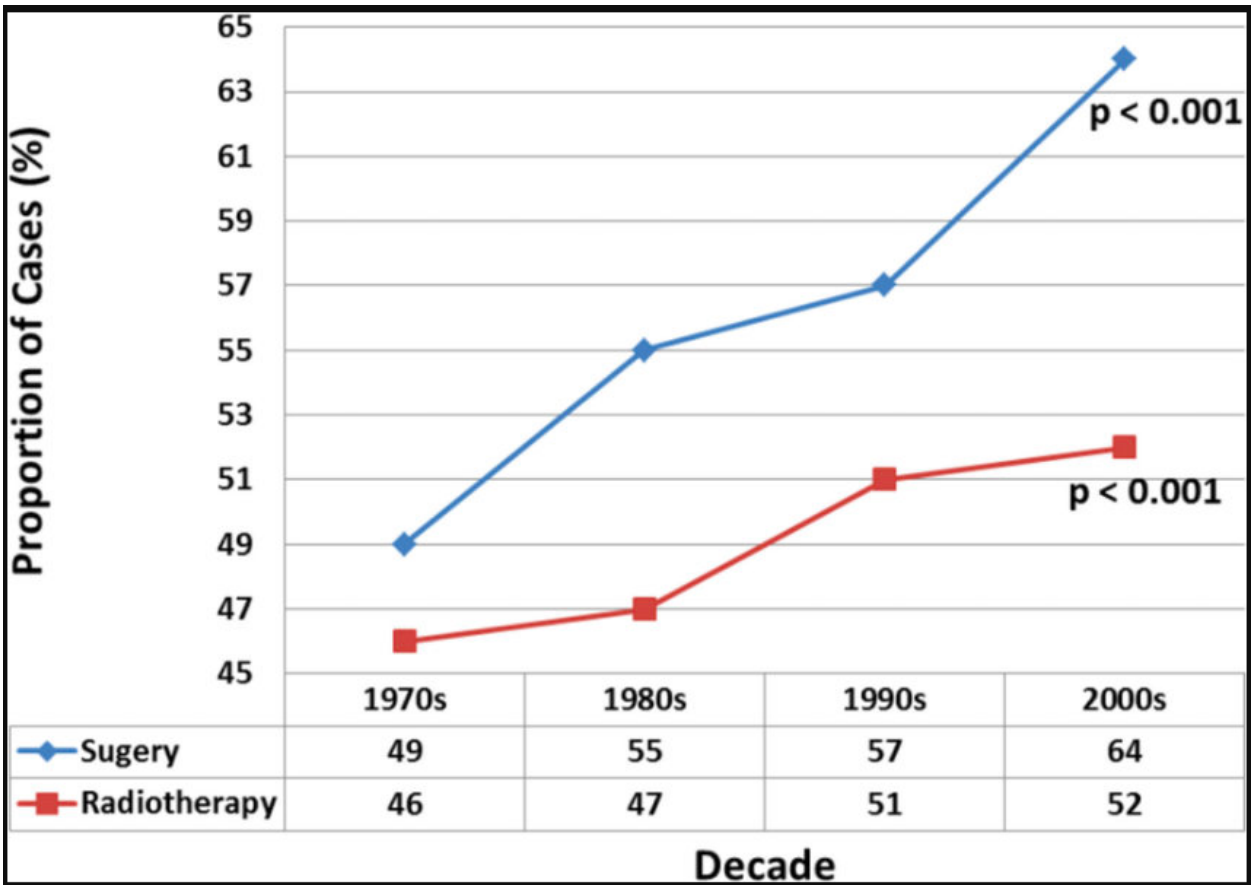
The graph shows that 75% of cancer patients do not undergo chemotherapy, while the remaining 25% use oral (12%), infusion (9%), or both (4%) chemotherapy. Oral chemotherapy is the most common among treated patients, while combination therapy is the least used. This trend suggests a need for further investigation into the reasons behind chemotherapy avoidance and potential alternative treatments for cancer patients. This is where the importance of microrobot treatment research comes in. Many cancer patients try their very best to avoid chemotherapy due to its horrible side affects.

Reference: [87]



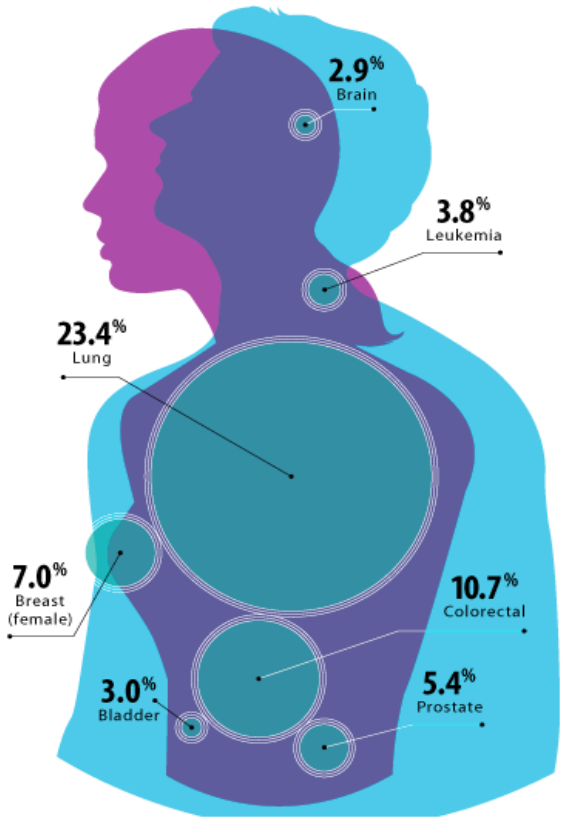
This graph displays the estimated number of cancer survivors in the U.S. as of January 1, 2022, categorized by cancer type. Breast cancer has the highest number of survivors (over 4 million), followed by prostate cancer (around 3.5 million). Other common survivor groups include colorectal, gynecologic, hematologic, bladder/kidney, and melanoma cancers, each with over 1 million survivors. Oral cavity, lung, thyroid, and testicular cancer have relatively fewer survivors, with testicular cancer having the lowest. This data highlights the variation in survivorship among different cancer types.

Reference: [88]



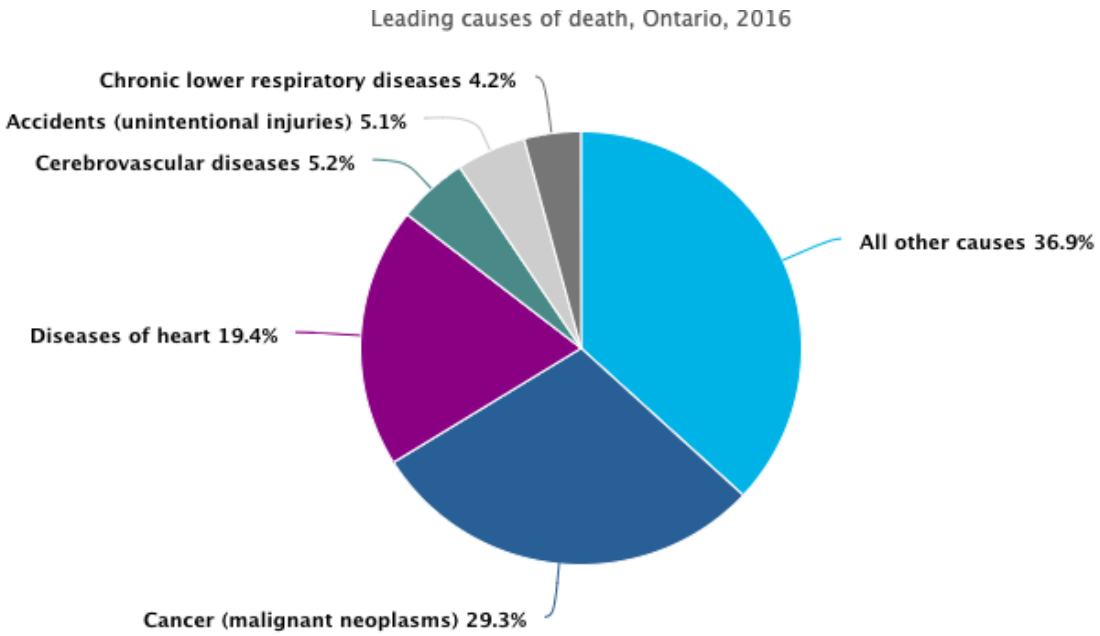
This is a trend graph of cancer-directed therapy showing increasing utilization of surgery and radiotherapy over four decades. The p-values reported for trend analysis refers to comparison among all of the four-decade quartiles. This increase in surgical methods suggests advancements in surgical techniques, better patient selection, and potentially improved survival rates with surgery. Additionally, the use of radiation therapy also increased, from 46% to 52% over the same period. This may indicate the growing role of radiation as a post-surgery or pre-surgery treatment, improving patient outcomes. The overall increase in both treatments suggests a shift toward more aggressive treatment strategies for cancer. It also reflects improvements in medical technology, allowing for better surgical and radiation techniques. The notation "p < 0.001" refers to the p-value in statistical hypothesis testing. P-value is a measure of the evidence against a null hypothesis. A p-value of less than 0.001 indicates strong evidence against the null hypothesis. In other words, it suggests that the observed results are very unlikely to have occurred by chance.

Reference: [89]



The figure visually represents cancer mortality rates in Ontario using overlapping male (blue) and female (purple) silhouettes, with labeled percentages indicating the proportion of deaths caused by different cancer types. The size of each circle corresponds to the mortality rate, highlighting lung cancer (23.4%) as the leading cause of cancer-related deaths in both sexes. Colorectal (10.7%), breast (7.0%, female-only), and prostate cancer (5.4%, male-only) are also significant. Smaller but notable contributors include leukemia (3.8%), bladder cancer (3.0%), and brain cancer (2.9%). The visualization effectively compares cancer mortality by type and gender, emphasizing lung cancer as the most fatal. Mortality rate refers to the proportion of people who die from a disease within a specific population, highlighting its impact on public health. IN this case it is per 100,000. The diagram means that 23.4% of all cancer-related deaths are due to lung cancer.

Reference: [90]



This figure represents the leading causes of death in Ontario. Cancer is a leading cause, as it is 29.3% of the causes of death. This is an incredibly high percentage. This emphasizes the need to focus on cancer treatments. Heart disease (19.4%) is the second leading cause. Other significant causes include cerebrovascular diseases (5.2%), accidents (5.1%), and chronic lower respiratory diseases (4.2%). A large portion of deaths (36.9%) falls under "all other causes," which includes a variety of medical conditions and factors. However, the largest percentage is for cancer caused deaths, so we must continue research for cancer.

Reference: [90]

Conclusion

Future Spinoff

If I were to do another research/study project in science fair in the future, I would add 3D models to fully execute and display the knowledge that I have gained throughout my project. For this project I could have incorporated 3D models by modeling the different

microrobot technologies at a larger scale. Additionally, I wish I could have completed an interview with the University of Calgary Biomedical Engineering department. I believe that receiving insights from an expert currently doing this research is extremely important. Unfortunately, for this project I did not get a response to my email. I sent an email to this department, but did not receive a response. So, in the future I would like to ensure that I have enough time to make this happen. I could try creating a simple prototype of a microrobot or simulating its function. Even if it's just a basic model, demonstrating its potential movement or tasks could add a hands-on element to my project, making it feel more real-world and tangible. Other than the three modifications I described above, I would keep my general process the same for future science fair projects.

Conclusion

In conclusion, microrobots are going to make a monumental difference in the treatment of cancer by allowing for highly accurate, targeted, and minimally invasive treatments that can greatly improve patient recoveries and the efficacy of treatments. Targeted drug delivery is perhaps one of the brightest horizons. Microrobots are hoped to move inside the body to locate a tumor or cancer cell and give the region chemotherapy or other cancer-causing chemicals without disrupting the tissue around it and injuring fewer than more conventional methods. The process not only has the capability to maximize therapeutic impact for the medication, but it also enhances patient quality of life.

Synthetic lethality is another revolution area where microrobots might attack vulnerability in cancer cells. Microrobots may kill cancer cells, bypassing drug resistance typically that tames, the affect of traditional drugs, by attacking penetrants that move across target genetic or biochemical pathways selectively. Microrobots could kill cancer cells while leaving healthy ones unharmed.

Minimally invasive surgery is also a desirable option with microrobots. They would perform surgical movements with accuracy at high speed without the large incisions used in traditional surgery, reducing infection risks and shortening recovery times for the patient. The aspect would enable procedures to be performed more often with less trauma, particularly where conventional surgery would be too risky or inconvenient. It would also be incredible to get micro swimmers more effectively along the circulatory system and into even tumors by combining drug delivery and micro swimming capabilities. They would be able to monitor and treat the tumour cells.

They would be more effective with sensors because they would then be able to detect tumor-associated biomarkers so that more specifically cancer cells can be attacked, while

healthy tissue is spared. Moreover, integrating the aspect of conducting minimally invasive therapies through microrobots would make them end-to-end in a system for diagnosing, treating, and tracking cancer on a cellular scale. Merging these technologies would make treatment for cancer more accurate, efficient, and versatile, thereby leading to better patient results. Overall, the use of microrobots in cancer therapy promises a future of more effective, targeted, and less harmful treatments for patients. As the technologies are further developed, we can look forward to a paradigm shift in cancer therapy, with greater success and less work for patients, with an overall improvement in quality of life and increased survival rates.

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