Title of submission: Robotics in Medicine: Robotic Surgeons

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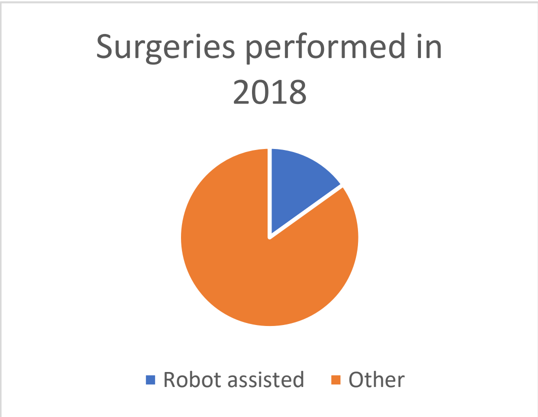
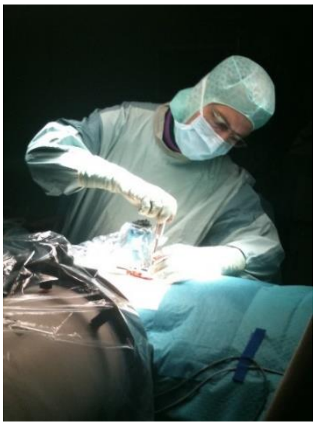
Robotics in Medicine: Robotic Surgeons

There has been a rapid advance in the use of robotic surgeons in recent years, with 15% of the surgeries performed in 2018 being robot-assisted (See Figure 1). Additionally, a recent study found out that there has been an 8.8% increase in the use of robotic surgery in the first 4 years after its introduction. The popularity of robotic surgery largely owes to robotic surgeons' precision and control a human would not be able to have. It is hoped that using robotic surgeons would reduce clinical mistakes and make surgeries safer and less painful. Usually, robotic surgeons would have camera arms and mechanical arms which a surgeon would operate using a computer. An example is the da Vinci Surgical System, which performs minimally intrusive surgeries which ultimately results in reduced pain, fewer complications, and recovery times. Over 7 million surgeries have been performed using this procedure.



Surgeries performed in 2018

Adapted from "Trends in the Adoption of Robotic Surgery for Common Surgical Procedures" by K. Sheetz, J. Claflin and J. Dimick, 2020, *JAMA Netw Open*, 3(1). (doi:10.1001/jamanetworkopen.2019.18911). CC BY.



Traditional methods of surgery are not as precise as robotic surgeons

From "File:Robotic Spinal Surgery.jpg" by Ap2296, 2012, Wikimedia Commons. (https://commons.wikimedia.org/wiki/File:Robotic_Spinal_Surgery.jpg). CC BY-SA 3.0

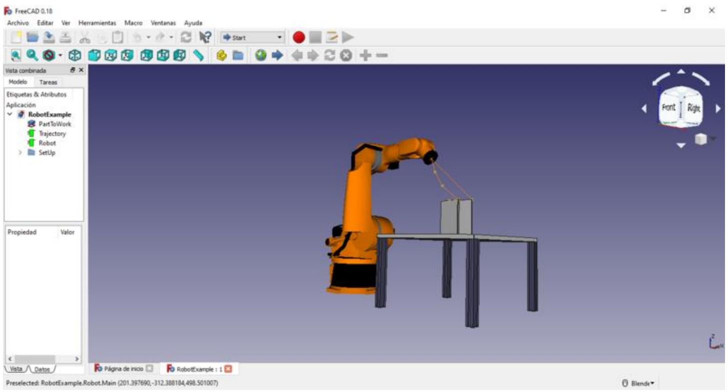
The engineering design process is a series of actions followed when solving problems that involve the steps of identifying the problem and constraints, creating, testing, and improving. This is used to guide engineers in creating the best possible solution and is followed by many people in the industry.

Da Vinci Surgical System

From "File:Davinci-xi-surgical-system.png" by https://www.intuitive.com, 2019, Wikimedia Commons. (https://commons.wikimedia.org/wiki/File:Davinci-xi-surgical-system.png). CC BY-SA 3.0

The first phase of the engineering design process identifies the problem and constraints. While many surgeries can be done by large stationary robots with motor arms, there are specialized robots designed to perform heart surgeries by attaching to the heart because of its rapid moving nature. Here, the designers have created the robot to perform surgeries, while addressing the constraint that the robot should not disrupt the beating of the heart. This step of identifying the problem and constraints is similar to what teams in VEX robotics do when they design robots that can compete in that year's challenge. For example, a robot designed for the Tipping Point would have motor arms that are tall and flexible enough to score goals. When compared to VEX robots, surgical robots tend to have more constraints such as limited material choice that withstands high temperatures and sterilizing.

The prototyping process for robotic surgeons is very similar to what VEX teams do. The previous step of identifying the problem and constraints is used to plan and research different ideas. Then, the ideas are put together into a prototype, where the designers can see the workability of their ideas in real life. CAD is often used to visualize prototypes by both robotic surgeon designers and VEX teams. CAD-CAM systems are often used for preprogrammed robots. Here, a human surgeon would create a plan based on patient models and the robot would implement it, similar to VEX teams who use robots to carry out their plans. The prototyping phase of both VEX robots and robotic surgeons involve creating prototypes that will successfully achieve their purpose within the constraints.



CAD is used to prototype robots

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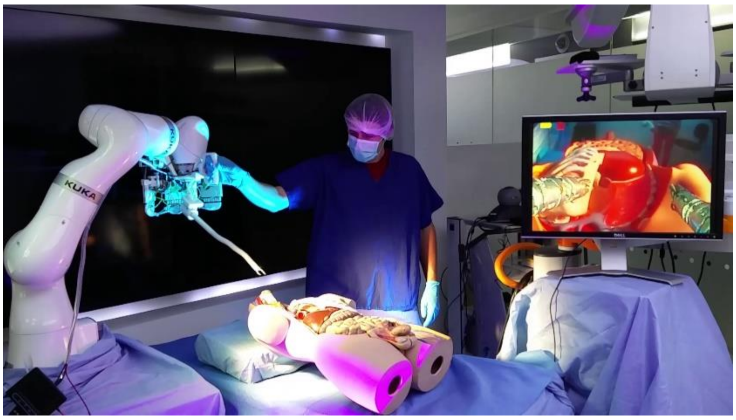


Many sensors, such as live video, are used in robotic surgery.

From "The i2Snake Robotic Platform for Endoscopic Surgery" by P. Berthet-Rayne, G. Gras, K. Leibrandt, P. Wisanuvej, A. Schmitz, C. Seneci and G. Yang, 2018, *Annals of Biomedical Engineering, 46, 1663-1675.* (https://doi.org/10.1007/s10439-018-2066-y). CC BY-SA 4.0.

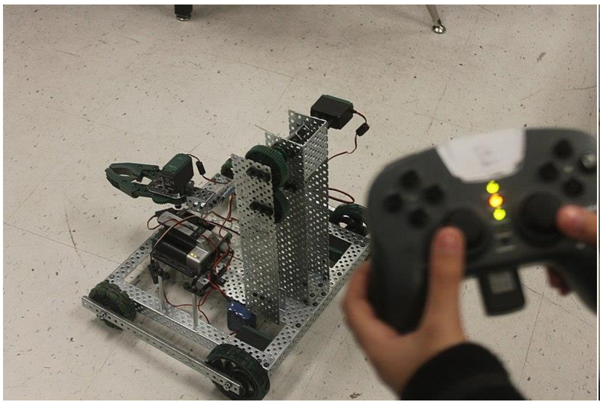
In robotic surgeons, the testing phase includes testing the functionality and safety of the robot. A range of sensors, including live video, imaging (x-ray, thermography, etc.) and movement sensors, are used in robots operated by surgeons in real time. While this assists in making them more informed about patient status than when using traditional methods, and helps in making better decisions, it also means that mistakes in sensors can be potentially life-threatening. Therefore, sensors undergo strict quality assurance processes and redundant sensors are used to ensure that they are working correctly. While more complex sensors are used in robotic surgeons, VEX serves as a good introduction to using sensors and controlling robots using the information given by sensors. Dangerous equipment like scalpels being handled at proximity means that even a small malfunction in robotic surgeons can threaten patients' lives. Therefore, robotic surgeons undergo a vigorous risk analysis process, some of which is similar to VEX teams (e.g., whether robots are overpowering, whether controls work properly). An example is the FMEA risk analysis, which analyzes the failure mode and effect on the system, investigates the cause, and develops a method of control. A process similar to this can be carried out by VEX robotics teams to refine their robots to be more functional and debug errors. Sometimes, a criticality component can be added to the risk analysis by mentioning the severance, occurrent and detectability. Robotic surgeons will also be analyzed using phantoms – which mimic real patient characteristics – to test and refine the robots' accuracy and functionality. This shows the importance of being as close to real conditions as possible when testing.

Failure mode	Effect on system	Causes	Method of Control
…	…	…	…

FMEA risk analysis

From "Surgical and Interventional Robotics: Core Concepts, Technology, and Design" by P. Kazanzides, G. Fichtinger, G. Hager, A. Okamura, L. Whitcomb and R. Taylor, 2008, *IEEE Robot Autom Mag,* 15(2), 122-130. (https://dx.doi.org/10.1109%2FMRA.2008.926390).

The next phase of evaluating and improving is something that both robotic surgeon designers and VEX teams use extensively. The analyses done in the testing process is used to inform the evaluations. This is supported by thinking about whether the problem is solved (e.g., Can the robotic surgeon perform the specific surgery successfully? Can the VEX robot lift rings and place them into the goals successfully?) and whether constraints are considered (e.g., Can the robotic surgeon withstand continuous sterilizing? Does the VEX robot meets challenge requirements?). Then this evaluation is used to improve the robot so that it can achieve its objective with maximum safety, effectiveness and efficiency. Human control (real-time or preprogrammed) is used in both VEX and in robotic surgeons due critical thinking quick and correct judgements being needed in changing situations, that cannot be achieved by a robot using current technology – in a surgery, a mistake could be life-threatening. The 'performing' part is done by the robot due to the precision and dexterity that cannot be achieved by a human (e.g., precise movements, no hand tremor).



Controlling VEX robots

From "File:VEX Robotics Competition Robot and Controller.jpg" by N. Wulf, 2018, Wikimedia Commons. (https://commons.wikimedia.org/wiki/File:VEX_Robotics_Competition_Robot_and_Controller.jpg). CC BY-SA 4.0.

Controlling robotic surgeons

From "File:Cmglee Cambridge Science Festival 2015 da Vinci console.jpg" by Cmglee, 2015, Wikimedia Commons. (https://commons.wikimedia.org/wiki/File:Cmglee_Cambridge_Science_Festival_2015_da_Vinci_console.jpg). CC BY-SA 3.0.

Lastly, operating robotic surgeons need a lot of practice. While every surgeon who will use robots in surgeries will undergo rigorous training, having prior experience in the field of robotics and being tech-savvy will be an advantage. Learning robotics at school teaches a lot of technical knowledge and skills, like controlling and programming, as well as personal skills like critical thinking and teamwork that will be beneficial if they choose to work with robotic surgeons in their careers.

Teamwork in robotic surgery

From "File:Da Vinci action 023874 10x7 150dpi.jpg" by Intuitive Surgical Inc, 2016, Wikimedia Commons. (https://commons.wikimedia.org/wiki/File:Da_Vinci_action_023874_10x7_150dpi.jpg). CC BY-SA 3.0

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