

“Future Assistive Robots”

Worcester Polytechnic Institute • Interactive Qualifying Project



WPI

Submitted to:

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Abstract

Assistive care robots have evolved rapidly in the last twenty-five years, bringing efficiency, safety and precision into the medical field [1]. Medical robots have been playing a crucial role in such an important and growing field. They have also brought uncertainty about future effects upon professionals due to their technological advances.

Purpose: Understand how assistive care robotics are presently helping in surgery, prosthetic and rehabilitation. Additionally, the effects they will have upon medical professionals within the next ten years. **Methods:** The team will Research on past, present and future projects involving assistive care robotics using different journals with the most recent work that is being done by professionals within the medical, biomedical and robotic fields. Posteriorly to the research, interviews were conducted with medical doctors, professors, PhD researchers and panel participants from The National Institute of Health (NIH). The objective of the interviews is to obtain experts' points of view in order to answer our problem question stated in the purpose section. **Results:** Show that assistive care robots are currently improving lives, and bringing efficiency to the medical field. Based on interviews and research we found that assistive robots will possibly assist better in surgical procedures and rehabilitation centers, as well as bringing safety to the performance of medical professionals within the next ten years. **Conclusions:** Robots are improving lives of medical professionals and patients by serving as tools that enhance the ability of the users through their implementation, execution and profound effect on people lives. Further interviews would need to be conducted, since we only interviewed eleven experts, this gives us insufficient data to make a conclusion of what the future effects upon medical could be within the next ten years.

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Table of Contents

Abstract	1
Acknowledgement	2
Table of Figures	5
Authorship	6
Chapter 1 – Introduction	7
Chapter 2 – Background	9
Chapter 3 – Approach	11
Chapter 4 – Prosthetic Robots	13
4.1 Past Prosthetic Robot	15
4.1.1 C-leg:	16
4.2 Present Prosthetic Robot	18
4.2.1 I-Limb:	18
4.2.2 ReWalk-Bionic Suit:	1
4.3 Future of Prosthetic Robots	3
4.3.1 Artificial Muscle:	3
4.3.2 Nanowire Sensors:	5
Chapter 5 – Surgical Robots	7
5.1 Past of Surgical Robots	9
5.1.1 PUMA 560 Robot	9
5.1.2 The Probot:	10
5.2 Present of Surgical Robots	12
5.2.1 da Vinci	12
5.2.2 Telelap ALF-X	14
5.3 Future of Surgical Robots	16
5.3.1 IBIS Pneumatic Surgery Robot	16
5.3.2 Complementary Situational Awareness	17
5.3.3 Painting Robot Lends Surgeons a Hand	19
Chapter 6: Rehabilitation Robots	21

6.1 Past of Rehabilitation Robots	23
6.2 Present of Surgical Robots	26
6.2.1 Armeo arm therapy (Upper Limb Exoskeleton).....	27
6.2.2 Anklebot (Lower Limb Exoskeleton)	29
6.3 Future of Rehabilitation Robots	31
6.3.1 Robotic Orthotic:	32
6.3.2 Co-robotic cane:	34
6.3.3 Robotic Ankle Exoskeleton control:.....	35
Chapter 7: Results and Analysis	37
Chapter 8: Conclusion.....	44
Appendixes.....	47
Appendix A: Interview with Dr. Douglas Dahl:.....	47
Appendix B: Interview with Dr. Shahin Tabatabaei:	50
Appendix C: Interview with Professor Gregory Scott Fischer:	52
Appendix D: Interview with Dr. Holly Yanco:	56
Appendix E: Interview with Dr. Mansoor:.....	60
Appendix F: Interview with Dr. Jeffery Borenstein:.....	68
Appendix G: Interview with Russ Agnold:	73
Appendix H: Interview with Dr. Heather Clark:	77
Appendix I: Interview with Professor Patricia Creelman:	81
Appendix J: Interview with Professor Margaret McGrath:.....	84
Appendix K: Interview with Professor Karen Carpenter:	86

Table of Figures

Figure 1: Interior view of i-WALK Robot [9]	14
Figure 2: Peg legs in 16th century [13].....	15
Figure 3: Side view of C-leg showing different parts [15].....	16
Figure 4a: i-Limb without covering [17].....	19
Figure 5: A paralyzed girl wore Rewalk bionic suit [18].....	2
Figure 6: A variety of sizes of the artificial muscles, with a pencil for scale [16].....	4
Figure 7: Assembling of nanosensor [20].....	5
Figure 8: A sensor based on silver nanowires is mounted onto a thumb joint [21].....	6
Figure 9: A doctor performing surgery using PUMA 560 robot [24]	10
Figure 10: Simplified drawing of the robot's structure [26]	11
Figure 11: Surgical system general procedure in operating room	Figure 12: da
Vinci System	14
Figure 13: IBIS view from the left [34].....	17
Figure 14: Proposed framework for robot-human [36]	18
Figure 15: Robot arm programmed to paint pictures [37].....	20
Figure 16: The Rancho Los Amigos Orthosis [39]	Figure 17: The Rancho Los
Amigos Orthosis [39].....	24
Figure 18: Final prototype of the BFO [39]	Figure 19: Exoskeleton
Hardiman [42].....	25
Figure 20: ArmeroPower [Upper Limb Exoskeleton] [44]	Figure 21: HULC [Lower Limb
Exoskeleton] [45].....	27
Figure 22: HAL-5 [Full Body Exoskeleton] [46].....	27
Figure 23: ArmeroSpring [Upper Limb Exoskeleton] [44].....	27
Figure 24: Anklebot [Lower limb Exoskeleton] [50]	29
Figure 25: U.S population older than 65 years [53].....	31
Figure 26: Robotic Orthotic on the right corner [55]	33
Figure 27: (Co-Robotic Cane CRC) [57].....	35
Figure 28: Robotic Ankle Exoskeleton Control [54].....	36

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Chapter 1 – Introduction

Medical robots have been defined as machines able to allow medical professionals to obtain more accurate and precise results in their procedures, using less invasive methods. These devices have been used since 1989 with the purpose of bringing efficiency, precision and safety to the medical field [2]. Robots in the assistive care area are divided into three main subareas which we will focus on: surgery, prosthetics and rehabilitation. They are currently helping people with physical and mental disabilities; as well as assisting surgical procedures reducing the risks of human error, thus increasing the possibilities of survival. Although these devices are helping to solve medical problems, their rapid evolution has also brought uncertainty to what the future effects hold for medical professionals such as doctors and nurses. Therefore, our group aims to understand how they are currently helping in assistive health care, and also the effects of the evolution of assistive care robotics within the next ten years upon medical professionals, more specifically regarding doctors and nurses.

Technology has evolved in the medical field with the presence of robots. In recent years, technology has been applied to the use of prosthetic limbs or robotic limbs, rehabilitative robots and surgical robots. Prosthetic robots help the people who lost extremities due to accidents, trauma, and diseases. Robotic surgery is a technological development, which use robotic systems to aid in surgical procedures such as: urological, cardiothoracic, gynecology, neurological and orthopedic surgery. Doctors can performed surgeries more accurately, precisely and efficiently. Rehabilitation robotics is the field that aims to understand and augment rehabilitation with the use of robotic systems. The main function of this area is to enhance the process of recovery

from injuries, illness or disease, emphasizing the central role of the patient during the motor exercise.

Chapter 2 – Background

Medical Robots have been defined as machines able to allow medical professionals, such as doctors and nurses, to obtain more accurate and precise results in their procedures, using less invasive methods. Robots in the assistive care area are divided in three main subareas: surgery, prosthetics and rehabilitation. Surgical robots are specialized in aiding surgical procedures in order to make them minimally invasive and to enhance the possibilities of success during open surgeries. The first surgical robot introduced to the industry was the PUMA 560 which was used to orient a needle for brain biopsy under computerized tomography guidance, this robot was discontinued for safety issues [3]. Robotic prosthetic limbs are mechanical devices made to substitute the functions of a loss limb. The first bionic limb was the Edinburgh modular arm system created by Dr. David Gow in 1988, which played an important role in patients that had lost their arms, allowing them to carry out activities that needed both arms [4]. Rehabilitation robotics is the field aimed to help improve sensorimotor functions through the help of robotic devices. One of the first rehabilitation robotic systems was a powered orthosis with four degrees of freedom. The exoskeleton structure supported the user's paralyzed arm, while performing pre-recorded manipulative tasks [5]. In this study we aim to understand the effects of the evolution of assistive care robotics and how the presence of these devices in each of the three areas helping in the present of medicine.

Medical Robots have come a long way technologically and mechanically in the past twenty-six years. Comparing the first surgical, prosthetic and rehabilitation robots to our present medical robots, it is evident how much these devices have evolved and how important the role they are playing is in today's society, within the assistive care

field. In surgical robotics one of the most recent robots is the da Vinci Surgical System, which has the potential as described in recent studies "...to improve the surgeon's confidence, as well as surgical safety, efficiency, and precision by filtering tremor" [1]. This could, indeed, save lives by bringing more precision and efficiency into the surgical rooms by potentially avoiding complications and risks. It is easy to be impressed by the great evolution this field has had when we look at current robotic prosthetics. Starting with a rigid and obsolete design with the Edinburgh modular arm system, to one of the most recent creations the i-Limb, which applies myoelectric technology, the i-Limb provides not only natural functionality but also natural appearance, allowing the patient to perform everyday tasks [6]. Another great advance within this area is the Luke Prosthetic arm from DEKA, which utilizes touch feedback, advanced grasp control, and contains multiple degrees of freedom. Rehabilitation robotics has also shown tremendous evolution with the different types of exoskeletons, such as the eLEGS, a system that allows paraplegics and those with mobility disorders to stand and walk [7].

Assistive care robotics is a field that does not stop growing. All the research done in the past, all the evolution that this field has been through has taught the engineers, researchers and designers that there is always room for improvement. The future of assistive care robotics is promising based on the newest research which includes: the Control of Powered Segmented Legs for Rehabilitation Robotics, advanced Bio photonics for Image-guided Robotic Surgery, High Performance Robotic Below-Knee Prostheses, among other encouraging research projects that are currently being funded by the National Institute of Health. Such projects are what arouse our curiosity of what the future of assistive care might be and what will be their effects on society.

Chapter 3 – Approach

Our approach to solve this problem was to find articles and journals related to the past, present, and future of surgical, prosthetic, and rehabilitation robots. With the objective of understand their technological advances since they were first introduced into the assistive care area. We also wanted to conduct interviews with experts, not only within the robotics department but also within the biomedical, medical, biology, and mechanical departments. With the purpose of gathering different points of view towards the rapid evolution of these systems. The experts we wanted to include on our interviews were: medical doctors, PhD researchers, professors and/or professionals inside the panels of the National Institute of Health (NIH). These experts needed to be either conducting or have a wide knowledge of current research being conducted in medical robotics.

After conducting some research, we found and contacted twenty three experts. We received response from most of them and conducted interviews with eleven of them. Which included two Doctors (Dr Douglas Dahl and Dr. Shahin Tabatabei), six researchers (Professor Gregory Fischer, Dr. Holly Yanco, Dr. Mansoor , Dr. Jeffery Borenstein, Russ Agnold, Dr. Heather Clark), and three nurses (Professor Patricia Creelman, Professor Margaret McGrath, and Professor Karen Carpenter). Interviews were focused on their current projects, and their thoughts about how assistive care robotics are currently helping in the assistive care area; as well as what they believed would be the effects upon medical professionals due to the technological evolution of these systems. Interviews were either in person or via phone, and took 15 to 30

minutes. These sessions were recorded for future reference, after obtaining the permission from participants.

Chapter 4 – Prosthetic Robots

Prostheses are artificial devices that replace a missing body part which have been lost due to different types of traumas, diseases or congenital conditions. Prosthesis is an Ancient Greek word meaning “addition, application and attachment”. Statistics say that more than 185,000 amputations are performed annually in the United States [8]. The first artificial program was established in 1945 by the National Academy of Sciences in order to advance the design and implantation of artificial/prosthetic limbs. Since then, many institutions and organizations started researching how fully functional prosthetic robots can be created. Prosthetic robots are also called mechanical limbs, because they are controlled by microprocessor and nerve impulses. There are many ways to transmit signals from human nervous systems to electronic parts within the prosthetic. The use of electromyography sensors (EMG) is a common form of sending signals from the remainder of the amputated limb to the prosthetic. The sensors are translated into the prosthetic, when amputees flex their muscles. “Targeted reinnervation” is another form of transmitting signals from the amputee to the prosthetic. During this procedure, the patient’s nerves from different parts of their body are rewired to control the missing limb. Another way to transmit signals is through surgery into the remainder of the patient’s limb, the stump, of a patient to connect their nervous system to the microprocessor in the prosthetic limb. As technology evolves, the design of robotic limbs evolves as well. The company iWalk (using technology developed at MIT) developed the PowerFoot One, a robotic ankle and foot. This device has several microprocessors and six sensors which evaluate and adjust ankle position, stiffness, damping and power as shown in figure 1 [9].

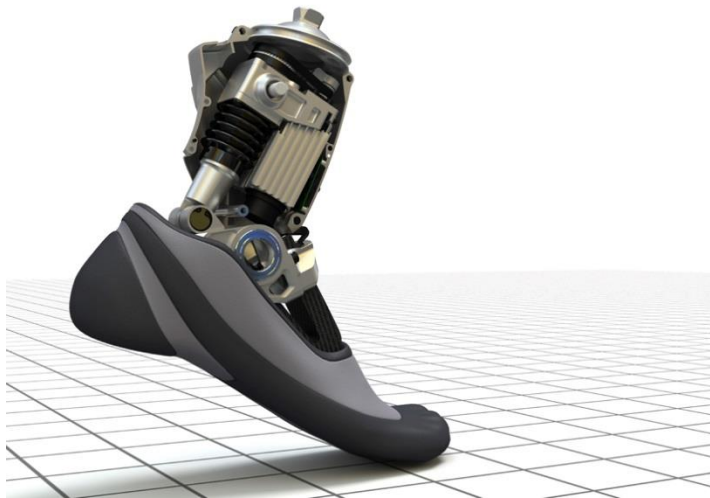


Figure 1: Interior view of i-WALK Robot [9]

The use of prosthetic robots has some limitations which need to be resolved in order to be implemented within the clinical environment. A commonly known problem is cost, because prosthetic limbs need to be designed differently depending on the patient's size, height and weight; the size variation can cause a cost change. Robotic limbs can range from high thousands to millions of dollars; most of them can easily cost more than "\$100,000" [10]. Another problem is the security at airports, the users of prosthetic limbs face the discomfort of being pulled aside for further screening. "A survey of 7300 amputees conducted by the Amputee Coalition of America in June showed that travelers with limb loss have been subjected to inconsistent, unfair, abusive and often embarrassing screenings by TSA employees" [11].

4.1 Past Prosthetic Robot

Prosthetic devices have existed for centuries. History shows that the oldest prosthesis were made with copper and wood, which was developed in 300 BCE and was discovered in Capua, Italy [12]. In the 16th century Iron prostheses arms were created for soldiers by the blacksmiths who also crafted their suits for arms which gave the soldier the ability to flex a digital hand. By the 19th century, “Anglesey Leg” was created with artificial tendons to lift the toe when bending the knee by James Potts. The first artificial leg was invented by Benjamin Franklin and received a patent # 4834 on November 4, 1846 [13]. It uses a spring and metal tendons, which act like joints allowing flexibility to the limb. This creation replace the use of peg legs as shown in figure 2. During the Civil War the demand of artificial limbs increased due to the large number of amputations.



Figure 2: Peg legs in 16th century [13]

4.1.1 C-leg:

This robot came out in 1976 after the approval of the FDA (Food and Drug Administration) [14]. This was the first microprocessor, which controlled lower limb prosthesis in the United States and became one of the most popular microprocessor prosthetic leg in history. It had highly stable lightweight carbon fiber frame for patient's, whose maximum weight is 300 lbs. /136 kg and with a maximum possible knee flexion of 125 degrees [15]. C-leg had multiple sensors that collect and calculate different data such as: amount of vertical load, sagittal plane ankle movement, and specifics of knee joint movement. There were many advantages of this microprocessor robot such as: decreased the effort involved in walking, improved posture symmetry, increased confidence of patients, and prevented accidents of falling.

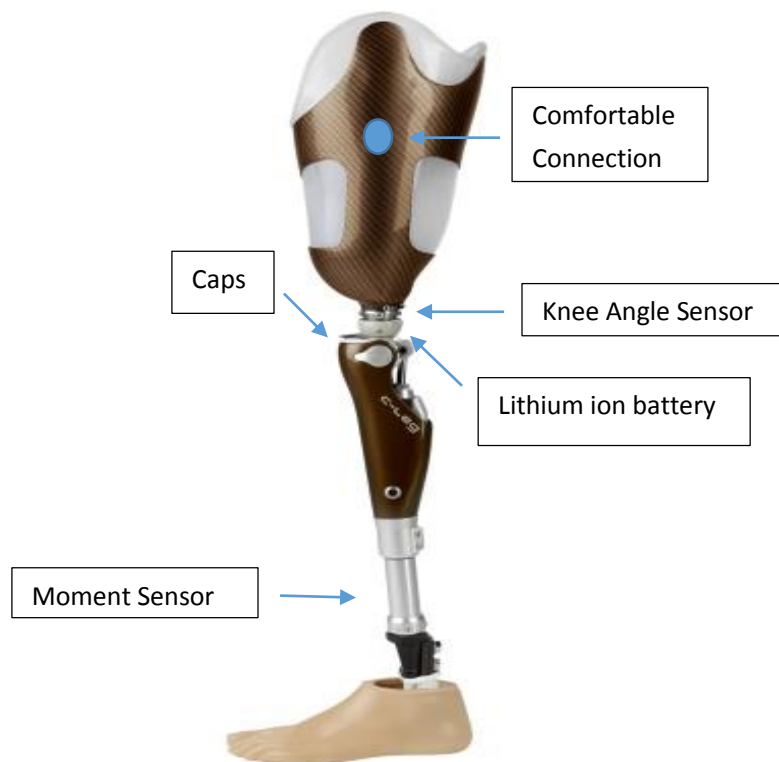


Figure 3: Side view of C-leg showing different parts [15].

Over 40,000 people have been benefited by the C-leg's proven function and stability [15]. This popularity helped to make the C- leg technology the Standard of care for above knee amputees. As shown in figure 3 this device contains a socket created to fit uniquely in the patient's limb to ensure a secure, comfortable fit. The knee angle sensor gives the microprocessor information needed for dynamic control during the swing phase and stability while standing by constantly measures the angle and speed of the knee joint. The attached caps covers the electronics, enhance security and improve protection from moisture and foreign matter. The lithium ion battery provides the 40- 45 hours of power before recharging is needed. A moment sensor located in the tube adapter measures the movement of the ankle. This microprocessor knows exactly, where the person is in the walking cycle and provides the appropriate support.

4.2 Present Prosthetic Robot

For years now, robots have worked tirelessly in the shadows to increase or enhance the productivity of humans. Prosthetic were just the simple replacement for missing limbs originally, but now they are helping people with their extremely active lives. Such improvements have been made because of the advancement of components for making prosthetics, engineers' creativity and new surgical techniques.

One great thing about robotics is that when you are aware of it, you know that it's improving your life. The real key here is the cultural acceptance, and our ability to touch and interact with the robots is also important. There are a lot of countries in world where people might actually be surprised to learn about the participation of robots. There are many ways that robots are increasingly being used to modernize healthcare and related services such as: iRobot's Roomba home robot vacuum cleaner. Which has sold more than 7 million units in over 50 countries worldwide [16].

4.2.1 I-Limb:

The i-limb prosthetic hand is designed by touch Bionics Company. This robot was designed for people who lost their hand, it duplicates the function of the hand and imitates the true movement and accuracy of human hands. The fingers have the ability to bend each joint, also open and close the hand. The i-limb is made by high strength plastics, this is the reason why it is highly appealing to both patients and health care providers.

The i-limb hand utilizes myoelectric technology along with self-contained individually powered digits. The electric signals are used by myoelectric technology in

the muscles of patients allowing the limb to control the movement of the hand. Two small electrode plates are placed against the skin on both upper and lower sides of the forearm, which detects electrical signals generated by the muscles in the residual limb. The i-limb hand has the ability to wrap around the objects, rotate the thumbs and create many different grips due to the motorized fingers as shown in figure 4a [17]. This gives the opportunity to an amputee to perform the daily task such as: typing, dialing the phone or shaking hands.

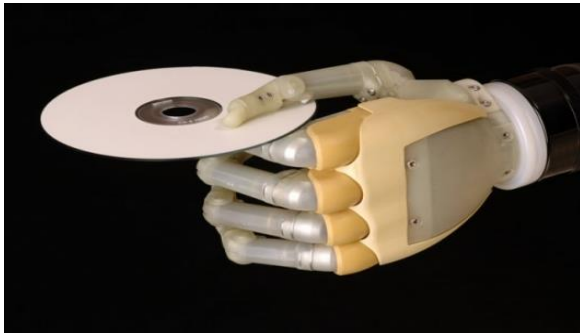


Figure 4a: i-Limb without covering [17]



Figure 4b: i-limb with plastic covering [17]

To provide the grip surface and protection from dust and moisture i-Limb requires the covering as shown in figure 4b [17]. A positive fact is that amputees have the option to choose the appearance of the hand robot. They can choose cosmesis to wear which is a flexible covering for the device. They can also choose to wear a transparent glove. Also, a lifelike covering is available for those people who like their device blend anatomically.

Traditional devices were difficult to maintain, because damaged devices were sent back for repair, leaving the amputees without their artificial limbs; as a result causing discomfort and disability to perform daily activities. i-limb on the other hand was designed to be easily maintainable, in order to give a sense of release to the amputees; by solving the past problems which artificial limbs faced in case of damages. Each individually powered finger can be detached simply by removing one screw. The fingers, which require servicing can easily be swapped out and the patient return to daily tasks after a short clinical visit.

4.2.2 ReWalk-Bionic Suit:

More than 50,000 people around the world suffer from spinal cord injuries annually, leaving thousands of people paralyzed as a result [18]. The ReWalk is a commercial bionic viable upright system which enables the paraplegics to stand, walk and even take stairs independently as shown in the figure 5. The Argo medical device company located in Israel, designed and developed this robot. The bionic suit detects shifts in the sense of balance of the patient and moves the patient's leg in a natural posture. This procedure is more complicated than it appears. It is a motor driven robotic device and its components are controlled by hundreds of algorithm, codes and sensors that all enable actions such as standing, sitting, walking, and even climbing. The weight of suit is around 44 pounds but it is necessary that the users wear it outside their cloths to prevent harm due to friction.



Figure 5: A paralyzed girl wore Rewalk bionic suit [18].

ReWalk Rehabilitation is currently in use by 22 rehabilitation centers in the United States. The personal version of the ReWalk, which costs 52,500 euros or \$68,000-\$69,000 is aimed at a fairly young market; the average age of spinal cord injuries is 32, and multiple sclerosis is often diagnosed in the twenties, according to the company [19]. Argo estimates that it reduces medical costs by \$30,000 a year over its 5-year lifespan, meaning the investment may be worthwhile for insurance companies [19].

It delivers benefit in overall health, social interaction, and achieving economical health care. The majority of health problems associated with long term need of wheelchairs such as: thinning of bones, pressure sores, urinary, cardiovascular and digestive system problems are being reduced by the use of the ReWalk system. This device keeps users upright on regular basis and exercise their paralyzed limbs. Patient's psychological and social comfort have improved by having the ability to communicate with people at eye level.

4.3 Future of Prosthetic Robots

The need for the assistive robots will increase. During the 1950s, only 4.9% of the world's population was over the age of 65 [12]. Today, almost 20% is over 65 and this figure is predicted to exceed 35% by 2050 [12]. Statistics suggest that the majority of people in the United States who require amputation are age 65 and half of these amputees are caused by diabetes, peripheral vascular disease or obesity [8]. These amputations are increasing at horrifying rates as the overall population ages. As population will increase the need of health care will also increase. Robots can help to solve these issues and enable the elderly people to regain their independence and maintain their healthy lifestyle. More than 1.6 million people in the U.S. have some type of limb loss, excluding fingers and toes which illustrate the extent of limb loss in the U.S [8]. Since the rate of amputees is increasing, scientists are working on improving prosthetic robot for future applications. New research is laying the groundwork for touch-sensitive prosthetic limbs that could provide real-time sensory information to amputees via direct interface with the brain [8].

4.3.1 Artificial Muscle:

Scientists from the United States, Canada, Australia, South Korea, Turkey and china are working to make remarkably sturdy artificial muscle which will be used in robots, prosthetic limbs, and exoskeleton. Scientist have discovered more down-to-earth materials such as, regular polymer fishing line, and metal coated nylon sewing thread as shown in the figure 6. which can be used to made very powerful artificial muscle.

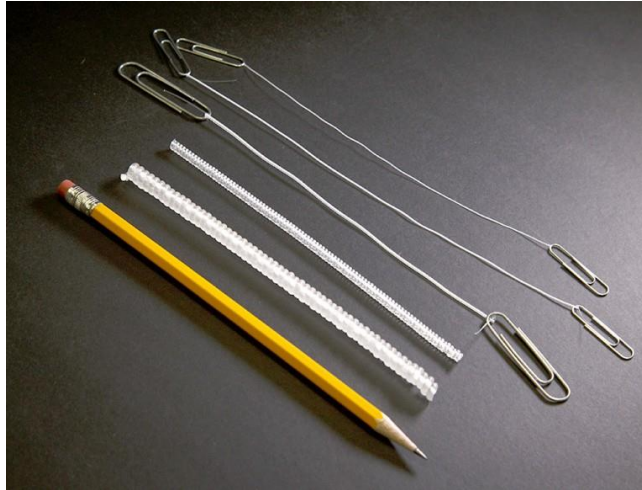


Figure 6: A variety of sizes of the artificial muscles, with a pencil for scale [16].

The following is the description of this synthetic muscle.

- It will be an inexpensive robot.
- It will be able to lift at least 100 times as much as human muscles.
- They will have the same weight and length as human muscle.
- This technology is simple and easy to make.
- The robotics muscle fibers will contract due to the electrical energy.
- The current humanoid robots and prosthetic limbs are still costly to produce and control. They are trying to make this muscle robot cheap and better than the current one.
- There are many different applications that could be used by new synthetic muscles such as invasive robotic micro surgery, better muscle for prosthetic limbs, and could achieve humanoid faces.

4.3.2 Nanowire Sensors:

Yong Zu, assistant professor of mechanical and aerospace engineering at N.C. state and Shanshan Yao is a graduate student have developed a new sensor utilizing nanowires made of silver that are both extremely sensitive and extremely flexible. The sensors are basically silver capacitors made of 3 layers. The top and bottom layers are a nanowire-based electrodes and the middle layer is an insulating layer as shown in figure 7. Dimension will change when the capacitors are stretched and pressed, increasing capacitance. The strain pressure and touch can be detected by the capacitance changes.

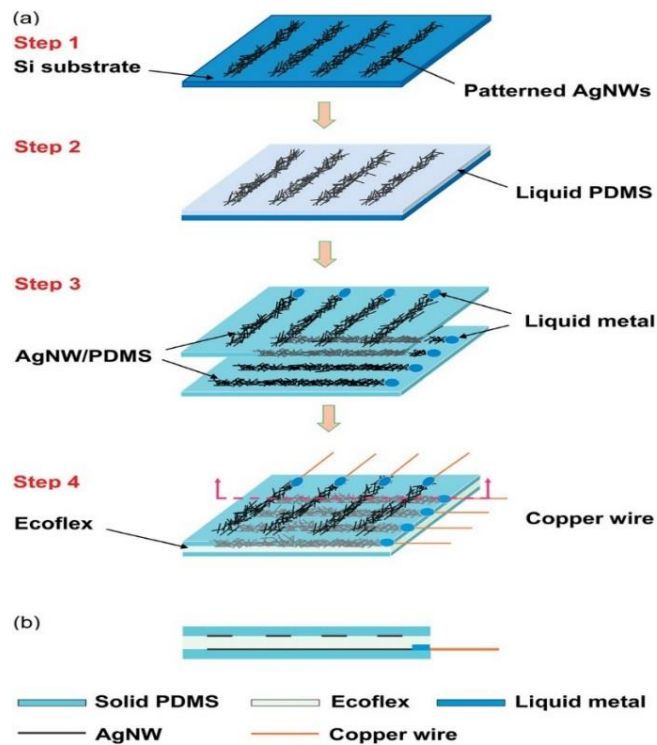


Figure 7: Assembling of nanosensor [20].

When the sensor is stretched, bend or pressed, the electric field between the two layers of silver wires is disrupted. The molecules in the dielectric material between them shift positions and increase the capacitance, or the amount electric charge it can store.

These sensors can be worn on a joint that bends intensely, incorporated directly into clothes or can be attached to the prosthetic robot as artificial skin to give them multiple sensitivity. Professor Yong monitor the skin strain associated with thumb flexing by mounting the sensor based silver nanowires onto a thumb joint as shown in figure 8.



Figure 8: A sensor based on silver nanowires is mounted onto a thumb joint [21].

Advantages:

- Simple and inexpensive to make
- Highly flexible sensors, can be stretched to 150 percent of their original length
- Can maintain a high degree of sensitivity
- The sensors display response times in as fast as 40 milliseconds.
- It can measure strain, pressure or finger touch from humans
- Mechanically robust
- It can be wrapped onto non-planar and dynamic surfaces
- Easy to wear

Chapter 5 – Surgical Robots

Robotic surgery is a type of minimally invasive surgery meaning instead of using large incision tools during surgery, it uses miniaturized surgical instruments that fit through a series of quarter-inch incisions. The first surgical arm “Puma 560” was used in a neurosurgical biopsy in 1985 to assist with a surgical procedure. The first robot-assisted laparoscopic procedure took place in 1987 because robotic systems brought greater precision and successful outcomes. The surgery-enhancing machines were improved over the next decades by experts. The da Vinci robot came out in 2000 and became the first complete robotic surgical system and approved by FDA for general laparoscopic surgery.

There are many advantages to robotic surgery such as: smaller incisions, less risks of infections, shorter hospital stays of patients, higher precision, higher accuracy, decreased pain, and better postoperative immune function. Although there are many advantages there are some limitations of robotic surgeries. The major limitations are technical and mechanical nature of the equipment, and also a decreased sense of touch which makes tissue manipulation more heavily dependent on visualization. Others issues include a loss of haptic feedback, natural eye-hand coordination and dexterity as shown in table 1 [22]. Although surgical procedures have had complications with the use of these devices they seem to be rising among users. According to the ECRI (Emergency Care Research Institute) robotic surgeries rose from 25,000 in 2005 to 360,000 in 2011 nationwide. The motivation to develop robotic surgery is rooted in the desire to decrease the limitations of current laparoscopic technologies and to expand the benefits of the minimally invasive surgery.

Human	Robots
Strengths	Strengths
Strong hand-eye coordination	Good geometric accuracy
Dexterous (at Human scale)	Stable and untiring
Flexible and adaptable	Can be designed for wide range of scales
Can integrate extensive and diverse information	May be sterilized
Able to use qualitative information	Resistant to radiation and infection
Good judgment	Can use diverse sensors (chemical, force, etc.) in control
Limitations	Limitations
Limited dexterity outside natural scale	Poor judgment
Prone to tremor and fatigue	Limited dexterity and hand-eye
Limited geometric accuracy	Coordination
Limited ability to use quantitative	Limited to relatively simple procedures
Information	Expensive
Large operating room requirement	Technology in flux

Table 1: Comparison between Robot and Human

5.1 Past of Surgical Robots

Robot is taken from the word Czech *robot* meaning “forced labor”. It has evolved in meaning from dumb machines that perform basic repetitive tasks to the highly intelligent anthropomorphic robots of today’s popular culture. Although present day robots are still unintelligent machines, great strides have been made in expanding their utility. Today’s robots are used to perform highly specific, highly precise, and dangerous tasks in industry and research previously not possible with a human work force. Robots are routinely used to manufacture microprocessors used in computers, explore the deep sea, and work in hazardous environments just to name a few. Robotics, however, have been slow to enter the field of medicine due to the possible implications for patients and medical professionals.

5.1.1 PUMA 560 Robot

The PUMA 560 was the first robot which assisted in a surgical procedure occurred in 1985, the PUMA 560 is surgical arm was used for neurological biopsies. This system was not originally designed to assist in surgical procedures but was used as an industrial robot. Its effectiveness in precise and accurate navigation of surgical tools was utilized by kwoh to eliminate brain tumors which had previously been inoperable. The robot was basically used as a positioning fixture. Once the robot was positioned correctly, it was locked in position and power was removed. The preliminary results were promising and, compared to conventional stereotactic frames, the robot could position itself automatically and accurately [23, p. 662]. Even though the outcomes were positive, it was still an industrial robot which was not designed for

surgical purposes. One of the other reason the companies that marketed the Puma 560 did not allow to continue its use in the surgical procedure on the basis that it was unsafe.

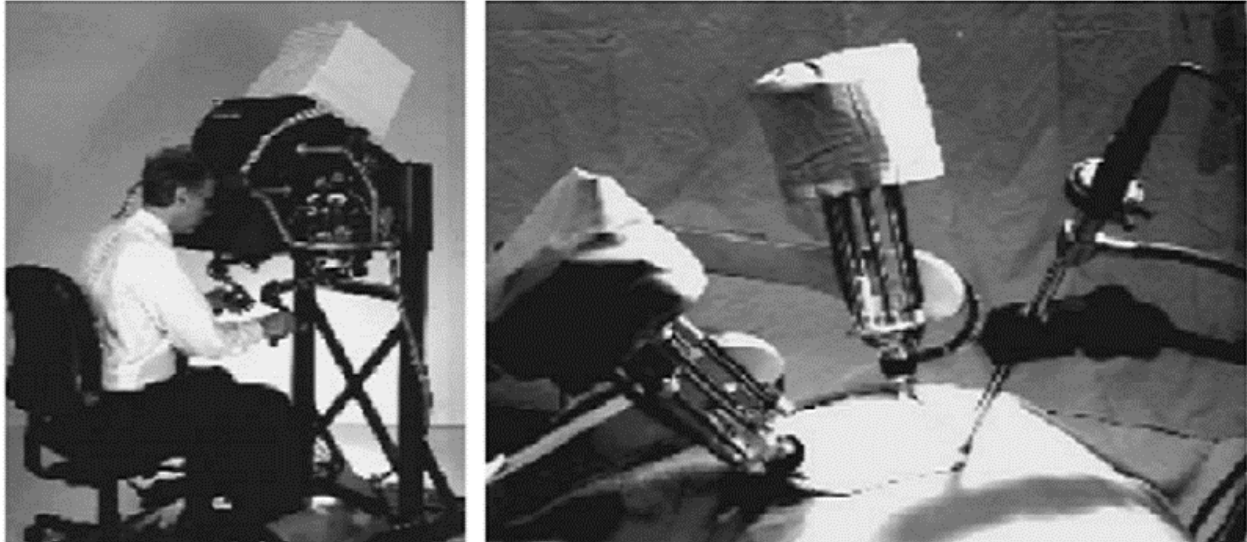


Figure 9: A doctor performing surgery using PUMA 560 robot [24]

5.1.2 The Probot:

In 1988, professor Brain Davies from Imperial College in London, designed the first robot called PROBOT that could remove soft tissue from a person. It could perform the task with a fair degree of autonomy. Most industrial robots had arms, elbows and wrist mechanism, which took up valuable space when the arms were in motion. Professor Davies thought it was dangerous to use the robot in small spaces inside human bodies. This was the reason why Davies and his team designed a small robot that had three axes of movement and the fourth axis enabled the cutter to be moved for prostate surgery as shown in the [Fig. 9]. The robot was meant to be controlled by a pair of programmable embedded motor control system (i486DX2-based PC). The robot allows surgeons to specify the correct cutting sequence to remove tissue. The idea of having any degree of independent behavior in a robot was not accepted in the medical

field. The PROBOT was tested in the lab and in human subject, but unfortunately it was never used widely in surgery. “The doctors didn’t feel comfortable with the idea” [25, p. 1]. When the funding ran out the PROBOT project was shut down.

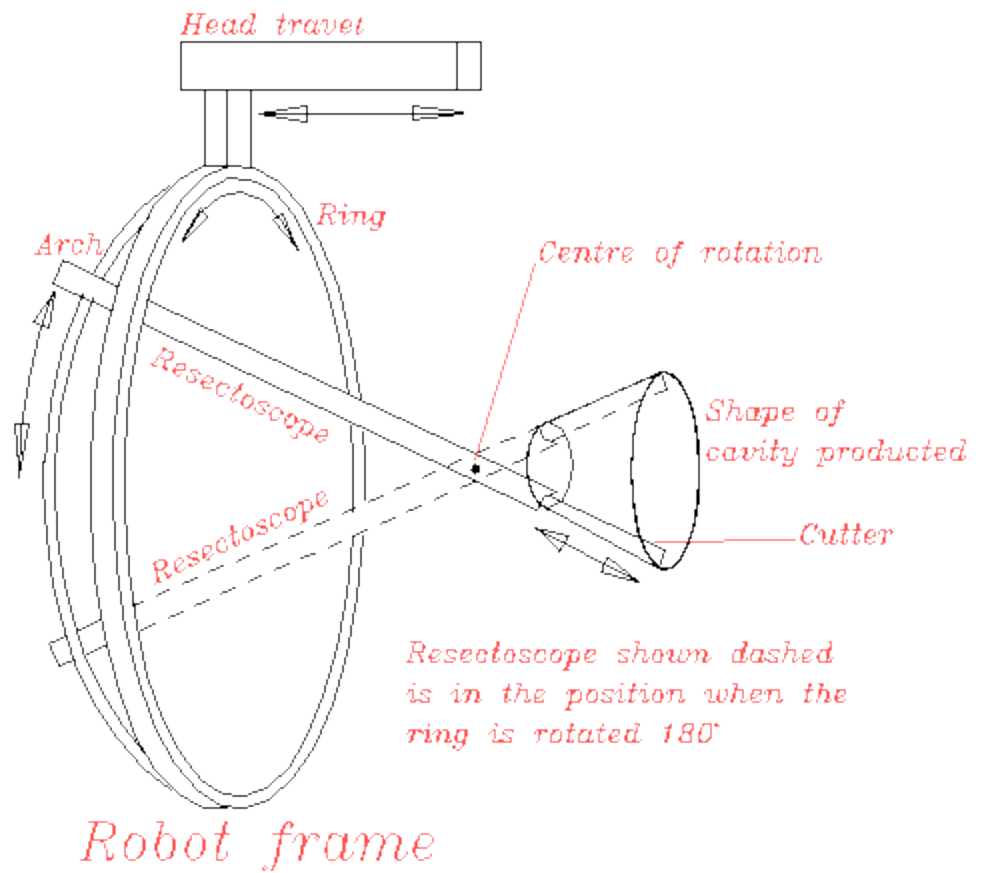


Figure 10: Simplified drawing of the robot's structure [26]

5.2 Present of Surgical Robots

Robotic-assisted surgery has its roots in 1972, when the National Aeronautics and Space Administration began to investigate a method to provide surgical care to orbiting astronauts through telepresence surgery [27]. Surgical robotics is the application of advanced technology to minimally invasive surgery (MIS) and open surgery training and procedures. Since the first laparoscopic splenectomy performed in 1997 [28], robotic-assisted surgery has gained popularity in several surgical specialties such as general, urological, cardiothoracic, gynecological, orthopedic, and neurological surgeries [29].

In orthopedic surgery, the robots surgeries are widespread, and accepted for two main reasons: 1) the technology is compatible for operations. 2) The robotic surgery increased accuracy. Neurosurgery was one of the first organ system in which the robotic surgery began to arise, because there was great need of high precision required where operating on the brain. In the 1980's the first robot in urology was introduced because of economic advantages, increased accuracy and improved quality by industrial robots. Nevertheless, robotic surgery has grown dramatically, increasing more than 400 percent in the United States between 2007 and 2011 [30].

5.2.1 da Vinci

The da Vinci was introduced to the market in 1999, and in July of 2000 it was approved by the Federal Drug and Administration for laparoscopic surgery. The first da Vinci system focused on overcoming the limitations of traditional laparoscopy by giving surgeons 3D vision inside the patient's body. The original da Vinci system had very

simple instruments that were not procedure-specific. In 2003, Intuitive Surgical offered the first major upgrade to the da Vinci System by offering a 4th instrument arm. This allows a surgeon to control his/her own retraction and control movement from arm to arm. The next model of the da Vinci System was introduced in 2006. The present model of the da Vinci System was released in April of 2009 and is being used worldwide. The da Vinci arms have the ability to move more than 360 degree and with 3D HD vision. It allows surgeons to make tiny incisions and it assists them in technically precise maneuvers involved in advanced minimally invasive surgeries, particularly gynecologic, gastrointestinal, and prostate procedures. Additionally surgeons have control over every move of the da Vinci. Instead of standing over the patient, the surgeon sits at a console in the operating room and looks at a large monitor. This gives the surgeon a few major advantages:

- The operating area can be magnified up to ten times.
- The 3D HD image provides an incredibly accurate field of vision.
- Small, precise instruments allow delicate cutting and stitching which is not possible through other minimally invasive techniques.
- The robot automatically removes the natural tremor of the surgeon and improves control.
- The da Vinci also has dual controls that allow two surgeons to work simultaneously on especially complex cases.

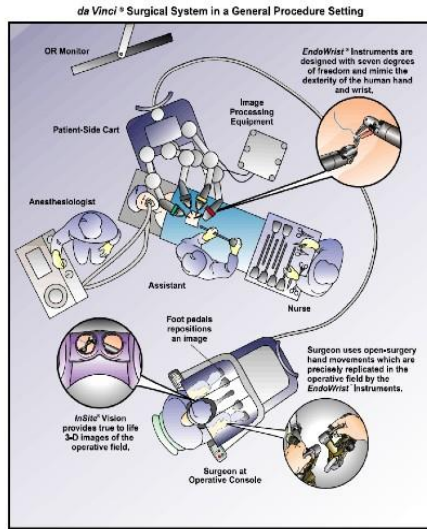


Figure 11: Surgical system general procedure in operating room



Figure 12: da Vinci System

There are some setbacks of da Vinci such as the cost of it. According to Dr. Makray “A 2010 study found that 56.8 percent of surgeons surveyed anonymously said that they had experienced irrecoverable operative malfunctions while using the da Vinci system” [30]. About 1,400 da Vinci systems, which cost \$1.5 million to \$2.5 million, have been purchased by hospitals, according to Initiative’s Investor reports [30].

5.2.2 Telelap ALF-X

Telelap ALF-X is a competitor of the da Vinci system. It was developed by SOFAR S.P.A it has four arms just like the da Vinci. The benefit for surgeons is that it has tactile sensing and 3D vision like da Vinci, it also has increased accuracy than the da Vinci does. Easy and comfortable to use. It offers improved intervention quality, efficiency and safety for patients. The Telelap ALF-X offers different specialties as da Vinci does, like gynecology, urology, general surgery and throacoscopy. Its costs is same as the cost of a laparoscopy and has reusable instruments. It was approved by the FDA in 2012 and came to the market in 2013.

It has safety sensors which makes the robot stop when the surgeon's gaze is not fixed on the surgery site. It has zoom functions to make it easier for surgeons to perform surgery. Since it is trying to compete with the da Vinci, the Telelap ALF-X leaves space between the patient and itself unlike the da Vinci which takes up too much space next to patient. The cost of Telelap ALF-X is set to be two thirds of the price of the da Vinci in order to gain some market share. As shown in the table 3 that's the first clinical trial [31].

5.3 Future of Surgical Robots

For years surgeons have relied on the capability of their hands and hand-held instruments to save lives. Today, there is a new cutting edge technology in surgery where robotic technology is used as an extension of the surgeon, enabling them to perform the most complex operations in innovative new ways. Surgical robots are gaining widespread acceptance across the globe as they enhance the surgeon's abilities in terms of surgical imaging, navigation, planning, and instrument manipulation. "Market participants are conducting extensive research in this field to strengthen the capabilities of surgeons through advanced imaging techniques, higher degrees of freedom, interactive interfaces, haptic feedback, and teleportation" [32]. Surgical robot manufacturers are also trying to reduce the footprint of existing robotic systems and lessen the invasiveness of surgical procedures by advancing single port, natural orifice, and swarm robotic technologies. The Global Robotic surgery market to grow at a CAGR (Compound Annual Growth Rate) of 11.65% over the period 2013-2018 [33].

5.3.1 IBIS Pneumatic Surgery Robot

Robotics has been famous within the surgical area for years now and the most known surgical robot is the da Vinci. Because of underlying technology the da Vinci's price is coming down so now the competition certainly will increase. One of the competitor is IBIS system developed at the Tokyo institute of technology, this will provide most of the functionality of the da Vinci; moreover it has the force-feedback features allowing the user to feel when the robot's tools come in contact with tissue or other organs. This

robot can absorb the force whenever it touches something. The force on the tip of the robot is estimated from the air pressure data, then that information is sent to the surgeon's master robot so it can be fed back to the surgeon's hand. One of the advantages of this system is, the overall robot can be made extremely compact. The developer aims to build this system for one-third to one-tenth the cost of da Vinci surgical system [34]. Currently they are working with surgeons to get feedback on how to improve this robot and expect to bring it to the market within the next 4-5 years.



Figure 13: IBIS view from the left [34]

5.3.2 Complementary Situational Awareness

The idea for Complementary Situational Awareness for Human-Robots Partnerships is to provide surgical robots with a new kind of machine intelligence that significantly extends their capabilities and make it easier and more intuitive for surgeons to operate. This system is awarded 3.6 million in the National Science Foundation. This system is being developed by close collaboration among teams directed by Nabil Simaan, Associate Professor of Mechanical Engineering at Vanderbilt University; Howie

Choset, Professor of Robotics at Carnegie Mellon University (CMU); and Russell Taylor, the John C. Malone Professor of Computer Science at Johns Hopkins University [Fig.14]. The goal is to establish a new concept called complementary situational awareness. “Complementary situational awareness refers to the robot’s ability to gather sensory information as it works and to use this information to guide its actions” [35]

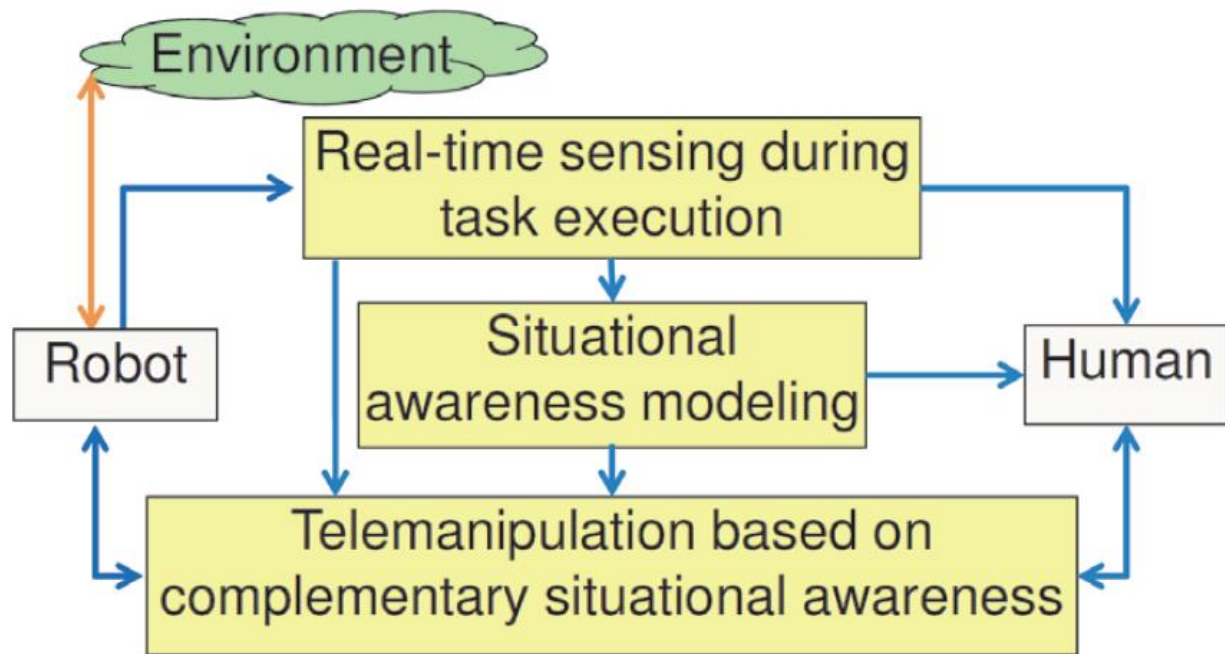


Figure 14: Proposed framework for robot-human [36]

One of the project’s objectives is to restore the type of awareness which surgeons have during open surgery where they have the ability to touch and see internal organs and tissues. The researchers also intend to create “virtual fixtures”. These are pre-programmed restrictions on the robot’s action. For example, a robot could be instructed not to cut where the major blood vessels are found. This will prevent the surgeons from accidentally cutting the wrong tissue when operating the robot manually.

Surgeons have tried to compensate for the loss of direct sensory through pre-operative imaging, such as MRI, X-ray imaging and Ultrasound to map the internal structure of the body before they operate. Therefore the researchers are planning to create a system that acquires the data from different types of sensors when an operation is underway; the real time maps which will precisely track the position of the robot probe and show how the tissue under it responds to its movement. To acquire sensory data during surgery, the UV team will generate models that estimate locations of hidden anatomical features such as arteries and tumors and then CMU team will create adaptive telemanipulation techniques that assist surgeons in carrying various surgical procedures.

5.3.3 Painting Robot Lends Surgeons a Hand

Lee, a high school student made a robot which paints exactly as it is told. He thinks that his robot acts like surgeon who knows where exactly to cut and it same goes for painters to paint Mona Lisa. After training his robot to paint something like a sunset or a house without any input from a human operator, he began to teach the robot to paint lines and corresponding to locations of human organs [37]. His robot arm may not be used in operating rooms, but it could be used as a training tool for surgeons who need practice operating the da Vinci surgical arm or any other system. At Wake Forest Medical Center, doctors use replica bodies to train surgeons to use the da Vinci system. These replicas are expensive compared to the robotic arm which Lee made cost around \$1500. This robot hasn't come out yet but if it comes out it could be the next surgical robot being used in hospitals.



Figure 15: Robot arm programmed to paint pictures [37]

Chapter 6: Rehabilitation Robots

Stroke is the third most frequent cause of death worldwide and the leading cause of permanent disability in the USA and Europe [38]. Neurological damage after stroke can lead to partial paralysis of the body. This affects the ability of the people to perform activities of daily living (ADL) such as walking, eating and grabbing. Typical and robotic therapy help to improve the lost functions [39]. Rehabilitation Robotics aims to understand and augment rehabilitation with the use of robotic systems. The main function of this area is to enhance the process of recovery from injuries, illness or diseases; emphasizing the central role of the patient during the motor exercise. The objective of Robot-assisted therapy is to restore the physical, mental or motor capabilities in patients with certain physical and neurological disabilities. There are four main areas in which rehabilitation robotics can be found: Cardiac, Musculoskeletal, and Pulmonary rehabilitation.

Cardiac rehabilitation, specializes in helping at the recovery of patients with heart diseases or, patients who had heart attacks, heart surgeries and percutaneous coronary interventions (PCI). Pulmonary rehabilitation is an area that aims to improve the well-being of patients with chronic breathing problems such as: idiopathic pulmonary fibrosis, cystic fibrosis, chronic obstructive pulmonary disease (COPD), etc. Musculoskeletal rehabilitation has the objective of enhancing and restoring the functional capacity of patients with disabilities, disorders or trauma in their muscles or bones; patients with amputations, arthritis, tendon tears, and trauma injuries among others can benefit from this type of rehabilitation. Neurological rehabilitation aims to improve the function of the

nervous system in patients with vascular disorders such as strokes, and patients with trauma, such as brain and spinal cord injuries.

Although rehabilitation robotics can be used in all four areas of physical therapy, the areas with greater advances within this field are the musculoskeletal and neurological rehabilitation. Thus we will be focusing in these two when explaining the advances of the current technologies and the future of the same.

6.1 Past of Rehabilitation Robots

Initially exoskeletons were developed to help and enhance the performance of the soldiers during the battle field. Later these devices were used to restore the physical, mental or motor capabilities in patients with certain physical and neurological disabilities. These systems give back hope to disabled people who had accepted they could never walk or perform simple daily activities again. The first computerized orthosis was developed at the Case Institute of Technology in 1960s [40]. This system had four-degrees-of-freedom. The Control of this manipulator was achieved by using a head-mounted light source to trigger light sensors in the environment. The Case orthosis was then continued by the Rancho Los Amigos Hospital which were able to develop a seven-degree-of-freedom upper limb exoskeleton named “Golden Arm” [Fig 16] [41]. The configuration of the Golden Arm was similar to the Case arm but did not include computer control. This system was mounted on a wheelchair and was found to be useful for people who had disabilities with intact sensation resulting from polio or multiple sclerosis (MS). The Rancho “Golden Arm” was controlled at the joint level by seven tongue-operated switches which made the operation tedious [Fig 17]. As the time elapsed new devices emerged and the first attempt to built an exoskeleton was in 1968 with the Hardiman [Fig 18] [42]. Which was intended for military purposes. This system had three-degrees-of-freedom and it was composed of two legs and two arms [42]. We then see one of the first articulated upper limb orthoses which had assistive purposes called the body-powered functional upper limb orthoses (BFO) [Fig 19] [39]. This system was developed in 1965. It was a wheelchair mounted which had two links and

four-degrees-of-freedom and used linear elastic elements to balance out the effects of gravity in three dimensions . The objective of this devise was to help disable people to accomplish movements in a horizontal plane. Burke rehabilitation center tried to developed a motirize version of the BFO in 1975, but the results were not sucessful. These were some of the systems that gave a solid foundation to the great developments and technologies we see nowadays. These technolgies taught the researchers, designers and engineers that science fiction can come true and that imagination is the first step to creation. The evolution of these technologies will be cover in sections 6.2 and 6.3 of this report where we discuss the present and future of rehabilitation robotics within the medical field.

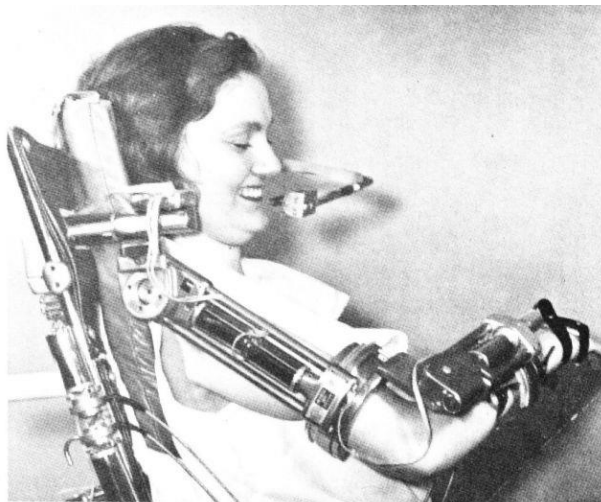


Figure 4. The Rancho Los Amigos Orthosis had 7 degrees-of-freedom. It was the first electric orthosis ammenable to external control. Joint specific control was accomplished with mechanical switch arrays. One of these arms was interfaced to the Stanford Artificial Intelligence Laboratory DEC-10 as part of a proof-of-concept demonstration.

Figure 16: The Rancho Los Amigos Orthosis [39]

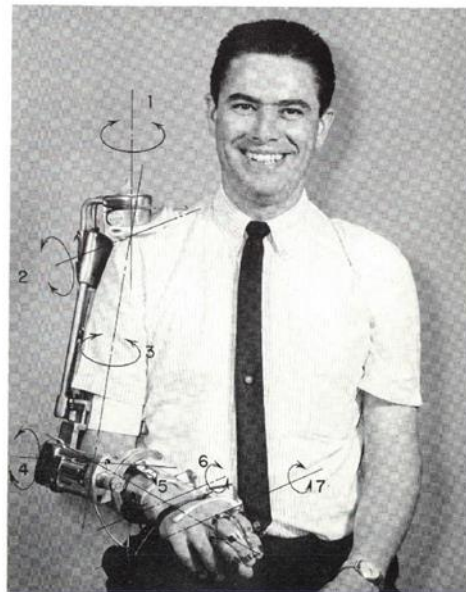


Figure 1. A Rancho Engineer Models the REA; the Seven Degrees of Freedom are Indicated with Arrows.

Figure 17: The Rancho Los Amigos Orthosis [39]

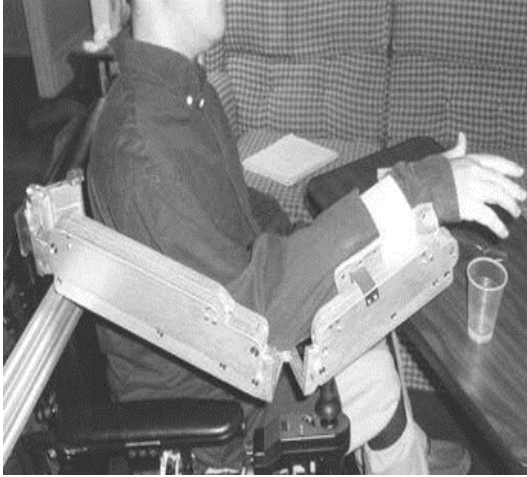


Figure 18: Final prototype of the BFO [39]

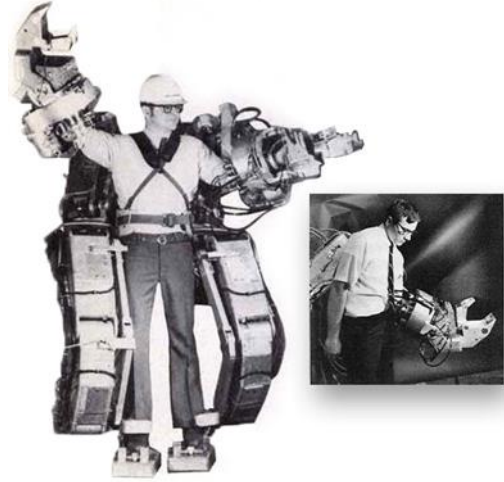


Figure 19: Exoskeleton Hardiman [42]

6.2 Present of Surgical Robots

Exoskeletons are defined in the military and rehabilitations areas as a system that can greatly augment a person's physical abilities. Body movements of disable people are limited by their muscle strength. Muscle weakness is one of the primary causes for neuromuscular diseases and injuries to the central nervous system. Robots can perform tasks that require high loads and forces but do not have the flexibility or control that a human possess. Therefore, if the best parts of these two are combine a human with physical disabilities or injuries can re-learn at a faster rate to perform everyday tasks such as walking, grabbing and claiming. Exoskeletons provide external strength and equilibrium to patients by enhancing a faster motor recovery [43]. Such devices are being commercialized within the rehabilitation industry and are divided in three types: upper limb, lower limb and full body exoskeletons. Examples of upper arm exoskeletons are: Armeo products such as the ArmeoPower shown in [Fig 20] [44]. (Hocoma Inc, USA). Lower limb exoskeletons are currently helping USA military and patients with mobility disorders. BLEEX, a Berkeley Lower Extremity Exoskeleton, funded by the Defense Advanced Research Agency (DARPA), and the Human Universal Load Carrier (HULC) as seen in [Fig 21] [45] Full body exoskeletons such as the Hybrid Assistive Limb (HAL-5) shown in figure 22 are designed to support and expand the physical capabilities of patients with physical disabilities in their arms, legs and torso but this exoskeleton is only available in Japan under rental fees [46].



Figure 20: ArmeoPower [Upper Limb Exoskeleton] [44]



Figure 21: HULC [Lower Limb Exoskeleton] [45]

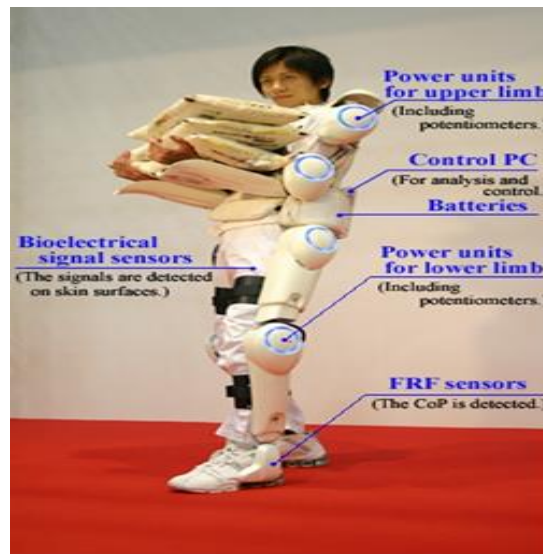


Figure 22: HAL-5 [Full Body Exoskeleton] [46]

6.2.1 Armeo arm therapy (Upper Limb Exoskeleton)

The ArmeoSpring [Fig 23] is an instrumented arm orthosis with a spring mechanism that supports the arm's weight and can be used as a real time input device to an associated therapy software called the Aremeocontrol. This exoskeleton provides



Figure 23: ArmeoSpring [Upper Limb Exoskeleton] [44]

functional therapy for patients who have lost or reduced upper extremities due to cerebral, neurogenic, spinal, muscular or bone-related disorders. The ArmeoSpring has the Health Canada, the European Union and the FDA market clearance in USA. It is currently used by different rehabilitation clinics in USA such as: Pate Rehabilitation and UT Southwestern Medical Center in Dallas Texas. Studies have shown that brain plasticity or reorganization of the functions of neurons can be achieved through intensive, repetitive, tasks-oriented movements [47]. ArmeoSpring embraces the arm of the patient from the shoulder to the hand; it counterbalances and adjusts part of the weight of the arm, enhancing any residual function and neuromuscular control [48]. The ArmeoSpring also has a pressure sensitive grip that acts as an input device for different exercises. It also acts as a control for the software that contain computer games that help the patient work on the specific affected area. The patient can use this exoskeleton by either sitting on a chair or wheelchair. The computer software contains different exercises, simulating real-life activities. Exercises simulate that the patient is shopping, and will make them pick up different objects from the shelf. During all activities the patient is receiving feedback on how they are doing. The exercises have different levels of difficulty that can be increased based on the patient's cognitive and physical condition and progress. Data is stored by the ArmeoSpring in order for the therapist to keep track of the patient's progress. ArmeoSpring consists of 7 angle sensors and 1 pressure sensor, it allows for instrumented physiological movements such as: shoulder abduction, shoulder flexion, horizontal shoulder abduction, shoulder rotation, elbow flexion, forearm pronation, wrist flexion and hand grasp. The ArmeoSpring has shown to be an effective rehabilitation system in rehabilitation [49]. It has also shown to have

significantly better outcome in motor ability at 6 months follow up. -Patients were in favor of Armeo therapy when compared to conventional or self-directed therapy.

6.2.2 Anklebot (Lower Limb Exoskeleton)

The Anklebot [Fig 24] (Interactive Motion Technologies Inc.), was developed at the Massachusetts Institute of Technology (MIT) [50]. The purpose of this robot was to rehabilitate the ankle after a patient had suffered from stroke. The Mendell MS Center at Mount Sinai (Hertfort, CT), the Blythedale



Figure 24: Anklebot [Lower limb Exoskeleton] [50]

Children's Hospital (Valhalla, NY), Bambino Gesù Children's Hospital (Rome, Italy), Riley Children's Hospital (Indianapolis, IN) as of 2011 were conducting research on this system, in order to show the robot characteristics and stability range as well as the potential of the Anklebot [50]. It allows a normal range of motion in all 3 Degrees of Freedom (DOF) of the foot relative to the shank while walking overground or on a treadmill. The robot is fixed to a knee brace and connected to a custom-designed shoe. When the patient moves their ankle, the robot moves the foot along a programmed trajectory in different directions within the ankle's normal range of motion. Electrodes record the angular displacement and torque at the joint, this is used to calculate the ankle's stiffness [51]. After conducting tests on healthy subjects, scientists have found that the ankle is stronger when moving up and down but weaker when moving from side to side, and even weaker when turning inwards. Their findings will most likely help to understand better physical limitations that stroke and other motor disorder cause on

patients. During tests the Anklebot moves the ankle of the stroke patient side to side, up and down. The robot senses when the patient is moving their ankle on their own and stops assisting movements which leads to a faster recovery because the patients are able to use their muscles by themselves. The device is currently going through more testing in order to find not only its potential but also to characterize biomechanical aspects such as the ankle stiffness.

6.3 Future of Rehabilitation Robots

As the population ages the demand for rehabilitation services keeps growing. According to the World Health Organization (WHO), senior citizens at least 65 years of age will increase in number by 88% in the coming years. By 2050, the amount of seniors in United States is expected to double from approximately 40 to 80 million (Fig 24) [52]. As age increases disorders related to age increase as well among those we see: stroke, Multiple Sclerosis, Cerebral Palsy and Parkinson's disease [53]

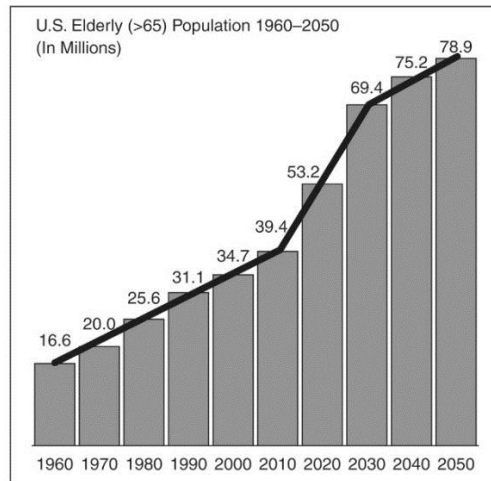


Figure 25: U.S population older than 65 years [53]

The high demand in rehabilitation services opens the doors for the development of new robotic technologies to assist and augment rehabilitation therapy. “These systems are helping physical therapist to concentrate in the rehabilitation of the patient instead of concentrating in physical tasks that were exhausting to them and the patients as well” says Russ Angold CTO of Ekso Bionics [Appendix G]. These systems will then allow physical therapist to focus on the rehab and patient's progress instead of focusing

in tasks irrelevant to the therapy. Russ says “we believe that this can speed the rehabilitation process” leading to a faster recovery.

Here we will explore future technologies being developed for rehabilitation robotics. Researchers and scientist are currently working in the next generation robotics called Co-Robotics. This aims to help Engineers better design systems that will help doctors to diagnose and treat different types of diseases. “These projects have the potential to transform common medical aids into sophisticated robotic devices that enhance mobility for individuals with visual and physical impairments in ways only dreamed of before” [54]. Among these projects we see the robotic orthotic, the co-robotic cane, and Robotic Ankle Exoskeleton control.

6.3.1 Robotic Orthotic:

This is a soft-wearable orthotic device that mimics muscle, tendons and ligaments of the lower leg [Fig25] [55]. The Robotic Orthotic could help people who suffers from neuromuscular disorders that affect specifically the foot and ankle (lower leg) rehabilitation. This system has been designed and developed by Yong-Lae Park, an assistant professor at Carnegie Mellon University. Dr. Park wanted the Robotic Orthotic to be a different exoskeleton, although the systems used nowadays improve function they are often rigid and limit body movement. This system has been funded by the National Institutes of Health (NIH), the National Institute of Biomedical Imaging (NIBIB), the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD), the National Institute of Nursing Research (NINR), and the National Institute of Neurological Disorders and Stroke (NINDS) [56]. Robotic Orthotic utilizes soft plastics

and composite materials in order to be able to simulate the ankle's movements in a more natural way. It contains four pneumatic artificial muscles capable of achieving 14° of dorsiflexion and 13° plantar-flexion. It also contains lightweight sensors located at the knee and ankle which are able to measure motion, strain and pressure. Advanced control software is also included in this design in order to allow a higher range of flexibility. The development of this device has encounter several problems such as: the transmission of forces through lighter materials and the interaction between the system and the patient's skin as if it exerts to much force in one area ($pressure = F/A$) this could cause discomfort. Obstacles to be overcome lies ahead if this systems wants to start clinical testing and even more obstacles if it wants to be implemented within the clinical environment. The researches envision applications for this device for other parts of the body since it could help people who suffer or have suffered from strokes or diseases such as palsy and multiple sclerosis.

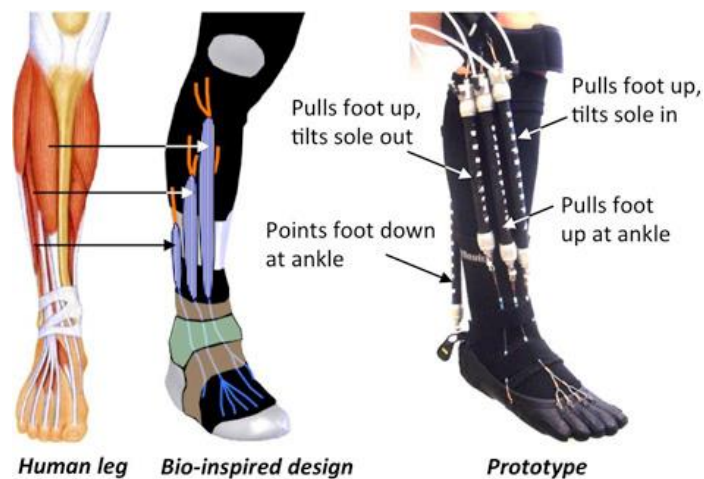


Figure 26: Robotic Orthotic on the right corner [55]

6.3.2 Co-robotic cane:

The co-robotic cane is a system that will aid people with vision disabilities, by allowing them to navigate through different types of environment [Fig 26] [57]. This system is being developed at University of Arkansas At Little Rock by Dr. Cang Ye an assistant professor and his research team. This project is being funded by the National Institute of Biomedical Imaging and Bioengineering and National Eye Institute of the National Institutes of Health. The co-robotic cane will collaborate with its user via intuitive human-device interaction mechanisms to navigate three-dimensional environments, and by using this mechanism the cane will then transport the user in the appropriate travel direction. In addition to increasing mobility for people with vision disabilities and thus quality of life [58]. This system will use computer vision to be able to detect obstacles such as stairways, doors, and objects. Its navigational functions will include position estimation of the device, way-finding, obstacle detection, and object recognition. The co-robotic cane will provide new navigational functions compared to those existing for the visual impaired in the present. Dr. Ye and his team are currently working on the development of this device with the objective of being able to improve independent mobility for the visual impaired as well as their quality of life.



Figure 27: (Co-Robotic Cane CRC) [57]

6.3.3 Robotic Ankle Exoskeleton control:

Although current systems are designed to help the recovery of patients with neuromuscular diseases and injuries to the central nervous systems. There is no device that focuses in a specific patient population. Therefore this project aims to create an experimental platform for an assistive ankle robot to be used in patients recovering from stroke [Fig 27], since this is the single largest cause of permanent disability [53]. This systems is being developed by Gregory Sawicki and Steven Collins at North Carolina State University and Carnegie Mellon University, Pittsburg respectively and funded by the National Institutes of Health, as well as co-funded by the National Institute of Nursing Research and the National Science Foundation (NSF). The platform created by this system will then allow researchers and investigators to analyze different robotic control methods and compare them based on measurable physiological outcomes. This results

will provide clear evidence in order to be able to create more effective, less expensive and more manageable assistive technologies within the rehabilitation areas [54].

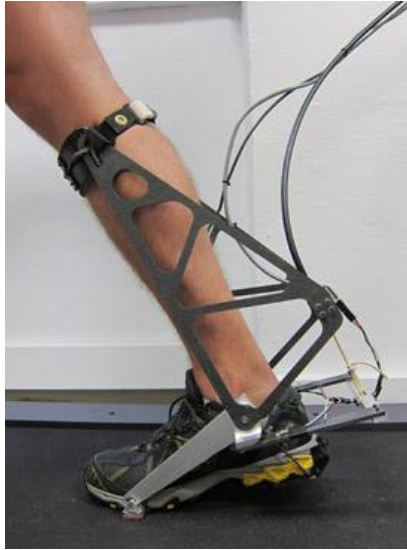


Figure 28: Robotic Ankle Exoskeleton Control [54].

Chapter 7: Results and Analysis

In this section explanations will be given as to how our data was analyzed. We evaluated the perception of our two focus groups towards assistive care robots. The two focused groups consisted of researchers and medical professionals such as doctors and registered nurses. The goal of our project was to answer two main questions:

- 1). How are robots currently helping in assistive health care?
- 2). What would be their effects upon medical professionals within the next ten years?

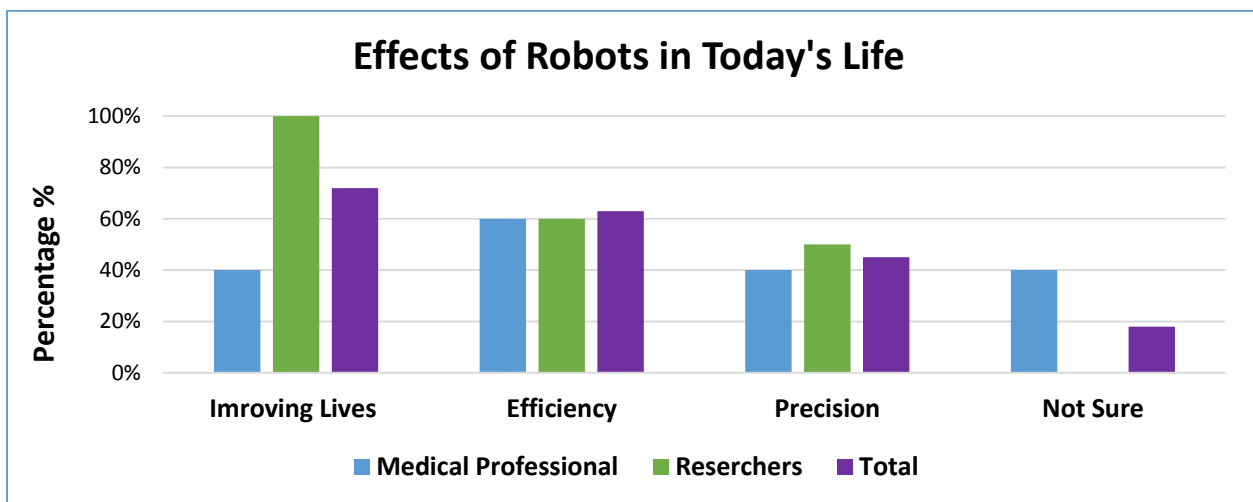
Our two focus groups were divided as follows: six researchers, and five medical professionals (two medical doctors and three nurses). Interview participants were chosen based on their high expertise and knowledge within the areas of surgical, prosthetic and rehabilitation robotics, due to their personal experience working with or close to these robotics systems. We aimed to compare different perceptions of researchers and users of these devices. Two tables and bar graphs were created to show our results based on their answers, which are: improvement of lives, efficiency, precision, better assistance, safety, adaptability, liability and job reduction.

In order to be able to analyze the results from the first question, we mainly focused on improving lives, efficiency and precision as to how assistive care robots are currently helping in assistive care. We performed calculations of percentages for both groups with respect to each person's responses. After we calculated the respective

data, we created a table of results as shown in table # 1 and graphically represented in a bar chart.

	Improving Lives	Efficiency	Precision	Not Sure
Medical Professional	40%	60%	40%	40%
Researchers	100%	60%	50%	0%
Total	72%	63%	45%	18%

Table 2: Results of 1st focus question



Graph 1: Effects of Robots in Today's Life

In our graph # 1 “Improving lives” refers to enhancing quality of life for disabled or diseased people. The result shows that 72% of participants (six researchers and two medical doctors) agreed that robots are improving lives. Assistive care robots are currently helping by making lives easier for people with physical and mental disabilities. Professor Yanco said they are allowing the disabled to perform daily life activities [Appendix D]. According to Russ CTO of Ekso Bionics, “patients are recovering hope,

they are taking steps that would otherwise not have done without a rehabilitation device” [Appendix G]. This shows a clear example of how these systems are improving lives of many disabled.

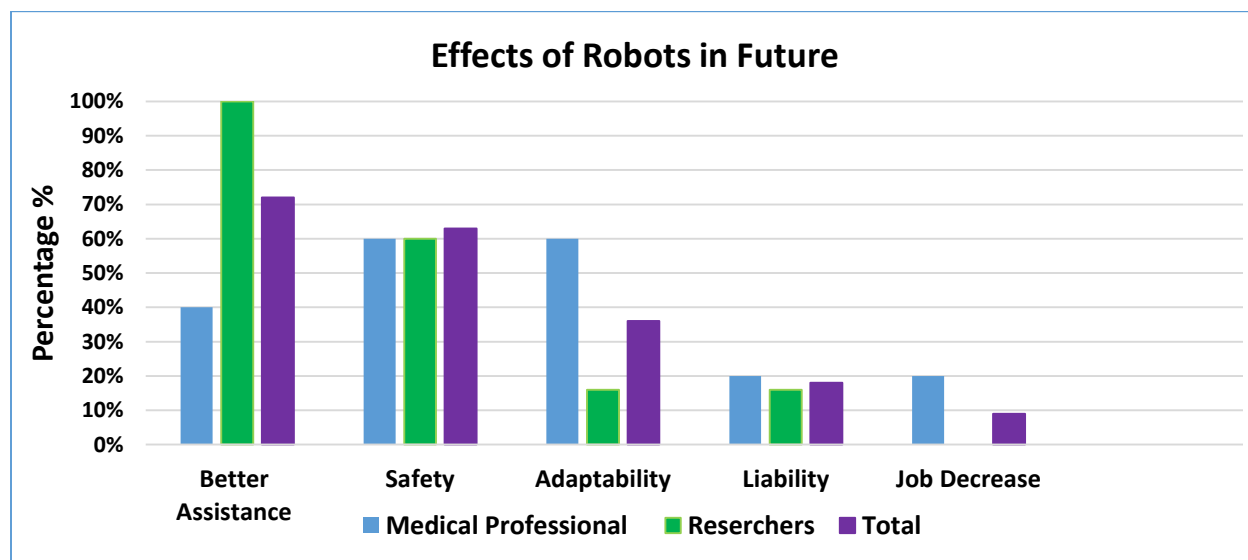
In our graphs we used the term “Efficiency” to describe the extent to which time, effort or cost is well used for an intended task; for our purpose efficiency is the extent to which assistive care robots are allowing medical professionals to perform their tasks at a faster rate and with less effort. The results show 63% of participants (three researchers, two doctors & one nurse) agreed that robots bring efficiency into assistive health care. Professor Carpenter believes that robots can make their job more efficient by decreasing the amount of physical tasks, therefore, saving them time and effort (Appendix K). Professor Fischer says that robots can make a doctor more efficient by speeding up the surgical procedures and allowing doctors to perform minimally invasive surgeries with more accuracy and minimum risks (Appendix C).

In our graphs “Precision” is defined as the quality of being exact when performing a specific task. We focused on the precision of robots while performing surgical procedure. The results show that 45% (two doctors and three researchers) of our participants said assistive care robots are currently providing precision within the medical field. According to Dr. Borenstein, assistive robots are allowing medical professionals to visualize better at higher resolution while working in surgical procedures as well as bringing precision to the operating room [Appendix F]. Professor Mansoor stated “Robots bring efficiency and precision as well as accessibility of surgical procedures in remote areas” [Appendix E]. This shows how minimal invasive procedures can be done nowadays with more precision and accuracy.

The main aspects we collected through our interviews for our second questions were: providing better assistance, bring safety and efficiency, increasing liability and lastly decreasing job availability. Results for this part are shown in table 3 and graph 2.

	Better Assistance	Safety	Adaptability	Liability	Job Decrease
Medical Professional	40%	60%	60%	20%	20%
Reserchers	100%	60%	16%	16%	0%
Total	72%	63%	36%	18%	9%

Table 3: Results of 2nd Question



Graph 2: Effects of Robots in future upon medical professionals

In our graph # 2 “Better assistance” is one of the main aspects we collected through our interviews. We used better assistance in terms of how robots can be helpful by enhancing medical professionals’ capability in the future. As a result 72% (six researcher and two doctors) of participants agreed upon robots being tools that will help medical professionals to perform better in their areas. As doctor Borenstein said

“Surgical robots will be great tools for the medical professionals, because the combination of precision and expertise will lead to great results in surgery” [Appendix F]. Professor Fischer as many others believes that the goal for assistive robots is not to replace doctors, on the contrary they are tools that will assist them, and make them more efficient [Appendix C].

In our graph # 2 “Safety” plays a major role within the assistive care area. A device needs to be designed with the purpose of not causing physical or mental harm to the users. The data shows that 63% (two doctors, one nurse and three researchers) believe that assistive care robots will bring safety for future applications in the areas of surgical, rehabilitation and prosthetic robotics. Registered Nurse McGrath says “the effects will be positive on medical professionals by making their profession more efficient and safe [Appendix J]. As professor Creelman talked about the da Vinci: “We can change the perception of these people by showing them that is safe, it reduces the complication, and its working effectively” [Appendix I]. This is how medical professionals perceive the future effects in assistive care in terms of safety.

As shown in graph # 2 “Adaptability” is the ability that humans have to fit on occurring changes, for our purposes this change will be the technological advances within the robotic assistive area. Therefore, our results show that our participants looks at adaptability as a negative effect due to those advances. Results show that 36% of participants (two doctors, one nurse & one researcher) believe that in the future, it will be difficult for medical professionals to adapt to the advances of these devices. This is because they will have to relearn how to manage certain procedures with the assistance of these new technologies. Dr. Clark believes that new technology will not be

immediately easier for professionals to adapt. They will have a lot more data, than they currently have and they will not know how to deal with that. It will be overwhelming [Appendix H]. Also, Dr. Douglas said that his older colleagues will not have a high degree of acceptance towards these systems because they are very comfortable with their traditional approaches [Appendix A].

In our graph in graph # 2 “Liability” looks at how the technological advances on future robots can put medical professionals at disadvantage or will hold them responsible for “machine” errors. The results show that 18% [1 researcher and 1 nurse] of the participants believe that medical professionals will be concern about the liability of assistive care robotics. Professor Yanco is mainly concern about the lawsuits the surgical area is currently presenting. Therefore, she is not sure where the problem of liability will lead to in the future [Appendix D]. Registered Nurse Karen Carpenter believes that it would be difficult for the doctors to give that liability since they have always been “captain of the ship”, she is not sure who would be the responsible in case of a lawsuit the robot, doctor or the company that create these systems [Appendix K], problem that will prevent this technology to move forward if it does not get address in the present.

In our graph # 2 “Job Decrease” could be one of the effects medical professionals will face in the future. Results show that 9% (one Registered Nurse) of participants believe this is a possibility. Carpenter believes that although medical professionals do not express it, they will always have that concern [appendix K].

We concluded that “Improving lives” and “Efficiency” were the most relevant ways in which robots are helping in today’s assistive health care according to the

participants. 73% of participants believed that these systems show great potential towards improving disabled people's lives. 63% of participants believed that these systems are bringing efficiency to the medical field by decreasing the time and effort of the medical professionals. Our results showed "Better assistance" and "safety" are two important aspects which assistive robot will bring into the medical field in the future. 73% of participants believed that these system will better assist the medical professionals by enhancing their capabilities to perform specific tasks, and 63% thought that these systems will bring safety to surgical procedures, and rehabilitation centers.

Chapter 8: Conclusion

The fields of surgical, prosthetic and rehabilitation robotics are growing rapidly. Their evolution has brought hope to patients and efficiency and better assistance into the assistive health care. After looking at the past, present and future of these three different areas, we can conclude that there are no limits for innovation. Among all the research and interviews conducted, we have found that robots have been created with the objective to enhance the capabilities of humans such as medical professionals and patients. Several devices were studied including lower and upper prosthetics, surgical robots, and lastly upper and lower rehabilitations systems. Currently, researchers and engineers are working on future devices which seem promising at providing better assistance and improving safety factors within the health care area.

Prosthetic robotics have been evolving for many years. These systems are currently helping physically disabled people that have lost their extremities. Prosthetic robots are giving patients back autonomy by allowing them to perform daily life activities. These technologies show great potential for future use as engineers and researchers are working on improving functionality by giving prosthesis sensation, natural appearance and flexibility. These devices are accessible, maintainable, and safe for amputees. A clear example is the i-Limb, It is easy to wear and maintain and its cost is relatively low (\$18,000) compared to other devices. Advances in prosthetic robots such as nanosensors will enhance the ability of the amputee in terms of strength, and speed, allowing them to experience an independent life style.

Although surgical robots are helping in the medical area, their use has been controversial. Surgical robots have the ability to cause harm to patients and medical professionals' due to lack of accuracy and feedback force during procedures. In the surgical area, patients' lives depend on the performance of the doctors and how well they use these devices. The performance of the robots implicates liability, where it is unclear whether the doctors or robots are at fault. According to New York Times, the robotic surgical procedures have inherent risk where "nearly one-third of deaths that were reported to the F.D.A. database occurred during gynecologic procedures, and 43 percent of the injuries were associated with hysterectomies" [16]. It also states that 56.8% of surgeons surveyed in 2010 said anonymously that they had complications using the da Vinci system. The state of Massachusetts came to the conclusion that hospitals should also talk about the risks of the robotic surgeries as well as their benefits.

Another disadvantage is that surgical robots are costly (\$1.5-\$1.75 million) which does not include the annual service fees and the cost of disposable instruments, which makes it even more expensive for the patients. According to the doctors we interviewed and research we conducted on articles and journals, information shows that surgical robotics allow surgeons to operate with higher precision, gives them more flexibility, and higher resolution to perform minimal invasive surgeries. *In January, a national medical safety organization, the ECRI Institute in Pennsylvania, concluded based on an analysis of relevant studies that robotic surgery is booming despite limited evidence that it works better than standard operations [59].*

Rehabilitation robotics is an area with immense room for improvement. These systems are currently helping patients recover from physical and mental disabilities. Patients with cerebral, neurogenic, spinal, muscular or bone-related disorders are the target users for such devices. Rehabilitation robots are specialized at providing the external strength patients need in order to perform certain activities such as grabbing, climbing and walking. The recovery of the patients is monitored and saved in the software systems of these robots, as seen with the Armeo products. This allows physical therapists to keep track of the progress of the patient on a daily basis. Lower limb exoskeletons are giving the opportunity for patients with muscular disabilities to walk again by giving them the extra strength needed to get up and take steps. The future effects imposed upon medical professionals from the technological evolution of these systems could be better suited for physical therapists. These therapists will be able to devote their attention to the recovery of the patient instead of spending time on unnecessary physical efforts, since the exoskeletons provide patients with the strength to perform basic tasks. Physical therapists will be able to quantify the progress of their patients due to the advanced software of these devices. It could be beneficiary for both patients and medical professionals.

Results show that technological advances within the prosthetic, surgical and rehabilitation areas are opening doors for new discoveries. Robots are improving lives of medical professionals and patients by serving as tools that enhance the ability of the users through their implementation, execution and profound effect on people's lives.

Appendixes

Appendix A: Interview with Dr. Douglas Dahl:

Doctor Douglas Dahl, is the chief of Urologic Oncology and urologic surgeon in the Massachusetts General Hospital department of Urology. He specializes in the treatment of cancer, minimally invasive surgery and related research. He went to Yale University school of Medicine Residency, Brigham and Women's hospital for his Medical Education. Our IQP group interviewed him aiming to understanding his point of view towards assistive care robotics; more specifically in the area of surgical. Also to see from his professional expertise as a surgeon, what he believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand his point of view on these topics we asked him the following questions and his answers were:

1) How can you compare both regular and robotic surgeries?

He has been conducted through his entire career minimally invasive surgeries. He thinks that the great improvement for patients with surgical robots is their recovery time as well as to be able to have major operations.

2) According to your experience what are the pros and cons of robotic surgery?

Pros are allowing surgeons to do complex minimally invasive surgery. The major cons have been still learning what the limits are and proper use of it (the system) when it's not appropriate. Also the marketing of the system has been so aggressive that there

hasn't been very good dialogue it's been religious conversion instead of thoughtful scientific assessment and what the proper uses are.

3) What is the degree of acceptance towards working with assistive care robot and what are the degree of acceptance are among your colleagues?

He uses them regularly so he accepts them as useful in particular circumstances. He uses the da Vinci and other system which is camera controlled system and that has been very helpful to him. Other colleagues do not necessarily have a high degree of acceptance towards these systems, some are very comfortable with their traditional approaches and some are comfortable using it.

4) Based on your knowledge and experience how do you think robots are helping in assistive health care today?

He responds with is amazing to look back at the history of medicine and medical care. He says if you look 100 years ago we had not antibiotics and not x-ray or imaging technologies; we had dangerous anesthesia procedures and it is unavailable how fast things change in the medical care and medical technology. He believes that all these technologies created by engineers are an enormous help. He also thinks that what they are using right now is somehow primitive of what he expects it to be in the future where integrating imaging with smarter technology can help people to do things more consistently better.

5) What do you think will be the effects upon medical professionals due to the evolution of assistive care robots in the near future (approximately 10 years)?

He thinks that there is going to be an increasing diffusion of these tools and acceptance of their role. But as with many things there will be some resistance from some groups. He believes that there should be some caution as they have seen in lots of different things, there sometimes they found out that technical issues are been unforeseen. Although things are going great there are always unintended consequences and side effects and he believes that it is important to be optimistic about the role that these technologies, but there is also a need to be careful and realizing that in surgery you can primarily alter people's lives and it is quite appropriate to be careful and cautious because there are always problems that you cannot foreseen. Assistance is also necessary to follow the impact and see problems with this devices because they always happen. He thinks there should be a better mechanism from the FDA to follow devices and so for after they have been adapted by different hospitals, business, etc.

Appendix B: Interview with Dr. Shahin Tabatabaei:

As you have experienced both robotic and regular surgeries. How can you compare these two?

He said although robotic surgery is more efficient and precise but you can get the much experience of regular surgery.

2. Based in your experienced what are the pros and cons about robotic surgeries?

Lack of actual feedback while doing surgery, because you can't touch the body. It is expensive and hard to maintain.

3. How was your first experience conducting a robotic surgery? What type of procedure was it?

It was good experience for me that is why I am still doing the robotic surgery. It was prostate surgery.

4. What is your degree of acceptance towards working with assistive care robots? What is the degree of acceptance among your colleagues?

Yes, I accept it very well, if I did not accept it than why would I am doing robotic surgery from last 7 years. But for my colleagues it is different. The old colleagues of mine are not comfortable to work with robots and they don't want to learn it, but my young colleagues are really interested to learn this now technology.

5. Based on your knowledge and experience how do you think robots are helping in assistive health care today?

I can just tell you that how robots are helping in surgeries I don't know how robots are helping in other fields.

6. What do you think will be the effects upon medical professionals due to the evolution of assistive care robots in the near future (approximately 10 years).?

7. What should I ask you that I didn't ask you?

I don't know because this is not my project and I have no idea what you guys are doing and what I can add to it.

Appendix C: Interview with Professor Gregory Scott Fischer:

Professor Fischer is a mechanical and robotics engineer with an appointment in biomedical engineering. At WPI he is an essential part in developing the robotics engineering program. Professor Fischer is the director of the Automation and Interventional Medicine (AIM) Robotics Laboratory. His research is primarily focus in medical robotics with the objective of taking the most advantage of robots in surgery implementing real time feedback, intelligence and autonomy.

Professor's Fischer research is based on medical robotics, MRI-compatible mechatronics, computer-assisted and Image-guided surgery, sensors and actuator development and robotics education. Our IQP group interviewed him aiming to understanding the current research that professionals are carrying on assistive health care robotics. Also to see from their professional experience and knowledge what they believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand his point of view on these topics we asked him the following questions and his answers were:

1. What is your current research Professor Fischer?

The focus on his labs are very different types of biomedical robotics. Most of the work is in the area of imaging surgery which divide into medical images from MRI, CAT scanner, and Ultrasonic essentially using wild images to guide surgical procedure.

2. What is the objective of your research?

The objective of his research is to improve health care system by providing medical robots with better precision, more accurate, faster and lower cost.

3. What inspired you to do this research?

He always been interested in health care and also robotic but it all started with first medical robotic project in his graduate. His graduate studies was all related to medical devices, medical robotic. He always been interested in health care and also robotic but it all started with first medical robotic project in his graduate. His graduate studies was all related to medical devices, medical robotic. In WPI for almost 6 years they build a lab which aims on De vinci guided surgery and couple different applications from robots: Image guided robot and neurosurgery (working with UMASS medical school). He finds really interesting and rewarding which desires him to improve the health care.

4. Which organizations or institutions are funding your research?

The National Institute of Health (NIH) is funding his research. NIH is funding two projects, one of them is on prostatic cancer diagnosis and therapy using the MRI machine to obtain really precise biopsies. The other one is for neurosurgery, particularly for brain cancer, and what they are trying to do is very precisely burn or freeze tissue with a laser; inserting very small needles and electrodes into the brain, very precisely killing brain tumors. The da Vinci device we have at WPI was donated from Intuitive Surgical for the purpose of developing it putting force feedback and more intelligence. Rehabilitation robotics is not being externally funded and they are trying to get some support from the National Institute of Disability and Rehabilitation (NIDRR) and also from the National Science Foundation (NSF).

5. Where do you see your research in 10 years?

He believes medical robotics are taking off and that there have been a lot of disability evaluation demonstrating that the objectives of using these assistive robotics are possible. He points out that, where they really need to go with this is to get more additional practice. Therefore developing something in the lab and demonstrating that it works but also the next step is taking very careful steps getting all the specifications and appropriate documentation and validation such as the IRB approval. He cannot stress enough that one of the most important objectives is to make these systems more reliable so they can be ready to use in patients. On the other side an important objective is going to be adding more intelligence to it. As Professor Fischer said “so the da Vinci is a really nice system it works very well, but it has absolutely not intelligence”. They want to start adding autonomy adding safety to it, also adding force feedback.

6. What do you think will the effects on doctors and nurses due to the evolution of robots within the medical field?

Professor Fisher said that, all these systems and devices have been designed to actually work with the doctor and it is something that is very important to clarify. The goal is not to replace doctors; essentially is to give them tools to assist what they are doing so something like the da Vinci, the idea behind it is to let the different surgeons work in much smaller areas ultimately do things that they couldn't do otherwise. With the neurosurgery for example Professor Fischer points out “we still need the doctors to tell us where to go and the robots are just there to make sure they are obtaining the biopsy from where we wanted to take it from”. The telepresence systems will let the doctors to work from home or the same doctor can work from multiple offices and be more efficient.

7. Will those effects still be the same in the near future?

Professor Fischer believes that, it is hard to say. If robots had more autonomy he guesses in the future they could be doing more, but he does not see at least any time in the near future robots replacing anybody. On the contrary they can actually make a doctor more efficient.

Appendix D: Interview with Dr. Holly Yanco:

Professor Yanco obtained her BA at Wellesley College and MS, Ph.D. at Massachusetts Institute of Technology all in computer science, and currently is a professor in the computer science department at UMASS Lowell. Her areas of expertise are: Robotics, assistive technology and artificial intelligence. Professor Holly is also the director for the New England Validation and Experimentation (NERVE) center. She founded the Robotics department at UMASS Lowell in 2001, where her research is conducted and students from all stages of their carriers are also part of it. Professor Yanco is an outstanding professor, and, thanks to her remarkable work within the robotics and computer science department she is the general chair of the [2012 ACM/IEEE International Conference on Human-Robot Interaction](#).

Professor's Yanco research is primarily focus in human-robot interaction, better visualization of sensor data, adjustable autonomy, urban search and rescue, assistive technology, and robotics education. Our IQP group interviewed her aiming to understanding the current research that professionals are carrying on assistive health care robotics. Also to see from their professional experience and knowledge what they believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand her point of view on these topics we asked her the following questions and her answers were:

1. Professor Holly we know that some of your research interest includes human-robot interaction, assistive technology, and robotics education. What is your current research specialized in?

Professor Yanco's research is based on human-robots interaction, better visualization of sensor data. In general she is working on care robots interaction very broadly but in depth they are researching on new ways to control robots. She is working on universal design to make easier life for people with physical disability. She is working on assistive robots and a lot of remotely controlled robots. One of her new project on which a PHD student is currently working on is a vego robot about which she talks about in her later interview. She is also working with one of the biology professor who have been taking maelstrom and growing them into new neuronal in patriot dishes that are on top of her protracted array which they are using to control robots. She is looking at a lot of different ways to control robots such as autonomy mode how people can trust robots. The research is really how the measures of the effectiveness of robots systems and where neuroreceptors came in.

2. What is the objective of your research?

The objective of Professor Holly Yanco's research is to design better robot system to help people do tasks in easier way in which they need assistance.

3. Which organizations or institutions are funding your research?

Her research is being funded by the National Science Foundation (NIH), the Defense Advanced Research Projects Agency (DARPA), the Army, and the National Science Foundation (NSF).

4. Could you see your research being applied in the medical field within the next 10 years?

She believes it will. Currently some of the areas where she is conducting research is being applied in the present such as the telepresence robots. She explains how Vgo robot is currently being used by a doctor at Children's Hospital in Boston, where he sends this robots home with his patients after their surgeries, and he is using it for surgical follow up, obtaining very effective results because the kids like the robots. Professor Holly adds that there are a lot of regulations that need to be done in order for this technologies to move forward. She expresses that a lot of these technologies are out there but the issue is the liability of the product and the cost of it. She thinks that In order to see the robots technology being incorporated to the healthcare domain the cost of this technologies is going to have to be reduced.

Web site: (<http://www.popsci.com/technology/article/2011-12/childrens-hospital-boston-turns-telepresence-robots-post-op-patient-care>)

5. As part of the computer science department and because of your extensive knowledge about assistive care robotics. We are sure that you have been able to see all different types of research with very innovative ideas. Which ones have been the most interested projects that you think could have remarkable effects in the near future of surgical, prosthetics and rehabilitation robotics?

She believes that from the technologies she has seen in the last years, the Luke arm that came out of DEKA was huge if we look at prosthetic technology and its advances since World War II. The comparison is from a hook "arm" to the Luke arm, which is an actual arm that can be controlled by nerves, muscles or even foot pedals with very fine motor control, and censoring feedback. Professor Holly also mentions that there has

been a lot of work on prosthetics on lower limbs as well. Therefore she believes this is one of the areas that has had a considerably improvement in the past years.

6. What do you think will be the effects on doctors and nurses due to the evolution assistive robots within the medical field?

Professor Yanco believes that it really depends on what kind of robot we look at. She gives the example where having an occupational therapist deliver a robotic wheelchair to a client, there are different technologies that have the tint but she does not believe they have much impact on it. In terms of surgical robots, it might allow surgeries to happen that did not happened before. But a con is that there are now lawsuit, so she does not know where that's going to go. She thinks medical sub introduces reliability in so much larger situation than anywhere else. She points out "If you have a roomba that does not vacuum your floor really well, ok it did not vacuum your floor well. It's not killing anybody, it is just not vacuuming your floor that day". It's quite different with the medical domain. But she thinks that robots have the potential to really improve physio-therapy for people .When you are working at stroke rehab, where the first few weeks, after the stroke, is when patients received their major rehabilitation coming in. therefore the more exercise someone can do, the more consistent, the better it is for the patients recovery. Having robots for low cost and able to do this for you and working with the physical therapist; would be great, because better and faster results will be observe. She does not believe that we would have robot doctors and nurses, on the contrary, these are devices that will help medical professionals to obtain better results in their respective tasks.

Appendix E: Interview with Dr. Mansoor:

Professor Mansoor obtained his B.S. in Pharmacy at Northeastern University and Ph.D. Pharmaceutics at Purdue University, and currently is a distinguished professor & chairman in the pharmaceutical science department at Northeastern University. His areas of expertise are: Polymeric Biomaterials, Drug Delivery Systems and Nanomedical Technologies. He is also the laboratory director for Biomaterials and Advanced Nano-Delivery Systems (BANDS), as well as a panel participant for the NIH within the Bioengineering, Technology and Surgical Sciences study section (BTSS). He is a member of the CRS Board of Scientific Advisors, fellow of the American Association of Pharmaceutical Scientists (AAPS), and has won several awards and recognitions in the field, including the AAPS Meritorious Manuscript Award and the Nano Science and Technology Institute (NSTI) Fellowship Award for outstanding contributions toward advancement in nanotechnology, micro technology, and biotechnology.

Dr. Mansoor's research is primarily focus in nanotechnology applications for medical diagnosis, imaging and therapy, and the development of biocompatible materials from natural and synthetic polymers, as well as target-specific drug and gene delivery systems for cancer and infectious diseases. Our IQP group interviewed him aiming to understanding the current research that professionals are carrying on assistive health care robotics. Also to see from their professional experience and knowledge what they believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand his point of view on these topics we asked him the following questions and her answers were:

1. We know that your current research is focus on the development of biocompatible materials from natural and synthetic polymers, target-specific drug and gene delivery systems for cancer and infectious diseases and nanotechnology applications for medical diagnosis, imaging and therapy. But could you give us more details about the areas you are working on?

Dr. Mansoor believes the challenge in drug development now is the number of different molecules that work really well as in terms of their usefulness in the body. These molecules have sort of a wide spectrum such as the molecules that are incredibly insoluble in water and molecules that are biological, that tend to be either protein based or nucleic acid peptide based. In that spectrum the challenge comes in how to get into the right place in the body, how to make sure that there are actually getting into the right tissue or cells. Look into how does it interact, what is the ability of these molecules to actually function the way we desire them to function so those are the challenges they are trying to address, by trying to make these molecules selective in deliverable to the right area of the body. In his lab they are also focusing on patients who developed resistance to multiple drugs in cancer. He is focused on understanding what goes wrong and based on that creates a better drug by increasing the delivery efficiency or by increasing the residence time in tumor. One of the areas he is thinking about is, sugar metabolism; their hypothesis is how to stop the metabolism of glucose and then make drugs more effective when the tumor cell is been produced.

Another area of his research is the inflammatory part due to cancer or any other inflammatory diseases such as arthritis and diabetes. These inflammatory diseases stay

there and they affect that environment by basically secreting various types of factors and propagates the inflammation making the situation worse. The questions they are trying to approach are: is it possible to reverse the method? The immune cells are programmed by the environment to continue to propagate inflammation, is it possible using genetics approaches to switch them and reprogrammed them? Instead of making the cells continue to propagate the information they will start healing the tissues in a reversed way of what the environment is telling them to do by programming them artificially.

Third area he is focusing on is the brain. Some of the challenges of the brain are diseases such as Parkinson's and Alzheimer's. The inflammation is the primary component that leads to the debilitating effects of Parkinson's. Therefore they are focusing more on inflammatory pathways in CNS disease. One of the challenges in the brain is how to get these genetics molecules into the brain. The other part of the project is finding a noninvasive patient friendly way to do so, that way these can translate in to the clinic. They are looking into the inter-nasal delivery in the brain instead of injecting it in the blood and trying to get it into the brain by drilling a hole into the skull. According to him, the better approach is through the nose (less invasive). He believes that understanding the problem is the most important aspect of diseases and then finding the right solution is really important and that is their goal.

In drug delivery most of their work is different kind of nanotechnology. His main focus is safety because they want to translate from his lab to the small/mid-size companies which will take over to large form and subsequently to the clinic. They tend to focus a lot on safety aspects of materials, by using polymeric nanoparticle because they are able

to encapsulate them and have them degrade into the body and also by selections of these different polymers which can increase resident time, they can have control on the released drug making sure it goes to the right place so there is a much longer effect from these nanoparticles.

2. What is the objective of your current research?

Dr. Mansoor's objective is to be able to create better therapies based on the molecular signature of individuals. Previously medicine was always thought of as a more patients (anatomy centric), for example doctors look at the person and try to identify diseases based in their anatomical presence. Breast cancer for instance, because it has a breast origin or ovarian cancer, because it has an ovarian origin. He says that medicine is changing to a more molecular aspect, they are interested in what is happening in the molecules of the cells at this levels. The emphasis is in cancer geometrics where 20 of the more common types of cancers will be decoded. He and his research team are trying to understand the difference between a normal genome and a cancer genome, and how they can then create better therapies based on this. A detail level of understanding is really creating opportunities for individuals to think about developing technologies that could help solve some of the challenges that are and will be faced within the medical environment. Therefore they are looking to develop more effective therapies that are more healer to the patient's molecular signatures rather than thinking of people as aggregates and using the law of averages for treatments. This is where medicine is moving towards the idea of personalized medicine called the (4P): personalized, participatory, predictive, and preventive. This is the model of medicine

that society is going into, and technology has a role to play in all the different fields that are very techno centric such as bioengineering and pharmaceutical sciences.

3. What inspired you to do this research?

His inspiration are the lives of people. Even though they are working in a very small scale and is sort of the analogy “that they get to put a brick on the wall”. He says “You have to have the picture of the whole wall in mind”. The whole picture includes the people that ultimately will be helped by their research, which is the most important part of what they do.

4. Can you see your research being applied in translational medicine?

He responds with an absolutely! That is really a very important part of what they do. He makes his students think that way, to think about the big picture in mind. It is important to understand that this has implications in humans, Dr. Mansoor says “what we do ultimately affects people”. They try to be simple, efficient and at the same time they try to save materials keeping the goal that translation is key. One of the researches that he believes will be first at translational medicine, could be the research of treating ovarian cancer. They developed a delivery system which combines different kinds of drugs in one package or one smart package as he calls it. This one, only targets ovarian cancer cells and leaves all the normal cells so they are able to get more of the drug in the tumor. By having this differential approach to therapy, they are able to shut down cell’s glucose metabolism pathway, they can affect tumor cells in 3 or 4 different ways and even though they are very smart, they are not smart enough for the 3 or 4 different ways that they are attacking them. This method is giving them better results with cancer cells

with less toxicity. Something else that they have found in ovarian cancer is that instead of giving the drug in the bloodstream, is that if they confine it in the peritoneal cavity they have a better effect. Clinical trials on patients will start soon, therefore he expects to obtain data from this so it could transition to clinic.

5. As part of the review panel for the NIH we are sure you have been able to see all different types of research that are being or will be funded by this institution. Which ones are the most interesting projects that you think could have remarkable effects on the future of surgical, prosthetics and rehabilitation robotics?

Dr. Mansoor first rephrases that by saying that medical professionals, researchers, practitioners, clinicians are here to stay. He believes that no matter how sophisticated robots get, medical professionals are going to be here and no one is going lose their jobs; but he thinks that there is going to be a greater influence of robotics in medicine. He gave us several examples of the trends that he is seeing; some of them were more in therapeutic science, some in the delivery of care, surgical or ambulatory care.

As being a professor in pharmacy school, he started with a question, what is going on in pharmacy? He gave an example about how the pharmacies have changed since 15yrs ago, back then a person would take the prescription and put the pills in a container and put a label making sure that the right drug was given and they might even spend two minutes with the customer saying what that drug was and its effects. When the computers weren't around the labels were written by using typewriter. And students were asked to type or retype the labels until they got it correct. Without computers and the technology pharmacies have now, it was hard for the pharmacist and their crew to

make liquid pills for those who couldn't take normal pills, especially with a pediatric or a geriatric patient, a lot was customized he says. Those eras are gone, now is what comes from the drug industry and this is what we are dispensing and computers really have become the mainstay so paper prescriptions are emailed. There is a much faster access of prescriptions from the physician to the pharmacy, barcodes have become a mainstay in many of these prescriptions can just be scanned and they don't need to type it. He thinks the real interesting thing is that pharmacies have become automated so no one counts pills and they have automatic cells which would count the pills (more precision = less human error) so there might be a person who is filling them but counting process have become automated.

He said amazing things happen within the surgical field. He then explains "You being on bed and cut by some machine where physicians are not in the room". The patients could be in remote areas in the world where there is no access to medicine and surgical centers. Therefore physicians can operate patients in a village located miles away. Another example of how technology is influencing the medical world is the monitor glucose app which can measure glucose levels for certain weeks, and patient can go to the doctor and show them the data they have collected during 2 -6 weeks.

6. What do you think will be the effects on doctor and nurses in near future due to the evolution of robots?

Dr. Mansoor believes there will not be significant effects on professionals due to the evolution of robots. He stated that one of the great thing of human being is adaptability. It Does not matter in which mold (environment) a human being is been put, he/she will adapt. One of the most important aspects is when you talk about new information,

technology and robotics we adapt at an incredible speed. We just have to find how important this is and how it will affect us and use our mind which is the only thing that cannot be replaced. He said there are certain types of jobs that robots can do such as bank tellers (ATMs), assembly works, etc. But Robots can never take a human's place because they cannot think. Humans will always have edge over any machine, because humans can take decisions.

In robot scenarios we have impact on jobs to some degree in retail, but if we are careful we can take advantage of that and actually apply the profession. Pharmacist for example could spend more time counseling or educating the public about their medications instead of being counting pills and making labels.

7. How long have you been a member of review panel?

DR. Mansoor has been a member of the review panel for the last 15 years. The first 5 years he was in an ad hack review panel (Members are invited if they need certain area of expertise). Since 2012 he is a full member of the review panel and will remain as a full member until 2015. He review projects for many different agencies for both national and international agencies (Foreign) such as: NIH, common foundation department of defense as medical program, Hong Kong, China, and Russia.

Appendix F: Interview with Dr. Jeffery Borenstein:

Dr. Jeffery Borenstein did his PhD in physics at the University of Albany. He has an extensive experience in microsystems technology and biomedical devices. He began his career at Draper 19 years ago and served as a fabrication manager, working on micro-electromechanical systems for six years. He spent two years as a group leader in the Micro-Electro-Mechanical Systems program (MEMS). He has worked in biomedical engineering for the last 10 years. While he had work in Draper and mentored numerous fellows and young engineers, he received multiple awards including the Distinguished Performance Award in 2001, the Best Publication Award in 2004, and was a member of the research group that won the team Distinguished Performance Award in 2012. His current work focuses on the application of Microsystems technologies toward pathogen detection, drug delivery, and cell based devices and systems. He is Director of the Biomedical Engineering Center and a Distinguished Member of the Technical Staff at the Charles Stark Draper Laboratory.

Dr. Borenstein is Draper's principal investigator of three NIH grants on artificial organs and drug delivery devices, and lead for the Draper engineering contract on a joint program with MIT aimed at creating a human "physiome on a chip." The project aims to develop a system for testing the safety and efficacy of drugs using human cells on a platform of miniature interacting organ models. He also holds several fundamental patents on use of MEMS technology to build artificial organs.

1. Doctor Borenstein we know that some of your research is focus on the application of Microsystems technologies toward pathogen detection, drug

delivery, and cell-based devices and systems. Could you give us more details about the areas you are working on?

In the area of drug delivery, Dr. Borenstein is currently working on implantable drug delivery devices that are, programmable and have the potential to transport one or more local drugs to different parts or organs in the body. The second area in which Dr. Borenstein and his team are working on is, microsystem technologies, where they use human cells to test their reaction to different types of drugs. By using human cells the results they have been obtaining at his lab, are more accurate compare to those in animal cells.

The other project in which Dr. Borenstein is currently working on, is drug induce vascular injury. The mechanism of how certain blood can cause injury to blood vessels is not well understood yet. Therefore they are developing a blood vessel microscope model in a chip, in which they culture cells and then flow the blood into that chip in order to observe if blood causes damage to the blood vessel or the chip.

2. What is the objective of your research?

The work of Dr. Borenstein in all his areas of research, is devoted to use micro technology to develop safer and less expensive diagnostic tools for different diseases, in order to provide a better therapy for the patients.

3. What inspired you to do this research?

He has always being interested and passionate about medicine; but also personal experiences in having people close to him experiencing life threatening diseases, has inspired him to help patients to fight for those diseases.

4. How was the process to obtain the patent to build artificial organs? Were there any competitors trying to achieve this patent?

Yes there were and are competitors. The technologies and approaches they use has not changed much or evolved as much as the technology used by Dr. Borenstein and his team, since their work came along earlier than their recent players. He says “basically there was one major competitor, who was working in space and applying some of our approaches to obtain the patent”. But Dr. Borenstein had a more concise approach to the problem, therefore he was able to obtain the patent. It has been observed that, the outcomes of their competitors are not as accurate and advanced as the ones obtain by him and his team.

5. We know the NIH is funding your research; are there any other organizations or institutions that are funding your research?

The two main institutions funding their research are, the National Institute of Health (NIH), and the Defense Advanced Research Projects Agency (DARPA), since they do a lot of collaborations for the military at Drapers Labs. Commercial areas also fund their research, most specifically pharmaceutical companies.

6. Could you see your research being applied in translational medicine within the next 10 years?

Dr. Borenstein says that all of his research can be applied in translational medicine, since it leads to treatments. He also takes a chance and says that the physiome on a chip (organ system devices) could be the first to be applied. Although this is the area with the major risks, it is the area with the highest urgent need, because there is no

other way to address it. Thus sometimes there is only two options for the patients where they either obtained an organ transplant or die.

7. As part of the review panel for the NIH we are sure you have been able to see all different types of research that are being or will be funded by this institution. Which ones are the most interesting projects that you think could have remarkable effects on the future of surgical, prosthetics and rehabilitation robotics?

Based on his knowledge and experienced as an NIH participant the area where he sees major technological advances is within the prosthetic robot area. The development of new prosthetic technologies that use nerve sensors that can detect signals sent from different muscles or the brain in order to control these devices show how far we have come with our new technology. He also points out of how the rehabilitation technology is not so advance compared to the one seen in prosthetics, but is also a very good and promising technology.

8. Based on your extensive knowledge within the biomedical field, what do you think will be the effects on doctors and nurses due to the evolution assistive robots within the medical field?

Dr. Borenstein point of view, is that the technology has been evolving and will evolve more in the future. He believes that the idea of robotic surgery is great in terms of the ability to visualize at very high resolutions, and also provides high precision applications which are very important. He thinks surgical robotics will be a great tool for the medical

professionals, because the combination of precision and expertise will lead to great results in surgery.

9. How did you get into the review panel? Is there a process behind getting into review panel?

He says that, it varies from person to person. Dr. Borenstein was asked to be part of the review panel. The NIH funded one of his first drug delivery projects. Therefore they had the information of his work and found him as a good candidate. Now he is a standing member of the NIH review panel, and he usually serves as a reviewer every six month. He is pleased to be part of the panel, because he feels that this is a good way to give back to NIH all the help they have provided him with his work.

Appendix G: Interview with Russ Agnold:

Russ Angold has achieved a bachelor's degree in Bioresource and Agricultural Engineering from the California Polytechnic State University, San Luis Obispo. He is a California registered professional Mechanical Engineer and has two granted patents. He is now the Vice President of Engineering, Co-Founder and CTO of Ekso Bionics. Russ has provided many of the concepts that shape today's current designs for ExoHiker™, ExoClimber™ and HULC™.

Due to Russ's extensive knowledge and experience in the design and creation of exoskeletons for military and rehabilitation purposes. Our IQP group interviewed him aiming to understanding the current technologies in assistive health care robotics. Also to see from his professional experience what he believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand his point of view on these topics we asked him the following questions and his answers were:

1. Could you tell in more detail about what your company specializes in?

His company specializes in exoskeletons it's about augmenting human capability whether a person suffers some sort of accident or medical injury or enabling people to do jobs like industrial logistic applications. His company focus is entirely on exoskeleton.

2. What are the most popular rehabilitations robots that you currently have?

They have ekso_{gt} cancer therapy that device can rehab people who have whether its spinal cord injury or stroke or general weakness that device can be tailored to apply the amount of force directly to proportional to patient's capability to enable rehabilitation.

3. Are these system being used in rehabilitation center?

Yes, there are about 60 devices in use globally US, Europe, Mexico, South America are some of the places these devices being used.

4 We know that you are currently working in the development of the Human Universal Load Carrier (HULCtm) exoskeleton for military use. Is there anything that makes this system better compare to BIEEX, EXOHIKER AND EXOCLIBMER?

HULC has more power than EXOHIKER and EXO CLIMBER, this is to reduce the users metabolic cost while using it. Therefore it's highly different from the other two systems in that respect.

5 Do you believe that these systems can also be used for rehabilitation purposes?

Russ says that some of the fundamental technology is used in the rehabilitation robots. Some of the controllers they use especially when someone has had a stroke. In one side of the body (the less effective one) they want to enable them to do what they want to do, so they actually use more of a whole type controller on that side of the leg versus the reposition type controller on the affective side.

6 Based on your expertise in the rehabilitation robotics area. What are your personal thoughts about the evolution of these technologies?

He believes in his own words "it is pretty exciting". Since they started working on exoskeletons back in 2005 it was science fiction in what they are working as part of a

DARPA program. Now they have devices all around the world that are helping people to recover hope. People are taking steps that would otherwise not have been able to do without a rehabilitation device. They think that in the expanding market there is a lot of opportunity to enable people to rehab.

7 How do you think they are helping in today's medical environment?

These systems are helping physical therapist to concentrate in the rehabilitation of the patient instead of concentrating in physical tasks that were exhausting to them and the patients as well. Now physical therapist can actually focus on the rehab and how the patient is progressing, and since the patients don't get as tired they are taking more steps in the same one hour sections. He and his business partners together with specialist in rehabilitation believe that this can speed the rehabilitation process.

8 Where do you see rehabilitation robotics in near future and what will be the effects on medical professionals?

He sees toward robots as a tool that really enable medical professionals to get best outcome to their patients, and allow the patient to be mobile earlier to a human process and it also allow people to stand and walk again. In his point of view it is a great motivational tool for users.

9 What are the technological barriers you see for performance?

They always looking for Lighter stronger material and better batteries in power site towards technology barriers. They also look at very complex control algorithm to be able to operate different system in different situation. He said there are some technology barrier but they solved it but other industries are trying to solve it.

10 How do you see the attitude of the users and physicians towards these technologies?

He said in early ages people were not comfortable and now people are seeing there is a lot of bio system out there and they are more aware of it. He thinks now patient and physicians are really positive on the technology and want to use it.

11 What inspired you to start this company?

Russ started working on exoskeleton to load tare to help helped his brother who lost his legs in navy. After working on it for three years his brother diagnosed with spinal herniated c67 and unfortunately lost the ability to use his arm and it took 2 years to get his arm back. So he decided to start a company and help the people who lost their extremities during accidents, trauma or any other reason.

12 How does the cost of this technology works?

They are selling primarily to the hospital and patients use it and paid to the hospital.

13 What do you think, what question we have to ask you which we did not ask you?

He thinks we ask pretty much everything related to his company.

Appendix H: Interview with Dr. Heather Clark:

Dr. Heather Clark did her PhD in Analytical Chemistry at university of Michigan. Her expertise are biology analysis, blood glucose monitoring via iPhone, diabetes and nano-tattoos. She began her career at university of Connecticut Health Center for Biomedical Imaging Technology as instructor and did research directed by prof. Les Loew. She also has experience in working at The Charles Stark Draper laboratory, biomedical Engineering Group where she had been Principal Member of the technical Staff. Currently she serves as graduate director, PSM in Biomedical Nanotechnology at Northeastern University, department of Pharmaceutical Sciences.

Her research interests focus on the development of novel fluorescent nanosensors for biological analysis, including subcellular imaging to in vivo monitoring. They are currently expanding their range of sensors into other areas, including redox-active species and small molecules. They have built strong collaborations with investigators at Harvard University, BIDMC, Boston University, MIT and Tufts Medical Center in order to bring a team approach to these projects. Our IQP group interviewed her aiming to understand the current research on assistive robots and how it will effect in future. In order to understand her point of view towards the development of assistive health care technology. We asked her the following questions and received the following answers.

1. Dr. Clark, we know that your current research is focus on the development of different types of nanosensors that aim to measure ion and small molecule concentrations in the intracellular and extracellular environment. Are there any

other research that you are currently working on? Could you give us more details about these research?

Dr. Clark is primarily working on developing nanosensors. She is always trying to push the envelope of what they can measure to make more biologically relevant tools. She and her team are also interested in using those tools in the intended biological environment which is twofold, one is the cellular signaling and the other is in vivo as a tattoo for physiological monitoring, they use it on the whole animal and at the cellular level as well. She also points out that working with experts in the biological problem has been invaluable, since they do not want to be engineers solving problems that do not exist.

2. What is the objective of your research?

Her objective is to make the tool box much larger for people who are doing biological research such as, cellular signaling, or physiological monitoring. She believes that if someone wants to understand biology, they need to develop tools that are on the level of the biology that is occurring right now. Large tools have their place in the lab but if they can get down on a much smaller level, they will create tools for other uses. Therefore, this way they can learn so much more of what is happening on the biological environment.

3. What inspired you to do this research?

She has always being very interested in the nanoscale. Dr. Clark says “there is an entire world that is going on that is too small for us to see. It has always fascinated me to have a view into that world”. When she started as a chemist, she found herself

thinking more about getting into a field of making nanosensors with the hope of being able to see into the nanoscale.

4. Which organizations or institutions are funding your research?

The National Institute of Health (NIH), really helped her to get her start, and it continues to fund her research. The Defense Advanced Research Projects Agency (DARPA), which is the more cutting edge funding agency in the department of defense, is also funding part of it, and lastly several commercial companies.

5. Could you see your research being applied in translational medicine within the next 10 years?

She thinks it will. She is mostly interested in transnational medicine and believe scientist should also show their great interest towards it. There are a lot of people trying to reach out to her for physiological monitoring applications such as monitoring for people with diabetes. It heartbreaking when people comes to her because there aren't many tools available. She said that they are making steady progress.

6. As part of the review panel for the NIH we are sure you have been able to see all different types of research that are being or will be funded by this institution. Which ones are the most interesting projects that you think could have remarkable effects on the future of surgical, prosthetics and rehabilitation robotics?

She believes there are a lot of exciting work going on now all the way from basic research to transnational there are a lot of microfluidic work. She thinks more basic

research like autogenic will make an impact someday. She believes it will be exciting interface between robotics and biology.

7. How long have you been a member of review panel?

Dr. Heather has been a member of the NIH since 2011, and worked as a volunteer in study section. Afterwards, she was also a member of the SBI panel which are small business grants instead of university grants. Although she has participated in the NIH since 2011, she has been a standing member of nano study panel for about a year.

8. Based on your extensive knowledge within the biomedical field, what do you think will be the effects on doctors and nurses due to the evolution assistive robots within the medical field?

She believes that, new technology will not be immediately easier for professionals. They will have a lot more data, than they have currently. Dr. Heather, gave an example of the iPhone glucose monitor, a project she has been working on. She said “it will be fantastic for an individual to have a data for his/her self, but not for nurses”. It will be hard to collect all the data of each patient, when there are several patients to keep track of. This will be overwarming for the nurses, having to collect the data for all of the patients while having to deal with other tasks as well.

Appendix I: Interview with Professor Patricia Creelman:

Professor Pat worked as nurse for 35 year since 1979. She worked in Hospitals, Long term cares, Rehabilitation settings and education settings. Because of her vast experience within the medical field. Our IQP group interviewed her aiming to understanding her point of view towards assistive care robotics; more specifically in the areas of rehabilitation, prosthetics and surgical. Also to see from her professional expertise as a registered nurse, what she believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand her point of view on these topics we asked her the fallowing questions and her answers were:

1. When did you became a professor?

She started teaching in 1979 as well and was practicing and teaching at the same time.

2. Did you ever consider the possibility of being helped by a robot?

She said absolutely, it depend how you define robotics. In her point of view there are different types of electronic systems which are helping nurses such as med dispensing system, and Pixel automated system. She sees these type of technologies as assistive technology, which have been approved in literature that it decrease the risk and increase the accuracy.

3. How would you feel if that was the case?

She thinks there are a lot of tasks that certainly could be delegate to robots, like we can delegate these tasks to unlicensed people. She said she would not feel threaten by the robot, she will feel comfortable to work with robot.

4. Do you know anyone that has had any experienced working with medical robots? If yes what was their degree of acceptance towards these technologies?

She gave the example of Davinci, and said when it first came out there was a lot of skepticism because there was believing of surgeons to laying on the hands. There was a question about how anyone can get good surgical experience if they are not touching the patients. She said there are still some people who believe that way because there was no long term studies are still there. We can change the perception of these people by showing them that is safe, it reduces the complication, and its working effectively that sort of things than it will prove itself. She thinks at this point the thinking of people is not there yet to fully accept the robotic as the operator.

5. How assistive care robotics are helping in the medical field?

She doesn't have a lot of experience with robots and does not know what type of other robots are out there. She thinks in certain application they must be helpful but she does not think that they will fully replace the health care provider.

6. Where do you see the technology of assistive care robotics in the near future?

She thinks cost is big issue, medical embracement and funding. To purchase that kind of technology is hard. This is very bad time for health care as far as purchasing big item like robots.

7. What do you think will be the effects upon medical professionals such as nurses, doctors, physical therapist due to the evolution of medical robotics in the near future?

She think there will be huge learning curve. There will be no problem for the young people who are in school, because may be the schools have the robot and they already learn. May be Population of healthcare providers will say I don't want to part of it when I will retire. Middle group may be some of them embrace it and some of not. She thinks changing the way of people think may change it because she think some people will not accept robots as a deliver care.

8. What questions should we ask you that we didn't ask you?

She is interested to know what type of robot are using outside and how privilege is that. She thing cost is huge factor, but when time will be pass it will get less expensive. She think we have to embrace this technology.

Appendix J: Interview with Professor Margaret McGrath:

Peg was a registered nurse who served as nurse for more than 30 years. She currently works as a nursing professor at Quinsigamond Community College while working at industry for clinical practice. Because of her vast experience within the medical field. Our IQP group interviewed her aiming to understanding her point of view towards assistive care robotics; more specifically in the areas of rehabilitation, prosthetics and surgical. Also to see from her professional expertise as a registered nurse, what she believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand her point of view on these topics we asked her the following questions and her answers were:

1. What made you become a professor?

She believes being a professor is a passion, for her she wants to make sure that her students are prepared and know the questions to ask and seek out the sources. It's a give back.

2. Did you ever consider the possibility of being helped by a robot?

Sure, even though she didn't work with robotics but she has heard of robotics in surgical field and how phenomenal it is.

3. How would you feel if that was the case?

She think nursing is such a people oriented field that it would have be specific on care. She believes that nurse embraces that whole human interaction. She believes robots

like high-five robot would be amazing that they could help the nurses with lifting or turning patients.

4. Based on your expertise, what is your point of view towards medical robotics?

She said that “she would be very interested and it’s something we need to embrace it”. Something that could assist nurses like lifting the patient would be great.

5. Where do you see the technology of assistive care robotics in the near future?

Technology like medical administration that is currently being used or repositioning patient. She can’t envision robots in other working area because she believes nursing is humanistic interaction that it is hard to see robot being able to understand. Like Human can tell that if something is wrong with patient by using their mind but it’s hard with robots.

6. What do you think will be the effects upon medical professionals such as nurses, doctors, physical therapist due to the evolution of medical robotics in the near future?

Hopefully it’s positive one something that can provide patient safety and making practice more safe.

Appendix K: Interview with Professor Karen Carpenter:

Karen is a registered nurse who has been in the clinical field since 1976, this is for the last 38 years of her life. She currently works as a Bioethics professor at Quinsigamond Community College while working at Umass Memorial Medical Center. Because of her vast experience within the medical field. Our IQP group interviewed her aiming to understanding her point of view towards assistive care robotics; more specifically in the areas of rehabilitation, prosthetics and surgical. Also to see from her professional expertise as a registered nurse, what she believed could be the effects these technological advances on robotics would have upon medical professionals within the next ten years. In order to understand her point of view on these topics we asked her the following questions and her answers were:

Key words: Intuition. Human touch, assessment and collaboration.

1. What made you become a professor?

Karen said “I wanted to make a change on students’ lives and how they were educated”.

2. Did you ever consider the possibility of being helped by a robot?

She answers with an “absolutely yes”. In clinical practice she has used a lot of machines in terms of assisting her in her practice.

3. How would you feel if that was the case?

She thinks it will be great. Right now they are using a type of bed side machinery that is brought from side to side and patient to patient with wheels. This system is able to take

vital signs, pulsations, and it does a lot of technical monitoring. Therefore she feels like she is already working with a robot that is helping, so the nurses don't have to do certain tasks manually. Karen thinks the idea of assistive care robotics is fantastic robots can make their life somehow easier, and make their job more efficient.

4. Do you know anyone that has had any experienced working with medical robots? If yes what was their degree of acceptance towards these technologies?

She knows some surgeons that have had experience using a surgical robot. During their conversations, these surgeons say that they feel it's hard for them to step back because it might make an error and they have to always anticipate whether something is cut in the wrong place or whether something is done that they have to intervene. She adds "But they are educated of what to do in case of an emergency with the machinery (the robot)". She thinks they are reluctant because they like to be in control and using a robots, it is like stepping back and not on control and the potential for error in practice is big. She then asks these questions: So who do you sue the robot? Do we sue the physician? The company that makes the robot? Doctors always say they are like the captain in charge of the ship so for them to give up that liability and the techniques that they may want to do differently is a big step. But she thinks that the younger they are and if they are train with the equipment is far more acceptable.

5. Based on your expertise, what is your point of view towards medical robotics?

She is excited about it, "it needs to happen 10 years ago" she says. It needs to progress faster. She believes that engineers should bring in the clinicians in every step of the way

in the development so there is not that hesitation, skepticism or paranoia about using it from the medical professional's side. Clinicians need to be next to the scientist to develop, the whole development needs to be a collaboration.

6. Where do you see the technology of assistive care robotics in the near future?

Just from watching things that are happening with amputations and spinal cord injuries. She believes that is amazing and she believes that it needs to progress faster to help these patients so she wants it to happen quicker for those patients.

7. What do you think will be the effects upon medical professionals such as nurses, doctors, physical therapist due to the evolution of medical robotics in the near future?

She believes that there will be some skepticism because medical professional will be thinking. Is this going to replace a nurse? How can you replace the critical thinking? A lot of nursing is intuition when things are going wrong, and she does not think that a robot could have the capability to anticipate that. Based in her experienced when she walks into a room she knows that something bad is going to happen, she asks: so how can a robot do that? She believes that the human touch and assessment is critical. Robots need to work side by side with a human to anticipate those outcomes, things can change in a minute and a nurse with experience will know that and pick it up very quickly; where she does not think that a robot can be programed to do this. Collaboration between the robot and the medical professional is important. Although medical professionals do not communicate it often they think to themselves: How many personnel will be deleted with the introduction of these robots? Maybe it will leave the

room open to get rid of 2 surgeons? Or nurses? Also nurses should be able to critically assess the systems they are using to see where the failure and the problem is, since the machines are not always accurate.

8. What questions should we ask you that we didn't ask you?

She would like to know how engineers would use collaboration in the development of robotics. Are engineers currently using collaboration with medical professionals? Or is it just engineers that are only developing it and then, they go to the bedside with it? How are engineers troubleshooting issues with robotics? How do they know what is needed? She thinks that collaboration needs to start at the beginning. Also engineers educating nurse students and medical students, in order for the engineers to educate these students about what they are developing or what they are using.

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