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# Perspectives of Soft Robotics in Medicines

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**Abstract**

Engineers design flexible machines for application in a range of industries, including surgery, prosthetics, pain management, and space exploration, in the rapidly increasing subject of soft robotics. When a robot is made of materials with Young's modulus on the order of 104 to 109 Pa, which is comparable to Young's modulus of human soft tissues, it is said to be soft. Their movements show how closely they are related to people, animals, and plants. Wearable soft robots, artificial limbs, and muscle robots made out of origami are some of the most exciting potential applications for soft robotics. Each field generally focuses on biomimetics, however once created, these technologies have a wide range of beneficial applications. The use of flexible and soft materials for the robot body is a new area of research.

***Keywords:*** *Articulated robots, Prosthetics, Soft tools, Soft robotics*

## INTRODUCTION

In scenarios when the kinematic characteristics of the system are not known in advance, such as dealing with objects of unknown shape and size, traveling across uneven terrain, and coming into contact with living cells and human bodies, soft robotics has the potential to function well (Ashuri et al ., 2020). The six most prevalent categories of robots are articulated robots, humanoids, cobots, autonomous mobile robots (AMRs), automated guided vehicles (AGVs), and hybrids. (Mudhivarthi and Thakur, 2022)

In scenarios when the kinematic characteristics of the system are not known in advance, such as dealing with objects of unknown shape and size, traveling across uneven terrain, and coming into contact with living cells and human bodies, soft robotics has the potential to function well. (Li et al., 2019)

Through a very slow structure-building process, which includes the smooth replacement of water in predesigned hydrogels with glycerol and thermal annealing while maintaining the structures and functions of the original hydrogels, GGs with extremely protected intra- and intermolecular networks are created (Mredha et al., 2023). As proofs-of-concept, four distinct

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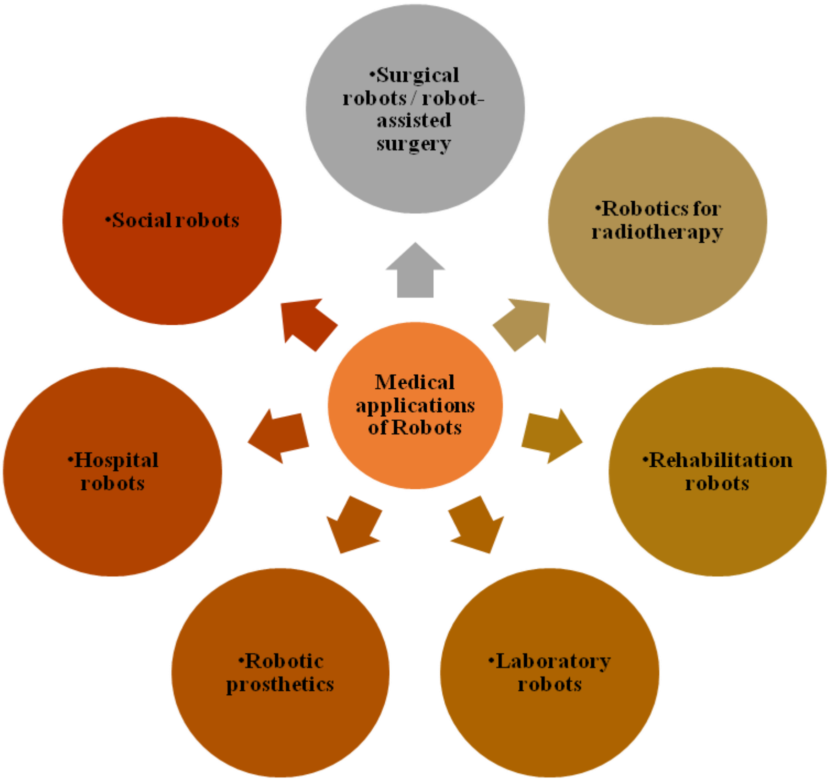
GGs are created utilizing various crosslinkers and polymers. In addition to having a wide variety of stiffness, strength, stretch ability, and toughness values, GGs also have the capacity for elasticity, plasticity, hysteresis, and self-recovery (Mredha et al., 2023). The GGs' electrical patentability, self-weldability, and application traits as electrolytes and supercapacitors illustrate their complicated 3D designability and simple functionalization capability elements.

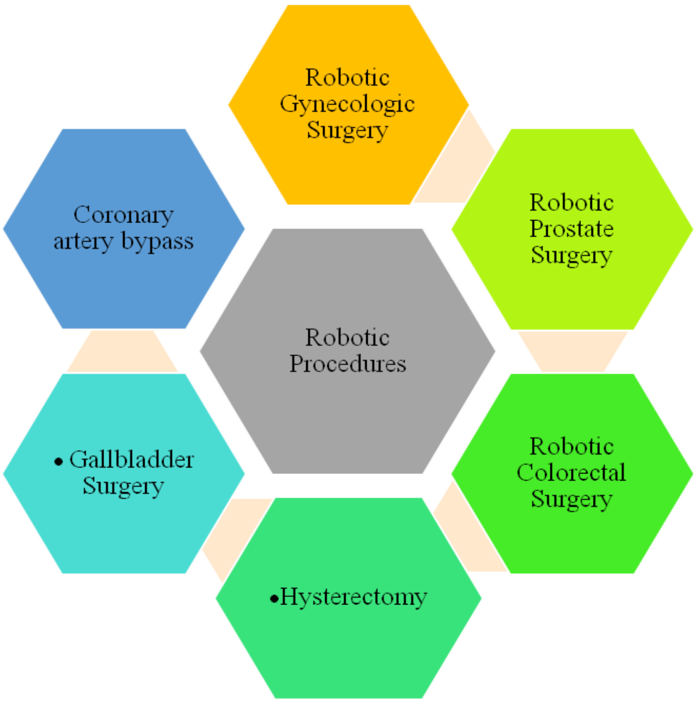



The proposed technology can be used to create a variety of flexible, stretchable, and extremotolerant devices for use in soft robotics, electrical/electronic, and biological applications. Because they enable chemists and materials scientists to join the core group creating a new subject, soft robots are so special (Mredha et al., 2023). Biomedical applications for soft robotics include tissue-imitating active simulators for training and biomechanical investigations, wearable and assistive devices, prostheses, artificial organs, and soft tools for surgery, diagnosis, and drug delivery (Cianchetti et al., 2012).

Since a few decades ago, 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 soft interface with a patient is sought. (Banerjee et al., 2018) Finally, robotic devices can be embedded inside or on the skin for drug delivery. Robotic etechnologies can be employed as prosthetics to replace human limbs, artificial organs, and body-part simulators to replicate human body parts. Soft robotics in biomedical engineering must take biocompatibility and biomimicry into account. (Hsiao JH et al., 2019) To ensure system functionality and body acceptability, soft robotics materials must be somewhat compatible with the human body and tissues; nevertheless, the degree of compatibility will vary depending on the specific biomedical application. (Majidi, 2014). Allergies and touch reactions must be considered for infrequent exterior usage; immediate immunological responses must be considered for intermittent internal use; and long-term implantation of soft robotic devices impacts the long-term immune response and may result in rejection. Additionally, the materials must, to some extent, mimic the mechanical characteristics of human tissues. Simulators, prostheses, or implantable replacements, for example, are required to replicate the mechanical properties and functionality of human tissues in order to use soft robots as organs. (Zrinscak et al., 2023).

**Soft Robotics in Surgery**

Over the past 30 years, there has been a significant advancement in surgery, moving from open surgery to minimally invasive methods that offer benefits like increased safety and reduced access trauma, leading to quicker healing and scar minimization. Minimally invasive surgery (MIS), particularly in abdominal procedures, has elevated to the position of industry standard.




In order to execute surgical procedures during MIS, two to three long, rigid tools are often inserted into the insufflate abdomen through tiny incisions (approximately 10-15 mm in diameter). These tools are used in conjunction with a rigid laparo endoscope for endoscopic vision. (Cho et al., 2010)

- During other operations (such as single-port laparoscopic surgery), the patient's navel receives a single, bigger incision (between 20 and 40 millimetres) through which a number of semi-flexible tools are inserted. This strategy lessens the requirement for abdominal access ports, but it may cause triangulation and tool encumbrance issues. In order to better access the target organs through natural orifices. (Blanco 2017).
- MIS can potentially be used in conjunction with particular procedures. For instance, to puncture the interior wall of an organ, a flexible endoscope with numerous tiny tools on the tip is inserted into a natural opening, like the mouth, vagina, or anus. Natural orifice transluminal endoscopic surgery (NOTES) is the name of this procedure. (Runciman et al., 2019)

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The path to the surgical target can be impeded in all conventional MIS operations by the presence of organs or anatomical structures. Soft robotics applications in biomedicine thus make it possible to construct soft machines and devices at various scales. Soft robots are particularly intriguing for medical applications because to their compliance dealing and mechanical characteristics. Different levels of biocompatibility and biomimicry are necessary for soft materials used in robots depending on the extent of interaction with people. (Cianchetti et al., 2018)

The success of the da Vinci surgical robot (Intuitive Surgical) serves as an example of how robotic technologies can assist surgeons in improving their accuracy, predictability, and repeatability by restoring the intuitiveness of the procedure and by providing additional dexterity to the tip; however, this procedure still requires rigid and inflexible tools, with the exception of wrist articulation. (Bartneck et al., 2021) Flexible tools, in contrast, can be used in conjunction with MIS techniques and have high intrinsic flexibility, although they are frequently lengthy and flexible with a swivelling tip, suggesting that they also have limited dexterity once they are at the surgical site. Additionally, they lack stability and have a limited capacity for force.

In surgery, stiff tools, conventional mechanical coupling, and cable-actuated devices are primarily used to achieve precision. Flexible instruments that are less exact but more appropriate are needed for endoscopy and catheter-like treatments in order to manoeuvre over difficult terrain and avoid barriers in order to access distant organs. 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 utilised for urgent procedures, not for long-term uses. As a result, the device must have tuneable stiffness, organ compliance, and general safety. (Jones, 2013). However, the long-term immunological response to the soft robotic device does not pose a problem.

The most promising techniques include new routing approaches to cable-driven flexible mechanisms, smart materials, and flexible fluidic actuators (FFAs) (Zhang and Lu, 2020). Active soft actuation technologies have been investigated to implement flexibility, accuracy, safety, and dexterity in soft surgical tools. In the case of external positioning of the motors, cable-driven approaches have the advantages of being lightweight and easily miniaturised, but they are typically expensive, have sterilisation issues, and have mechanical limitations like fatigue, nonlinear friction, backlash hysteresis, and inadequately transmitted forces. (Laschi et al., 2016) Smart materials have been investigated not just for conventional endoscopic or surgical procedures but also for catheter-like treatments that call for miniaturisation since they address some of these problems. (Dong et al., 2022)

For instance, shape memory alloys (SMAs) have been thoroughly studied due to their exceptional properties, including their high corrosion resistance, biocompatibility, and non-magnetic behaviour. (Dutta et al., 2022) They also have a high energy density, can exert localized forces, and can be made in a variety of shapes and sizes (Balasubramaniyan et al., 2022). Furthermore, due to their operating principle, they perform better and faster when arranging small wires, maximizing heat exchange and minimizing the current needed for the Joule effect. Many catheters, active endoscopic capsules, and one-shot miniature surgical

tools (Ovesco) have been developed in an effort to find the best compromise between actuation speed and controllability. (Cianchetti et al., 2018)
However, SMAs have quite a few severe limitations, including limited strain, low speed, control issues, and the requirement of high currents to reach the activation temperature. Thus, SMAs, often referred to as 'muscle actuators' because of their bio-like overall performance, have been increasingly used in their super elastic configuration. In this form, the alloy is in the elastic phase at normal working temperature and therefore able to recover its shape once the external load (producing a plastic-induced phase) is removed. The visible behaviour seems super elastic because the material appears to return to its shape after very large bending, which normally produces plastic deformation.
Superelastic materials have been applied in cannula-like and continuum robots. (Wang., 2022) These medical devices expand the working space and extend the reach of small-diameter catheters. They are made up of super elastic concentric tubes that are moved into each other by external motors to create bent configurations that can reach far places. Because they contain rigid metals or alloys, the size of which is not altered in response to external forces, such robots cannot be considered soft. (Cianchetti et al., 2018)

Force–contact sensors can be further integrated to control the interaction forces between the medical device and tissue. FFAs, which are based on soft and shrinkable materials, address many of the aforementioned limitations. First used in colonoscopy, FFAs made of pneumatic bellows enable self-propelled locomotion, and FFAs made of expanding balloons increase the friction between the device and the intestine walls. Such systems have been integrated into inchworm-like active colonoscopy systems. (Wang., 2022)

Current FFAs have many advantages for use in surgical devices.

- Because they are elastomeric and don't require a direct electric source, they can be used in environments with magnetic fields and radioactivity, which makes them suitable for magnetic resonance imaging.
- Since there is no stiff motion, leakages from the chambers that come into contact with tissues can be kept to a minimum.
- FFAs can move in intricate ways with a minimal number of pieces. They are constructed of biocompatible substances. Their compliance lowers the possibility of injury and enables safe interaction with the nearby organs and tissues.
- Pressurised gas-powered FFAs are safe to activate because they can be inflated at low pressure and are lightweight.
- • Rigidity controls are made possible by combining FFAs with other semi-active actuation technologies. These systems can dexterously reach the surgical site thanks to their soft construction, but they can also take advantage of the adjustable rigidity to stabilise the configuration and improve the robot's stability for force transmission.

FFAs have been employed in surgical tools, manipulators, and actuators for cannula robots and needle insertion. By integrating several chambers that may be pressurised differentially, small catheters and manipulators can be created.

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A cylinder made of silicone rubber reinforced with nylon fibres that is circularly deposited to create three internal chambers that may each be separately inflated is the foundation of the flexible micro-actuator (FMA), which was first introduced in 1991. (Shapiro, 2103). An alternative is to have the chambers function in opposition to a central, flexible spine, which establishes a neutral axis for the bending moment of the chambers. Based on a similar idea, a surgical manipulator with omnidirectional bending and elongation capabilities can be created. In this technique, a cylindrical silicone body is embedded with three fluidic chambers but no internal spines. when a result, the length increases when all three chambers are simultaneously inflated. (Cianchetti et al., 2014). A bellows-shaped sleeve or inextensible threads wrapped around the person can contain the system. (Kan et al., 2022)

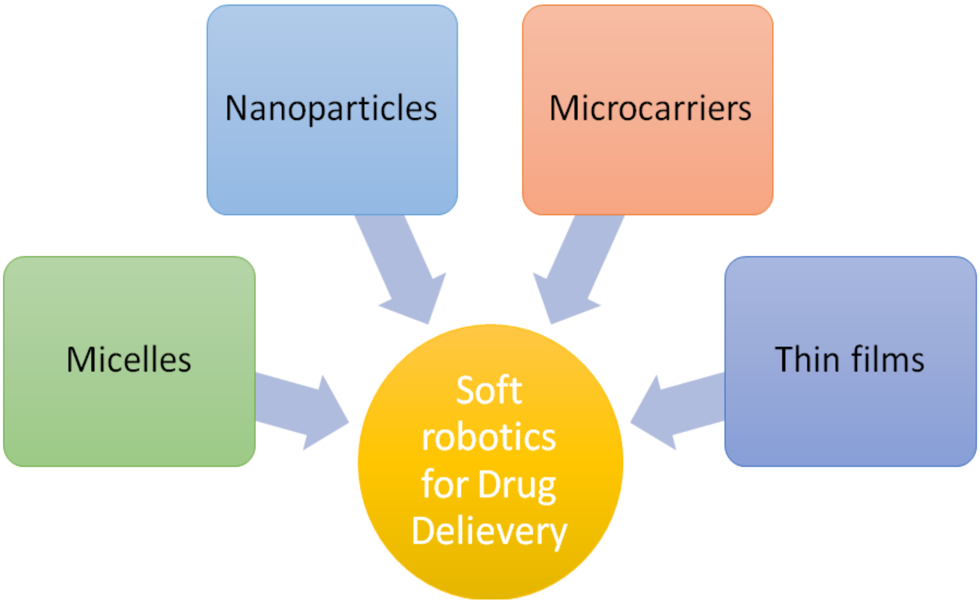
The device can be built using an anisotropic material composition as an alternative to differential pressurisation. For instance, pneumatic balloon actuators (PBAs) are constructed from two flexible films: the lower hard (but still flexible) polyimide film serves as the substrate, and the upper silicone rubber film serves as a membrane. In order to produce a hollow that can be expanded, the two films are adhered together. (Hartmann et al., 2021) Due to the bending moment produced by the silicone membrane's tensile forces when under pressure, the polyimide film bends. A significant out-of-plane vertical displacement is produced by this behaviour. The most researched actuation mechanism for fluidic-driven devices is bending.

Due to the presence of radially and vertically oriented fibres and the connection of two FFAs with a rotational joint, fluidic pressure can also be used to create torsion in surgical micromanipulators. FFAs can also be utilised to create flexible and useful instruments, such grippers. (Luan and Zhang, 2021) A plate placed along the path of a bending FMA, a number of bending actuators coupled at the base, or a linear fluidic soft actuator to activate a conventional metallic claw are a few examples of FFA-based grippers. (Hartmann, 2021) Task tools like retractors and forceps have been supported by the bending action of FFAs. Despite the ideal properties of FFAs, issues related to miniaturization and control have hampered their wider use in surgery thus far.

**Soft Robotics for drug delivery**

Endoscopic and surgical tools cannot be employed if the target location for therapy is very far away, such as for the inner portions of the brain, liver, or pancreas, or if the therapy is dependent on the chronic release of a drug by implantable devices (Joyee and Pan, 2020). Wired surgical tools are unable to deliver medications with exact administration profiles or navigate through the vasculature to reach small target locations (Nguyen et al., 2021). Hydrogels and other biocompatible and biodegradable materials are the basis of many soft materials used in soft robotics for medicine administration. These materials break down over time to release their contents. The reach frequently relies on systemic injection, which has limited effectiveness, and the release profile can only be tuned to a limited extent.

The medicine can be released either passively or actively utilising such soft robots, for instance by employing external stimuli like magnetic fields, ultrasound, or temperature. (Chung et al., 2021) Thin films, micelles, nanoparticles, and microcarriers can all be utilised as drug delivery systems.




Thin-film technology was initially developed in the 1970s with the goal of removing difficulties related to swallowing tablets and capsules. Thin films are made up of layers of conformable material that range in thickness from a few nanometers to hundreds of micrometres. A few of the special characteristics of thin films include their great flexibility, non-covalent adhesiveness, molecular permeability, vast surface area, high aspect ratio, and high drug-loading capacity. By incorporating nanofillers, such as magnetically or optically responsive particles within thin films, a generally inert polymeric material can be turned into a responsive matrix that can be remotely controlled. As a result, the materials' abilities to implement material responses are improved. (Zhao et al., 2015)

. Traditional (passive) release frequently uses monotonic drug delivery, which might generate unfavourable tissue reactions due to high drug concentrations (Vannozzi et at., 2018). A long-term treatment, for instance, for chronic diseases, is made possible by active medication release by external stimuli because it provides for the temporal and spatial regulation of drug release and dosage. In the last four to five years, the field of soft micro-robotics has investigated microscale hydrogel drug delivery systems with magnetic particles. Such sensitive nanomaterials can be used for diagnostics or therapy, and using a soft shell lowers the body's immunological reaction. For the targeted, on-demand delivery of biological agents, an untethered, self-folding, soft micro-robotic platform incorporating several features can be deployed.

Within a bilayer hydrogel matrix that reacts to near-infrared light are magnetic alginate microbeads in this device. When the surrounding temperature hits 40 °C, the hydrogel structure is supposed to open and release the beads after sealing and safeguarding them. The creation of soft microgrippers that can self-fold and have thermomagnetic responsiveness followed a similar methodology. The photo-crosslinked soft hydrogel is given a stiff segmented polymer (polypropylene fumarate) to increase grabbing capabilities. Iron oxide nanoparticles are also incorporated to allow for remote magnetic steering. Such methods have been researched for a long time, but soft micro-robotics is only recently being used to group them together since various scientific communities are looking into connections with soft robotics for example, regarding scalable biohybrid actuators. Moreover, traditional lithography has been partially replaced by fabrication technologies that are based on soft materials, including silicones and a variety of other polymers as well as hydrogels, enabling the fabrication of various shapes of soft devices at the microscale. (Kim and Zhao., 2022)

**Soft robotics in Rehabilitation**

Rehabilitative Robots offer a practical answer to the demands of an aging society. Robotic help in rehabilitation is useful for administering therapy and for regaining motor function. The value of adaptive systems for upper limbs was recognized in 1958 by Dr. Joseph McKibben, who created an assistive device based on fluidic actuators (which bears his name) to restore the motion of his young daughter's polio-paralyzed hand. Active adaptive systems, as opposed to passive approaches, are important for assisting or replacing lower limbs. Systems for assistance and rehabilitation have the same difficulties in directing limb mass displacements by applying the required force. (Chu and Patterson., 2018)

Systems that interact closely with the user must also be reliable, safe, and able to exert force (typically greater than the user's force) without harming the patient. robotic soft wear. Active adaptation can be achieved utilising soft robots made of materials with inherent adaptive properties or by applying compliance and impedance control on robots based on rigid linkages (Connolly et al., 2015). In order to take use of their inherent changeable stiffness, biomimetic techniques, such as muscle-like active technologies, such as electroactive polymers (EAPs), SMAs, and FFAs, have been used. (Polygerinos et al., 2015)

Robotic systems for rehabilitation and assistance gradually evolved from rigid interfaces connected through bioinspired actuators to entirely soft wearable systems, with active adaptable parts designed to remain in close contact with the user, with the advent of dependable and effective soft mechatronic devices. In order to support ankle and hip rehabilitation for ambulation, simple assistive devices for the lower limbs are built on stiff interfaces and rotational joints that are fastened to the patient's body and propelled by soft actuators, such as McKibben-like actuators. Different soft actuator types, such FFAs, whose restraining strategy relies on straight, inextensible fibres, can be interfaced with using the same method. (Wang, 2022)

SMAs can also be used in assistive devices (like SHADE and Leia) to encourage ankle dorsiflexion, but these devices have the disadvantages of having large amounts of inertia that restrict human motion and requiring precise joint alignment with the user's joints to avoid unnatural loads that could harm cartilage (Heng et al., 2022). These problems can be solved without the use of external rigid structures by using soft and lightweight actuators that are in close touch with the user's skin and directly utilise human joints. SMA actuators must be isolated since they are thermally activated when in contact with the human body. (Wang, 2022)

Additionally, to increase the response time and working frequency, more interfaces and equipment are frequently required. As an alternative, pneumatic actuators can be used to create more wearable and conformable robotic systems for the treatment of the ankle and foot (Asbeck et al., 2014). Based on this idea, a whole-body soft exosuit for gait aid has been developed employing cable-driven mechanisms, exploring cutting-edge textile materials that transmit assistive torques without the need for rigid exterior structures. Due to their organic

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movement and ability to expand in reaction to user movement, these garments passively create supportive forces for specific tasks without confining the wearer (Kian et al., 2022).

For force and deformation sensing, many sensors can be integrated into wearable technology; elastomer-based sensors, for instance, have been successfully mounted and tested on a soft exosuit (Souri et al., 2020). In an elastomeric chamber, liquid metal is used to create these sensors. A change in the chamber's cross-section caused by elongation affects the sensor's longitudinal electrical resistance. For upper limbs, platforms based on stiff linkages have been investigated together with the addition of soft actuators. These systems have the advantage of adjustable compliance, offering a wide range of capabilities, safety, and lightweight, and can be operated by pneumatic artificial muscles. (Cianchetti et al., 2018)

However, the majority of efforts have been directed to recovering hand functionality. Soft systems have also been designed for individual body regions, such as the wrist, elbow, shoulders, and single fingers (Pérez et al., 2021). Hand gadgets are frequently designed like gloves to take advantage of the patient's joints. With the help of this method, the patient can bend their fingers with sufficient force to carry out assistive or rehabilitation duties. These technologies, like the use of EAP67, however, demand high voltages, which can be harmful to the user. As a result, tendon-driven and pneumatic actuators are being considered as alternatives. By using an integrated cable system to open and close the patient's hand, gloves can also function as exomusculature. (Cianchetti et al., 2018)

Tensile forces produced by servomotors (located in a backpack) are applied to the fingers via a Bowden system to help with extension and flexion. To maximize comfort, each cable is routed through a certain type of guide. Five servomotors drive ten tendons in total, separately activating each finger to retain the flexibility of the design (the same motor is used for both flexion and extension). The Exo-Glove, based on the same idea but with fewer necessary tendons, is a less comprehensive but more optimised system that couples the movements of two fingers through an infra-interdigital under-actuated mechanism.

The middle and index fingers have a single tendon that runs down them, passing through U-shaped tubes that serve as pulleys. Both fingers experience the same tendon shortening and strain since they travel along the same path. When the glove comes into touch with uneven surfaces, the mechanism allows for adaptation between the phalanxes on the same finger and between the two fingers. The use of two fingers provides a more secure grasp when combined with the thumb. (Tiboni and Amici 2022)

Exo-Glove Poly is an enhanced version of this concept that totally replaces the textile components with elastomers for simple sanitization. The fundamental disadvantage of systems based on cables is similar to that of surgical instruments: friction and interference from the wearer's body make it difficult to efficiently transmit the force produced by the servomotors to the end of the kinematic chain (in this case, the fingers). To reduce routing, there is an alternative: pneumatic actuators. The placement of tubes is flexible as long as they deliver compressed air to the fluidic chambers because the main transducer (the air compressor) also functions remotely. (Cianchetti et al., 2018)

For instance, the Pneuglove glove has five polyurethane chambers that are positioned along the fingers on the palmar side of the glove. Chamber expansion is utilized to support digit extension in the device, which is intended for patients with residual control of finger flexion.

Additionally, 'wearable actuators' that are flexible fiber-reinforced have been suggested to restore flexibility. Similar to how soft robotic gloves are constructed, strings inserted in the silicone material are employed to limit the fluidic actuators' ability to expand so that the deformation occurs along the fingers. With internal patterning-based elastomeric pneumatic actuators, the first Pneu Nets prototype's flexion is achieved while restricting radial expansion. (Tiboni and Amici 2022)

Utilising fiber-reinforced fluidic actuators, improved systems (Yi et al., 2018). The performance of the entire system shouldn't be impacted by the inclusion of soft sensors in the glove for upper limb systems. For instance, by utilizing embedded sensorized actuators made up of soft pneumatic actuators and flexible strain sensors to detect bending through electric resistance fluctuation, a comprehensive solution for hand rehabilitation can be produced. These actuators' foundation is a thin layer of screen-printed silver nanoparticles on an elastomeric substrate, allowing for good conductivity and stretchability. additional soft assistance robots (Xiong et al., 2021). Rehabilitation equipment can also benefit from soft robotics' inherent advantages in independent systems.

In order to provide customizable stiffness in both clinical and home settings, a haptic device for hand neuromuscular rehabilitation has been developed (Sebastian et al., 2017). Based on a pneumatic soft structure constructed of extremely flexible materials, this handle drives the haptic interface. Pressure rise (in an open or closed loop) and the use of interchangeable sleeves that can be customised to incorporate materials of varied stiffness allow for the stiffness to be regulated (Yang et al., 2017). Tremor reduction techniques can also make use of soft robotics (Zahedi et al., 2021). For instance, the dynamically responsive intervention for tremor suppression (DRIFTS) (Manto et al.,2003) initiative seeks to create a wearable dynamic orthosis to suppress upper limb tremors without impairing natural mobility.

The tremor energy can be selectively reduced by using materials (magnetorheological fluids) that can alter their viscoelastic properties when magnetic fields are applied. Personal hygiene can be helped by assistive technology (QADER et al., 2019). Soft robots can interact with the user and work efficiently with them. A robotic shower, for instance, can assist users with bathing activities (Zlatintsi et al., 2020). Three cylindrical modules are connected in series to form the I-SUPPORT soft arm, a soft robot arm with omnidirectional bending capabilities. Each module is built around three pneumatic chambers in the form of tubes wrapped in a polymeric material and guided by a plastic braided structure to maximise elongation.

Transverse plastic discs give the overall structure its shape and distribute the three chambers' deformations along the longitudinal axis. Three cables allow for shortening, omnidirectional bending, and the ability to adjust the arm stiffness by acting antagonistically on the pneumatic chambers (Apsite et al., 2021). The material that interacts with the user can be customised to their tastes and is detachable, washable, and replaceable. Soft machines that resemble the human body Prostheses. Soft robotic technologies have the potential to significantly enhance the usability and acceptance of limb prosthesis (Heng et al., 2022).

For instance, upper limb prosthetics that use adaptive and effective grippers or hands with a limited number of control variables can offer amazing dexterity. Robotic manipulation performance has generally increased thanks to soft robotics. Compliance, for instance, can use mechanical intelligence to improve grasping abilities (Mutlu et al., 2016). Utilising soft

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mechatronic technology to distribute the required level of compliance is the key problem. Soft robotic technology have been used to create many artificial hands, but few of them have been created with prosthetics in mind.

Similar to assistive and rehabilitative devices, soft robotic prosthetics must be portable and controllable in order to be developed (Chu and Patterson 2018). As a result, similar technological options for prosthetic devices have been researched. For instance, prosthetic hands composed of soft or flexible materials can have their fingers flexed using cable-driven methods. With the help of finite element method (FEM) simulations, elastomeric fingers can be designed to have the best possible material properties (Polygerinos et al., 2013). Elastomeric fingers can be produced using the low-cost, reproducible 3D printing technique. This method has led to the conclusion that the best geometrical shape for a flexural hinge for a soft, monolithic robotic finger is a non-symmetric elliptical flexure hinge.

However, because to the limited selection of printable materials available in this instance, only one material with a specified elastic modulus has been examined. Although mouldings is slower and less repeatable than 3D printing, it nevertheless makes it possible to create a range of elastomers (Au et al., 2016). To best develop pneumatically propelled fingers, a study comparing various materials and fabrication techniques was conducted, considering both material characteristics and geometrical factors. To identify the segments that depict the phalanges and material portions, an actual human hand was first scanned (Tsutsui, 2022). Then, using finite element analysis and a genetic algorithm, the best material for each section was identified.

An easy method (there is only one free parameter, either pressure or cable displacement) to build a finger with human-like motion is made possible by the correct description of the geometries and material properties. From an aesthetic perspective, designing a prosthetic hand with fingers and a palm is crucial, but alternative successful methods of regaining grasping ability have also been suggested, such as a prosthetic terminal device based on jamming transition (Wang, 2022). A physical phenomenon called granular jamming depends on the interaction of granules encased in an elastomeric membrane (Shintake et al., 2018). When a vacuum is applied, the membrane covering the granular material collapses, stopping the relative mobility of the granules. This results in the stabilization of the system's structure and an increase in stiffness (Mazzolai et al., 2022).

Although in-hand manipulation is not possible, items can be handled and grasped quite well. However, this technology is limited in terms of portability and patient acceptance because pumps are required for vacuum generation and the object must be pushed in order to be gripped (Cianchetti et al., 2018). By actively or passively supporting the adaptation to body changes, soft robotic technologies can increase the conformability of conventional prostheses, such as artificial limbs made of stiff materials (Heng et al., 2022). A significant issue in wearing lower limb prosthesis is the socket between the mechanical limb and the stump's poor flexibility.

High interfacial stresses and volume fluctuations may be resolved by granular jamming, which could provide increased stiffness with rising limb volume, which often happens at softer tissue regions (Ibrahimi et al., 2021). Alternately, for lower limbs, particular delicate areas within the socket wall can be used to implant inflated actuators. The actuators can be operated in an open loop (externally or manually adjusted) or in a closed loop (via wearable sensors) (Lenne and Trivedi, 2022). They can be filled with gas (light) or liquid (heavier but easier to regulate).

**Applications of Soft Robotics in Rehabilitation**

| **S.No.** | **Area of Rehabilitation** | **Utilization** | **Developed by** |
|---|---|---|---|
| 1. | Elbow | Stroke patients with paralysis | Researchers of the University of Reading, U.K. and Ritsumeikan, University, Japan |
| 2. | Shoulder | Abduction and adduction in Stroke | Harvard University and Worcester Polytechnic Institute |
| 3. | Finger | Prevents contractures post-stroke | Tsuyama National College of Technology, Japan |
| 4. | Robotic Gloves | Functional grasp pathologies | Harvard University researchers |
| 5. | Robotic orthosis | Wrist rehabilitation | Harvard University researchers |
| 6. | Mandibular mobility disorders | soft robotic device along with a low-profile balloon-type soft pneumatic actuator (SPA) | National University of Singapore |
| 7. | Gait/ Foot/Ankle | Assistance with dorsiflexion/plantarflexion and inversion/eversion | Carnegie Mellon University, BioSensics, University of Southern California, Harvard University, Boston Children's Hospital |
| 8. | Knee | Assist with knee flexion and extension | Carnegie Mellon University and Harvard University |

## Conclusion

Soft Robotics is a field that has many wonderful potential applications. Truly, incredible capabilities are being sought and demonstrated in research and medicine all over the world. It is very difficult to build a device that is comparable to human body parts. Further, it is more problematic to design such a system that could perceive the stimulus and act accordingly. In contrast to this, robotics is filling an increasingly important role in enhancing patient safety and care. Robotics provides speed, accuracy, reliability, repeatability, and cost-effectiveness. Therefore, numerous steps are to be followed for further use and development of robotics as medical aid, for welfare of the society everywhere.

Since then, robotics has been included in radiotherapy and radiosurgery procedures. For instance, robotic treatment couches place the patient precisely before treatment. They also enable clinicians to move the patient from a distance without going into the treatment area.

Conditions affecting your bladder, prostate, heart, digestive system, and more can be treated using robotic surgery. Less blood loss, shorter hospital stays, and speedier recovery are all advantages. Compared to open surgery, robotic surgery has a number of advantages for patients, including a shorter stay in the hospital, reduced discomfort, and agony, quicker return to normal activities and healing, reduced risk of infection due to smaller incisions, reduced transfusions, and blood loss, hardly any scars. A high-definition three-dimensional camera and miniature devices are inserted into your body through tiny incisions made by your surgeon during a robotic surgery; occasionally, skin incisions are not even necessary. Your surgeon will then control those instruments to carry out the procedure from a nearby console.

**References**


- Apsite I, Salehi S, Ionov L. Materials for smart soft actuator systems. Chemical Reviews. 2021 Dec 27;122(1):1349-415.
- Asbeck AT, De Rossi SM, Galiana I, Ding Y, Walsh CJ. Stronger, smarter, softer: next-generation wearable robots. IEEE Robotics & Automation Magazine. 2014 Dec 18;21(4):22-33.
- Ashuri T, Armani A, Jalilzadeh Hamidi R, Reasnor T, Ahmadi S, Iqbal K. Biomedical soft robots: Current status and perspective. Biomedical Engineering Letters. 2020 Aug; 10:369-85.
- Au AK, Huynh W, Horowitz LF, Folch A. 3D- printed microfluidics. Angewandte Chemie International Edition. 2016 Mar 14;55(12):3862-81.
- Balasubramaniyan C, Rajkumar K, Santosh S. Enhancement of machining and surface quality of quaternary alloyed NiTiCuZr shape memory alloy through ultrasonic vibration coupled WEDM. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications. 2022 Apr;236(4):816-33.
- Banerjee H, Tse ZT, Ren H. Soft robotics with compliance and adaptation for biomedical applications and forthcoming challenges. Int. J. Robot. Autom. 2018 Jan 1;33(1):68-80.
- Bartneck C, Lütge C, Wagner A, Welsh S. An introduction to ethics in robotics and AI. Springer Nature; 2021.
- Cho JE, Shamshirsaz AH, Nezhat C, Nezhat F. New technologies for reproductive medicine: laparoscopy, endoscopy, robotic surgery and gynecology. A review of the literature. Minerva ginecologica. 2010 Apr 1;62(2):137-67.
- Chu CY, Patterson RM. Soft robotic devices for hand rehabilitation and assistance: a narrative review. Journal of neuroengineering and rehabilitation. 2018 Dec;15(1):1-4.
- Chung HJ, Parsons AM, Zheng L. Magnetically controlled soft robotics utilizing elastomers and gels in actuation: A review. Advanced Intelligent Systems. 2021 Mar;3(3):2000186.
- Cianchetti M, Laschi C, Menciassi A, Dario P. Biomedical applications of soft robotics. Nature Reviews Materials. 2018 Jun;3(6):143-53.
- Cianchetti M, Ranzani T, Gerboni G, Nanayakkara T, Althoefer K, Dasgupta P, Menciassi A. Soft robotics technologies to address shortcomings in today's minimally invasive surgery: the STIFF-FLOP approach. Soft robotics. 2014 Jun 1;1(2):122-31.

- Connolly F, Polygerinos P, Walsh CJ, Bertoldi K. Mechanical programming of soft actuators by varying fiber angle. Soft Robotics. 2015 Mar 1;2(1):26-32.
- Dhanda, P., Sura, S., Lathar, S., Shoekand, N., Partishtha, H., & Sethi, N. (2022). Traditional, phytochemical, and biological aspects of Indian spider plant.
- Dong X, Luo X, Zhao H, Qiao C, Li J, Yi J, Yang L, Oropeza FJ, Hu TS, Xu Q, Zeng H. Recent advances in biomimetic soft robotics: fabrication approaches, driven strategies and applications. Soft Matter. 2022.
- Dutta, S., Singh, A.K., Paul, B. and Paswan, M.K., 2022. Machining of shape-memory alloys using electrical discharge machining with an elaborate study of optimization approaches: a review. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *44*(11), p.557.
- Hartmann F, Baumgartner M, Kaltenbrunner M. Becoming sustainable, the new frontier in soft robotics. Advanced Materials. 2021 May;33(19):2004413.
- Heng W, Solomon S, Gao W. Flexible electronics and devices as human–machine interfaces for medical robotics. Advanced Materials. 2022 Apr;34(16):2107902.
- Hsiao JH,Chang JY, Cheng CM. Soft medical robotics: clinical and biomedical applications, challenges, and future directions. Advanced Robotics. 2019 Nov 2;33(21):1099-111.
- Ibrahimi M, Paternò L, Ricotti L, Menciassi A. A layer jamming actuator for tunable stiffness and shape-changing devices. Soft Robotics. 2021 Feb 1;8(1):85-96
- Jangra, Ujjwal. "INTERNATIONAL JOURNAL OF SCIENTIFIC INFORMATION."
- Jones P. Design for care: Innovating healthcare experience. Rosenfeld Media; 2013 May 1.
- Joyee EB, Pan Y. Additive manufacturing of multi-material soft robot for on-demand drug delivery applications. Journal of Manufacturing Processes. 2020 Aug 1;56:1178-84.
- Kan Z, Pang C, Zhang Y, Yang Y, Wang MY. Soft actuator with programmable design: Modeling, prototyping, and applications. Soft Robotics. 2022 Oct 1;9(5):907-25.
- Kaura, S., Parle, M., Insa, R., Yadav, B. S., & Sethi, N. (2022). Neuroprotective effect of goat milk. *Small Ruminant Research*, *214*, 106748.
- Kian A, Widanapathirana G, Joseph AM, Lai DT, Begg R. Application of wearable sensors in actuation and control of powered ankle exoskeletons: A Comprehensive Review. Sensors. 2022 Mar 14;22(6):2244.
- Kim Y, Zhao X. Magnetic soft materials and robots. Chemical reviews. 2022 Feb 1;122(5):5317-64.
- Kumar, A. In vitro evaluation of antimicrobial property of nanoparticles and chlorhexidine against Streptococcus pneumoniae.
- Kumar, A. In vitro evaluation of antimicrobial property of nanoparticles and chlorhexidine against Streptococcus pneumoniae.

- Kumar, R., Sethi, N., & Kaura, S. (2022). Bio-processing and analysis of mixed fruit wine manufactured using Aegle marmelos and Phoenix dactylifer.
- Laschi C, Mazzolai B, Cianchetti M. Soft robotics: Technologies and systems pushing the boundaries of robot abilities. Science robotics. 2016 Dec 6;1(1):eaah3690.
- Lenne PF, Trivedi V. Sculpting tissues by phase transitions. Nature Communications. 2022 Feb 3;13(1):664.
- Li S, Bai H, Shepherd RF, Zhao H. Bio- inspired design and additive manufacturing of soft materials, machines, robots, and haptic interfaces. Angewandte Chemie International Edition. 2019 Aug 12;58(33):11182-204.
- Luan H, Zhang Y. Programmable stimulation and actuation in flexible and stretchable electronics. Advanced Intelligent Systems. 2021 Jun;3(6):2000228.
- Majidi C. Soft robotics: a perspective—current trends and prospects for the future. Soft robotics. 2014 Mar 1;1(1):5-11.
- Manto M, Topping M, Soede M, Sanchez-Lacuesta J, Harwin W, Pons J, Williams J, Skaarup S, Normie L. Dynamically responsive intervention for tremor suppression. IEEE engineering in medicine and biology magazine. 2003 Jul 22;22(3):120-32.
- Mazzolai B, Mondini A, Del Dottore E, Margheri L, Carpi F, Suzumori K, Cianchetti M, Speck T, Smoukov SK, Burgert I, Keplinger T. Roadmap on soft robotics: multifunctionality, adaptability and growth without borders. Multifunctional Materials. 2022 Aug 23;5(3):032001.
- Milind, P., Sushila, K., & Neeraj, S. (2013). Understanding gout beyond doubt. *International Research Journal of Pharmacy*, *4*(9), 25-34.
- Mredha MT, Lee Y, Rama Varma AV, Gupta T, Manimel Wadu RR, Jeon I. Tardigrade-inspired extremotolerant glycerogels. NPG Asia Materials. 2023 Apr 7;15(1):22.
- Mudhivarthi BR, Thakur P. Integration of artificial intelligence in robotic vehicles: A bibliometric analysis. Paladyn, Journal of Behavioral Robotics. 2022 Jan 1;13(1):110-20.
- Mutlu R, Alici G, in het Panhuis M, Spinks GM. 3D printed flexure hinges for soft monolithic prosthetic fingers. Soft Robotics. 2016 Sep 1;3(3):120-33.
- Nguyen KT, Go G, Jin Z, Darmawan BA, Yoo A, Kim S, Nan M, Lee SB, Kang B, Kim CS, Li H. A Magnetically Guided Self- Rolled Microrobot for Targeted Drug Delivery, Real- Time X- Ray Imaging, and Microrobot Retrieval. Advanced Healthcare Materials. 2021 Mar;10(6):2001681.
- Pérez Vidal AF, Rumbo Morales JY, Ortiz Torres G, Sorcia Vázquez FD, Cruz Rojas A, Brizuela Mendoza JA, Rodríguez Cerda JC. Soft exoskeletons: development, requirements, and challenges of the last decade. InActuators 2021 Jul 19 (Vol. 10, No. 7, p. 166). MDPI.
- Polygerinos P, Lyne S, Wang Z, Nicolini LF, Mosadegh B, Whitesides GM, Walsh CJ. Towards a soft pneumatic glove for hand rehabilitation. In2013 IEEE/RSJ International Conference on Intelligent Robots and Systems 2013 Nov 3 (pp. 1512-1517). IEEE.

- Polygerinos P, Wang Z, Galloway KC, Wood RJ, Walsh CJ. Soft robotic glove for combined assistance and at-home rehabilitation. Robotics and Autonomous Systems. 2015 Nov 1;73:135-43.
- Poonam, D., Sethi, N., Pal, M., Kaura, S., & Parle, M. (2014). Optimization of shoot multiplication media for micro propagation of Withania somnifera: an endangered medicinal plant. *Journal of Pharmaceutical and Scientific Innovation (JPSI)*, *3*(4), 340-343.
- QADER İN, Mediha KÖ, DAGDELEN F, AYDOĞDU Y. A review of smart materials: researches and applications. El-Cezeri. 2019 Sep;6(3):755-88.
- Ranga, S. Green synthesis and evaluation of the antibacterial activity of Silver nanoparticles from Bambusa affinis leaves.
- Runciman M, Darzi A, Mylonas GP. Soft robotics in minimally invasive surgery. Soft robotics. 2019 Aug 1;6(4):423-43.
- Saini, Ashu. "Lycopene: A Review on Biological Properties."
- Sebastian F, Fu Q, Santello M, Polygerinos P. Soft robotic haptic interface with variable stiffness for rehabilitation of neurologically impaired hand function. Frontiers in Robotics and AI. 2017 Dec 20;4:69.
- Sethi, N., Bhardwaj, P., Kumar, S., & Dilbaghi, N. (2019). Development and Evaluation of Ursolic Acid Co-Delivered Tamoxifen Loaded Dammar Gum Nanoparticles to Combat Cancer. *Advanced Science, Engineering and Medicine*, *11*(11), 1115-1124.
- Sethi, N., Bhardwaj, P., Kumar, S., & Dilbaghi, N. (2019). Development and Evaluation of Ursolic Acid Loaded Eudragit-E Nanocarrier For Cancer Therapy. *International Journal of Pharmaceutical Research (09752366)*, *11*(2).
- Sethi, N., Kaura, S., Dilbaghi, N., Parle, M., & Pal, M. (2014). Garlic: A pungent wonder from nature. *International research journal of pharmacy*, *5*(7), 523-529.
- Shapiro Y. Kinematics of Continuous Hyper-redundant Robots. Technion-Israel Institute of Technology, Faculty of Mechanical Engineering; 2013.
- Sheelu, M., Neeraj, S., Sushila, K., Milind, P., & Sarita, L. INTERNATIONAL RESEARCH JOURNAL OF PHARMACY.
- Shintake J, Cacucciolo V, Floreano D, Shea H. Soft robotic grippers. Advanced materials. 2018 Jul;30(29):1707035.
- Souri H, Banerjee H, Jusufi A, Radacsi N, Stokes AA, Park I, Sitti M, Amjadi M. Wearable and stretchable strain sensors: materials, sensing mechanisms, and applications. Advanced Intelligent Systems. 2020 Aug;2(8):2000039.
- Suman, J., Neeraj, S., Rahul, J., & Sushila, K. (2014). Microbial synthesis of silver nanoparticles by Actinotalea sp. MTCC 10637. *American Journal of Phytomedicine and Clinical Therapeutics*, *2*, 1016-23.
- Tiboni M, Amici C. Soft Gloves: A Review on Recent Developments in Actuation, Sensing, Control and Applications. InActuators 2022 Aug 10 (Vol. 11, No. 8, p. 232). MDPI.

- Tsutsui S, editor. Intelligent biometric techniques in fingerprint and face recognition. Routledge; 2022 Jan 26.
- Vannozzi L, Iacovacci V, Menciassi A, Ricotti L. Nanocomposite thin films for triggerable drug delivery. Expert Opinion on Drug Delivery. 2018 May 4;15(5):509-22.
- Vivek, V., Sethi, N., & Kaura, S. (2022). Green synthesis and evaluation of antibacterial activity of zinc nanoparticles from Calotropis procera leaves.
- Wang J. The impact of development and application of soft material and novel actuators in soft robotics technology on future biomedical engineering. Journal of Student Research. 2022 Aug 31;11(3).
- Xiong J, Chen J, Lee PS. Functional fibers and fabrics for soft robotics, wearables, and human–robot interface. Advanced Materials. 2021 May;33(19):2002640.
- Yang Y, Chen Y, Li Y, Chen MZ, Wei Y. Bioinspired robotic fingers based on pneumatic actuator and 3D printing of smart material. Soft robotics. 2017 Jun 1;4(2):147-62.
- Yi J, Chen X, Song C, Wang Z. Fiber-reinforced origamic robotic actuator. Soft robotics. 2018 Feb 1;5(1):81-92.
- Zahedi A, Zhang B, Yi A, Zhang D. A soft exoskeleton for tremor suppression equipped with flexible semiactive actuator. Soft robotics. 2021 Aug 1;8(4):432-47.
- Zhang Y, Lu M. A review of recent advancements in soft and flexible robots for medical applications. The International Journal of Medical Robotics and Computer Assisted Surgery. 2020 Jun;16(3):e2096.
- Zhao F, Yao D, Guo R, Deng L, Dong A, Zhang J. Composites of polymer hydrogels and nanoparticulate systems for biomedical and pharmaceutical applications. Nanomaterials. 2015 Dec 3;5(4):2054-130.
- Zlatintsi A, Dometios AC, Kardaris N, Rodomagoulakis I, Koutras P, Papageorgiou X, Maragos P, Tzafestas CS, Vartholomeos P, Hauer K, Werner C. I-Support: A robotic platform of an assistive bathing robot for the elderly population. Robotics and Autonomous Systems. 2020 Apr 1;126:103451.
- Zrinscak D, Lorenzon L, Maselli M, Cianchetti M. Soft robotics for physical simulators, artificial organs and implantable assistive devices. Progress in Biomedical Engineering. 2023 Feb 22;5(1):012002.