HIGH SCHOOL EDITION
Journal of Student Research
Volume 12 Issue 1 (2023)

Recent Developments of Soft Robotics in Medical Applications

Tegh Singh

Staples High School

ABSTRACT

Soft robotics is an emerging technology able to provide novel solutions that standard robots are not capable of addressing. When thinking of robots, typically rigid, mechanical machines come to mind. **SCARA** robots, sanitation robots, automated cars, and other rigid robotic systems offer unparalleled precision and consistency and are widely used throughout various industries. However, in certain situations, specifically biological or medical applications, rigid robots are unable to provide the adaptability and flexibility required to produce a beneficial outcome.

Soft robotics refers to the subfield of robotics related to developing and fabricating robots using compliant, tractable materials. Soft robots lack rigid joints or a constrained, fully mechanical body. In combination with their compliant materials, soft robots have infinite degrees of freedom and can easily conform to any shape or surface. Benefits of soft robotics include increased flexibility and range of motion, superior biomimicry, and gentler, safer interactions with humans. This review paper investigates the applications of soft robotics in the biomedical field, including prostheses, assistive and drug delivery devices, soft surgical tools, and body-part simulators. The paper compares attributes of rigid and soft robots to examine specific advantages for each of these categories. It highlights the limitations of biomedical soft robotics covering functionality, durability, reliability. Finally, the paper discusses prospects and promising technologies intersecting soft robotics and the biomedical field.

Introduction

The employment of robots has expanded during the past century to practically every industry. Robotics can be used in a wide range of situations, including transportation, agriculture, and production lines. Robots are a useful tool in our daily lives since their primary function is to reduce the need for manual labor and to improve accuracy and efficiency. Robotics are increasingly being designed and used in every industry thanks to technologies like artificial intelligence, miniaturization, and computer power.

In the past few decades, the field of medicine has seen a drastic increase in the use of robots to aid with diagnosis and treatment. Medical robots are well known for their roles in surgery, where computers, and software accurately manipulate surgical instruments through one or more small incisions for various surgical procedures (Alexander, 2020). Such robots in the surgical field enable the surgeon to operate with high precision and control. For example, approved by the FDA in 2000, the da Vinci is said to have been used to perform over 6 million surgeries, worldwide. Patient benefits from robot-assisted surgery are largely those associated with the laparoscopic approach — smaller incisions, reduced blood loss, and faster recovery. Long-term surgical outcomes don't appear to be different from those of traditional surgery (Gyles, 2019). Surgeons benefit from improved ergonomics and dexterity in comparison with traditional laparoscopy. Various companies are developing surgical robots designed for a single specific procedure such as knee or hip replacement. Other companies are seeking to build systems that incorporate artificial intelligence to assist surgical decision-making (Sullivan, 2018). In neurosurgery, Modus V is an automated robotic arm and digital microscope built by a Toronto company and based on the space shuttle Canadarm technology (Holland, 2019). The arm tracks surgical instruments, automatically moves to the appropriate area in which the surgeon is working, and projects a magnified, high-resolution image on a screen. Prostheses are benefitting considerably from new structures and control systems. Robotic limbs with bionic skin and neural system are allowing a remarkable degree of user control. Robotic exoskeletons (orthoses) are finding use in rehabilitation, assisting paralyzed people to walk and to correct for malformations (Alexander, 2020). Robots are also finding a place in keeping hospitals clean as hospital rooms are being disinfected with the use of high intensity UV light applied by a robot (Gyles, 2019).

Currently, most machines used in the medical field are rigid. The Da Vinci machine used for surgeries - the CyberKnife System, the TUG, Modus V - conduct life changing services and provide medical professionals with unparalleled precision and accuracy. However, in various biological and medical applications, rigid robots fall short. For one, the human body is made of soft tissue, requiring soft materials to replicate bodily functions and processes. Prosthetics and assistive devices also must contain some flexible, soft materials in order to replicate the natural human body to the highest degree. Over 6,000 people die annually while awaiting organ transplants (Stutter, 2022). The current organ shortage has led to various companies attempting to produce artificial organs, which has led to the rise of soft robots in the medical field (Yang et al., 2018). Even in surgery, certain procedures will benefit from softer robots. Endoscopy involves inserting a thin, flexible tube called an endoscope through the digestive system or circulatory system for diagnosis or stent placement. Due to the inflexibility of rigid robots, patients are more likely to face injury during such surgical procedures as the rigid materials are more dangerous when encountering the human body. When it comes to flexibility, range of motion, biomimicry and artificial organ production, safer interactions with humans, and even certain medical procedures, rigid robots fall short.

Soft Robotics

Soft robots lack rigid joints or a constrained, fully mechanical body, and in combination with their compliant materials, soft robots often have infinite degrees of freedom (directions of movement/deformation) and easy conformity to any shape or surface. Flexibility, versatility, biomimicry, increased range of motion are all benefits of soft robotics. However, despite these benefits, soft robotics has its shortcomings as well.

Soft robots are typically unable to withstand heavy loads and large quantities of actuation (Ashuri, et al., 2020). Plus, due to their infinite degrees of freedom, soft robots pose challenges with precise controls and movements. Another distinct challenge in developing soft robotic systems is accurately modeling their behavior. Traditional, rigid robots are modeled with relative ease as they have discrete joints and limited directions of movement. Soft robots are designed to continuously deform so modeling their behavior when there are countless variables and infinite degrees of freedom, is a difficult task (Ashuri, et al., 2020).

Soft robotics is gradually impacting several industries across the globe, especially promising in replicating biological systems and solving problems in the medical field. One major advantage of soft robots is the capability of distributing forces evenly over large surface areas of contact (Ashuri, et al., 2020). This prevents damage caused by high forces concentrated at only a few points of contact. Due to this property, soft robotics allow for far safer interaction with humans than rigid robots. Soft robots are so coveted due to their multifaceted applications, morphing behavior, biomimicry capabilities, gentler handling and gripping, and versatility. (Cianchetti et al., 2018)

Soft Robots in Medicine

For the past few decades, robots have been used in the biomedical area, but more recently, the use of soft matter in robotics has enabled new robot capabilities that offer up possibilities for biomedical applications where a gentler interaction with a patient is desired. Robots, for instance, can operate within the human body during surgery and endoscopy, and can also physically interact with patients during rehabilitation and aid. Robotic devices can be embedded inside or on the skin for drug delivery. Robotic technologies can be employed as prosthetics to replace human limbs, artificial organs, and body-part simulators to replicate human body parts. Biocompatibility and biomimicry are key considerations for soft robotics in biomedical engineering. (Cianchetti et al., 2018).

To ensure system functionality and body acceptability, soft robotics materials must be compatible to a certain extent with human body and tissues; nevertheless, the degree of compatibility will vary depending on the specific biomedical application. Allergies and touch reactions must be considered for infrequent exterior usage; acute immunological responses must be taken into consideration for brief internal use, and long-term implantation of soft robotic devices impacts the long-term immune response and may potentially result in rejection (Cianchetti et al., 2018). Additionally, the materials must, to some extent, mimic the mechanical characteristics of human tissues. For instance, replicating the mechanical characteristics and operation of human tissues is necessary for the application of soft robots as prostheses, organs, simulators, or implantable replacements.

Table 1. Comparison between soft robots and rigid robots.

Soft Robots	Rigid Robots
Made of soft, flexible, compliant materials	Made of hard materials with rigid physical properties
Infinite degrees of freedom, flexibility to navigate the human body	Finite degrees of freedom consisting of joints; specific movements typically aligned with joints in the human body
Low degree of precision - For surgery? Endoscopy? - Why is the precision needed?	High degree of precision - For surgery?
Distributes high forces over large surface area	High forces applied to one singular area of contact
Superior biomimicry capabilities	Inferior biomimicry capabilities
Superior biocompatibility	Inferior biocompatibility
Safer for human interaction - Patient interaction and safety	Unsafe and potentially dangerous for human interaction - Rigid materials can harm patient's tissues
Relatively lower fabrication cost	Higher production cost
Applications in surgery, endoscopy, artificial organ production, rehabilitation, drug delivery	Applications in surgery, rehabilitation, drug delivery, diagnostic equipment
Broader, more acceptable applications	More streamlined goal and applications

Soft Robotics in Surgery

Surgery has significantly improved during the past 30 years, switching from open surgery to minimally invasive procedures that provide advantages including better safety and reduced access trauma, leading to rapid recovery and little scarring (Fearon). The success of Intuitive Surgical's da Vinci surgical robot demonstrates how robotic technologies can help surgeons increase their accuracy, predictability, and consistency by giving the tip of the instrument more dexterity and enabling precise movements; however, this procedure still calls for rigid and inflexible tools (Blog, 2017). Contrarily, flexible tools can be utilized with minimally invasive surgery (MIS) methods and have a high intrinsic level of flexibility; yet, they are usually long, flexible, and have a swiveling tip, indicating that they may also have a limited range of motion once they are at the surgical site. Additionally, they are unstable and have limited force capabilities. In order to achieve precision in surgery, stiff tools, traditional mechanical coupling, and cable-actuated devices are typically used. Endoscopy and catheter-like procedures require flexible, less precise devices in order to navigate over challenging terrain, avoid obstacles, and harm distant organs.(Cianchetti et al., 2018).

Both strategies are merged in the realm of surgical endoscopy, making endoscopic operations as precise and efficient as conventional MIS procedures. Devices for endoscopy and surgery are utilized for urgent procedures, not for long-term uses. As a result, the device must have adjustable stiffness, organ compliance, and overall safety, but long-term immunological response to the soft robotic device is not a concern (Cianchetti et al., 2018).

Minimally invasive surgery (MIS), particularly in abdominal procedures, has elevated to the position of industry standard. Minimally invasive procedures, endoscopy and catheter procedures require flexibility and softer materials (Tse et al., 2018). With minimally invasive procedures, endoscopy and catheter procedure, flexible fluidic actuators, shape memory alloys, pneumatic balloon actuators, even integrating soft-bodied robots into the da Vinci surgical system to combine flexibility with precision, can drastically improve the safety for endoscopic procedures. Robotics capable of self-propulsion have been proposed to improve colonoscopy and other endoscopic procedures (Cianchetti et al., 2018).

References

Alexander, D. (2020). *15 Medical Robots That Are Changing the World.* https://interestingengineering.com/health/15-medical-robots-that-are-changing-the-world

Alici, G. (2018). Softer is Harder: What Differentiates Soft Robotics from Hard Robotics? *MRS Advances*, *3*, 1557-1568.

Ashuri, T., Armani, A., Jalilzadeh Hamidi, R., Reasnor, T., Ahmadi, S., & Iqbal, K. (2020). Biomedical soft robots: current status and perspective. *Biomed Eng Lett*, *10*(3), 369-385. https://doi.org/10.1007/s13534-020-00157-6

Blog, C. W. E. (2017, December 28). 5 Medical Robots Making a Difference in Healthcare. https://online-engineering.case.edu/blog/medical-robots-making-a-difference

Cianchetti, M., Laschi, C., Menciassi, A., & Dario, P. (2018). Biomedical applications of soft robotics. *Nature Reviews Materials*, *3*(6), 143-153. https://doi.org/10.1038/s41578-018-0022-y

Fearon, R. *Learn More About the Soft Robots that are Changing the Field of Robotics*. Warner Bros. Discovery, Inc. Retrieved October 9th from https://www.discovery.com/technology/soft-robotics

Gifari, M. W., Naghibi, H., Stramigioli, S., & Abayazid, M. (2019). A review on recent advances in soft surgical robots for endoscopic applications. *Int J Med Robot*, *15*(5), e2010. https://doi.org/10.1002/rcs.2010

Gorissen, B., Reynaerts, D., Konishi, S., Yoshida, K., Kim, J.-W., & De Volder, M. (2017). Elastic Inflatable Actuators for Soft Robotic Applications. *Advanced Materials*, *29*(43), 1604977. https://doi.org/https://doi.org/10.1002/adma.201604977

Gyles, C. (2019). Robots in medicine. *PubMed Central.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6625162/

Holland, M. (2019). Modus V brings robotic assistance to neurosurgery. Retrieved October 21, 2022, from https://www.techtarget.com/searchhealthit/feature/Modus-V-brings-robotic-assistance-to-neurosurgery

Rastogi, N. (2022). *Soft Robotics: Robots Featuring Biological Movements*. WTWH Media LLC. Retrieved October 9th, 2022 from https://www.engineersgarage.com/soft-robotics-robots-featuring-biological-movements/

Rus, D., & Tolley, M. T. (2015). Design, fabrication and control of soft robots. *Nature*, *521*(7553), 467-475. https://doi.org/10.1038/nature14543

Song, W.-K. (2016). Trends in rehabilitation robots and their translational research in National Rehabilitation Center, Korea. *Biomedical Engineering Letters*, *6*(1), 1-9. https://doi.org/10.1007/s13534-016-0211-9

Stutter, D. (2022). The Organ Shortage. Retrieved October 22, 2022, from https://www.aier.org/article/the-organ-shortage/

Sullivan, F. (2018). Robot-Assisted Surgery. Retrieved October 20, 2022, from https://aabme.asme.org/posts/robot-assisted-surgery

Tse, Z. T. H., Chen, Y., Hovet, S., Ren, H., Cleary, K., Xu, S., Wood, B., & Monfaredi, R. (2018). Soft Robotics in Medical Applications. *Journal of Medical Robotics Research*, *03*(03n04), 1841006. https://doi.org/10.1142/s2424905x18410064

Yang, G.-Z., Bellingham, J., Dupont, P. E., Fischer, P., Floridi, L., Full, R., Jacobstein, N., Kumar, V., McNutt, M., Merrifield, R., Nelson, B. J., Scassellati, B., Taddeo, M., Taylor, R., Veloso, M., Wang, Z. L., & Wood, R. (2018). The grand challenges of <i>Science Robotics</i>. *Science Robotics*, *3*(14), eaar7650. https://doi.org/doi:10.1126/scirobotics.aar7650

Zürich, E. (2019, January 24th, 2019). *WEF19 | SAM - The Soft Robotic Hand*. https://www.youtube.com/watch?v=T7cRbpIhgsI