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# Design and Assessment of an Innovative Hybrid Soft Surgical Gripper for Safe Digital Nerve Handling

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## Introduction

Surgical tools have evolved dramatically over the past few decades, with advancements in material science, robotics and automation. One of the key challenges in surgery, particularly in delicate procedures involving the nervous system, is the safe and effective handling of soft tissue and nerve structures. The human body, especially the peripheral nervous system, requires surgical instruments that provide not only precision but also adaptability to the intricate, often unpredictable, nature of biological tissues. Among these challenges, managing delicate structures such as digital nerves in hand surgeries stands as a prime example of where current tools fall short, as traditional grippers, forceps, or clamps can cause damage, trauma, or poor tactile feedback. The need for a more sophisticated tool that offers a combination of softness, adaptability and precision is clear. Hybrid soft surgical grippers are emerging as a promising solution. These devices combine the flexibility of soft robotics with the control and precision of traditional mechanical systems. By utilizing materials like elastomers, smart polymers and actuators designed to mimic biological tissues, these grippers can safely interact with soft, sensitive tissue such as nerves, arteries and muscles without causing excessive damage. This innovation has the potential to revolutionize minimally invasive surgeries, offering better outcomes, reduced recovery times and greater safety for patients [1].

This paper focuses on the design, development and assessment of an innovative hybrid soft surgical gripper specifically tailored for the safe handling of digital nerves during hand surgeries. The gripper design incorporates both soft and rigid components, allowing for a balance of compliance, dexterity and control. The goal is to address the limitations of existing surgical tools by providing a device that is adaptable to the varying contours of the hand's internal structures while offering tactile feedback for the surgeon. The assessment includes testing the gripper's ability to safely interact with digital nerves, evaluate its mechanical performance and determine its usability in clinical settings. In this study, we outline the detailed design process, which integrates multiple fields of engineering, including robotics, materials science and biomechanics. We explore the conceptualization of the gripper, its development and the iterative design process that included prototyping, material selection and actuator integration. Furthermore, the assessment procedures include laboratory experiments and simulation studies that validate the gripper's ability to handle soft tissues without causing harm. Finally, we present the potential impact this hybrid soft surgical gripper can have on the future of minimally invasive surgeries, highlighting its versatility, effectiveness and the opportunity to improve patient care [2].

## Description

The design of the hybrid soft surgical gripper begins with understanding the biomechanical properties of human tissues, especially the digital nerves in the hand. Digital nerves are small, fragile structures that require careful handling during surgery. To address the challenge of handling these nerves safely, the gripper combines soft robotics principles with traditional rigid mechanical components to create a device that is both versatile and precise. The gripper features a flexible, soft exterior made from a high-elasticity elastomer, which allows it to conform to the shape of the target nerve or surrounding tissues. This material is chosen for its ability to mimic biological tissues in terms of compliance and texture, providing a cushioning effect that prevents damage to the delicate nerve fibers. At the same time, the internal actuation system is designed using Shape-Memory Alloys (SMAs) or pneumatic actuators, which allow the gripper to adapt to varying shapes and pressures, providing precise control during surgery [3].

The choice of materials is crucial in achieving the desired performance of the gripper. For the soft components, elastomers such as silicones and Thermoplastic Poly Urethanes (TPUs) are commonly used due to their high flexibility and biocompatibility. These materials offer a soft, conforming surface that helps in minimizing the risk of nerve damage while maintaining the mechanical strength needed for manipulation. Actuation of the gripper is a key challenge in this design. Conventional actuators used in robotic surgery tools are typically rigid and offer limited flexibility, which is not suitable for soft tissue manipulation. To address this, we employ a hybrid actuation system that uses pneumatic actuators, which inflate and deflate to change the shape and size of the gripper and shape-memory alloys, which change shape in response to temperature variations. These systems work together to provide both soft deformation for tissue compliance and rigid motion for precision handling [4].

A major consideration in the design of any surgical gripper is its interaction with the tissue. Digital nerves, while important for hand function, are very susceptible to damage if mishandled. Therefore, the gripper is designed with an articulated structure that adapts to the contours of the target tissue. The gripper's flexible surface allows it to maintain contact with the nerve in a controlled manner without exerting excessive pressure or pinching. The gripper's mechanism includes a set of movable, flexible fingers, each equipped with pneumatic chambers that inflate to open the fingers and deflate to close them. The fingers can conform to the nerve's shape, mimicking the natural grasping motion that a human hand might use. This compliance allows for greater dexterity and control over delicate tissue manipulation. Additionally, the gripper's fingers can be adjusted to different configurations to achieve optimal grip strength for various surgical tasks, such as lifting, separating, or manipulating nerves without causing tissue damage [5].

## Conclusion

In conclusion, the design and assessment of the innovative hybrid soft surgical gripper for safe digital nerve handling represents a significant step forward in the evolution of surgical tools. By integrating soft robotics principles with traditional rigid mechanisms, this gripper offers a versatile and adaptable solution for delicate nerve manipulation, providing a much-needed balance of flexibility, precision and safety. The use of advanced materials such as elastomers, coupled with smart actuators and real-time force-feedback systems, ensures that the gripper can interact gently with fragile structures like digital nerves while minimizing the risk of damage. The iterative design process, combined with rigorous mechanical testing and usability

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assessments, has proven the viability of this tool for clinical applications, particularly in hand surgeries. As this technology continues to evolve, it holds great promise for improving patient outcomes, reducing surgical trauma and enabling more precise and minimally invasive interventions. The hybrid soft surgical gripper not only enhances the safety and effectiveness of nerve handling but also paves the way for more advanced and refined tools in the field of soft robotics and surgical instrumentation, ultimately transforming the future of surgery.

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## Conflict of Interest

None.

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