

Design and development of a non-contact robotic gripper for tissue manipulation in minimally invasive surgery

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Summary. This paper describes the design and testing of a gripper developed for handling of delicate and flexible tissues during minimally invasive surgery. The device operates on the Bernoulli principle for generating high-speed flow between the gripper and product surface thereby creating vacuum which lifted the product. The Bernoulli gripper, which is widely employed in automated production lines, is a pneumatic manipulator capable of non contact gripping. This study experimentally investigates the applicability of Bernoulli gripper in minimally invasive surgery. The gripper allows tissues to be lifted with minimal contact thereby reducing the possibility of damaging the object. Most of the robot grippers are not easily applicable in minimal invasive surgery due to the tissues are often delicate, easily damaged, adhesive and slippery. Due to surgeons can not gauging the force exerted on the grasped tissue during laparoscopic grasping, excessive grasp forces may lead to tissue damage. Although Minimally invasive surgery has many benefits, force feedback or touch sensation is limited during the operation in the currently available tools, creating the potential for excessive force application and unintended tissue injury. To overcome such problems, this paper proposes a concept to enable the use of non-contact grippers instead of traditional grippers. In this paper, an innovative approach of a gripper for grasping variable in sizes, shape and weight of chicken tissues are presented. The experimental results show that the Bernoulli principle gripper can be used to lift tissues of different texture and shape without damage. The main objective of this study is to highlight the importance of a non-contact end effector in Minimally invasive surgery and develop a gripper to grasp different tissues. A novel gripper such as the tested prototype has the potential to be used as grasper instrument in minimally invasive surgery. The results will be valuable for literature and future works. (www.actabiomedica.it)

Key words: non-contact handling, bernoulli gripper, radial flow, minimal invasive surgery, Tissue damage

Introduction

In recent years, technological advances in robotic field have led to novel and less invasive techniques for surgery. In this context, open surgery is often replaced by less invasive techniques, such as laparoscopy, towards Minimally Invasive Surgery. Laparoscopic surgery is a type of minimal invasive surgery where long thin instruments and a camera are used to perform the procedure. The instruments and camera are introduced into the abdominal cavity through small portholes, so-

called trocars. Workspace is created inside the abdominal cavity by means of carbon dioxide gas.

The aim of the present work is to develop and evaluate a tissue gripper that prevents tissue damage during Minimally invasive surgery. This could be achieved with non-contact gripper. This technique is used for variety of delicate materials, including jelly block (1), woven fabrics (2), vegetables (3), leather plies (4) and thin silicon wafers (5). The human tissues are large, delicate, flexible, and has a natural lubricant on the tissue surface, making it difficult to grasp and manipulate.

Therefore instruments that are used to grasp and manipulate the tissues must provide a firm and safe grip. Minimally Invasive Surgery has brought substantial benefit to the patient, such as less traumatization, less risk of infection, shorter recovery time and better cosmetics. In Laparoscopic surgery, a single large incision is replaced by multiple small incisions from 1 mm to 15 mm in diameter (6). Due to advantage in reducing the surgical trauma, postoperative pain and cosmetic problems, the laparoscopic surgery has been adopted in several medical fields, such as urological, thracic and pediatric. Although much work has been done to develop laparoscopic grippers, they are still inadequate to grasp and manipulate internal organs without damage. Force feedback or touch sensation is limited in the currently available Laparoscopic tools, thus creating in most cases the potential for excessive force application during surgery and unintended tissue injury (7-9). The risk of complications of soft tissues while trying to securely grip them is still an unresolved issue using conventional instruments. Current research is focused on improvement of traditional grippers to limit the force exerted and preventing damages on the tissues (10-13). In addition to the robotic surgery field, there are different previous inspiring examples on the use of soft grippers. In 1991 Suzumori et al. (14) already developed a device based on pneumatic actuators which is able to manipulate small objects. Demiel and Brock

have been developed an entire hand with high dexterity and capabilities which resemble the functionality of a human hand (15).

This study proposes a method to exploit a non-contact robotics technologies in the minimally invasive surgery. The idea at the base of this proposal is to study the feasibility of grasping soft tissues by using a non-contact end effector based on the Bernoulli principle. Due to designed gripper for working with air flow and made biocompatible materials, there is no risk of damaging blood vessels or delicate organs during manipulating procedures.

Bernoulli principle

In conventional Bernoulli gripper operations compressed air is supplied to the gripper through a central channel with circular cross section as can be seen Fig. 1. The air flows down this channel until it hits the object to be gripped. This generates repulsive force on the object which pushes it away from the gripper. At the same time the air, which is now unable to continue to travel away from the channel is deflected to flow lateral direction. Due to circular nature of the gripper the air radiates in all directions away from the central channel. This causes the air to travel across the upper surface of the grasped object and inline with Bernoulli

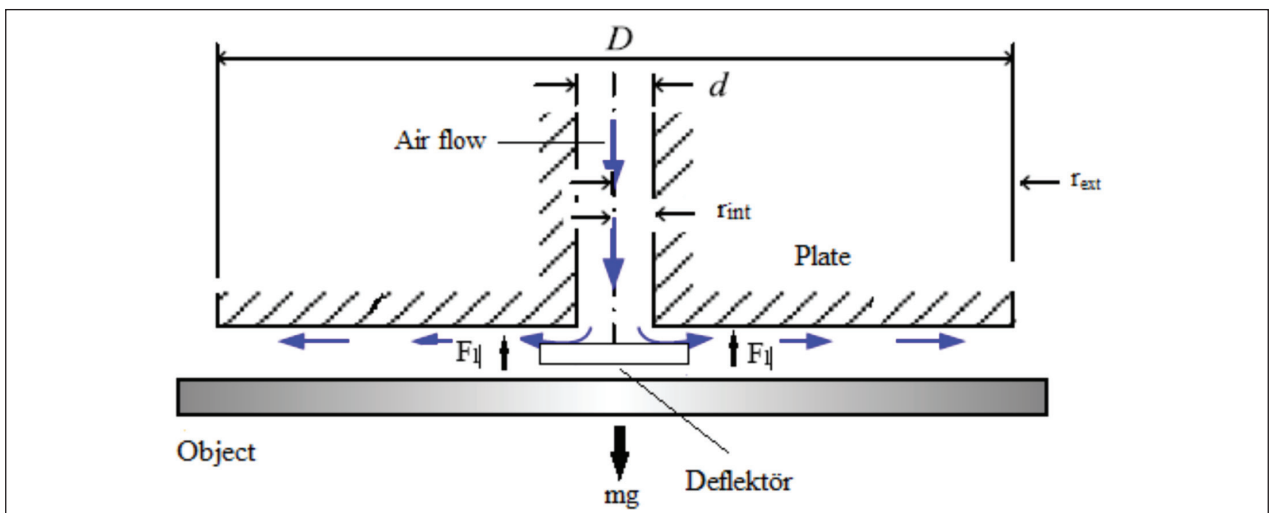


Figure 1. Bernoulli gripper with deflector (16). D is diameter of the gripper surface, d is diameter of the nozzle, F_l is lifting force. Where Q is the volumetric flow rate and ρ is the air density.

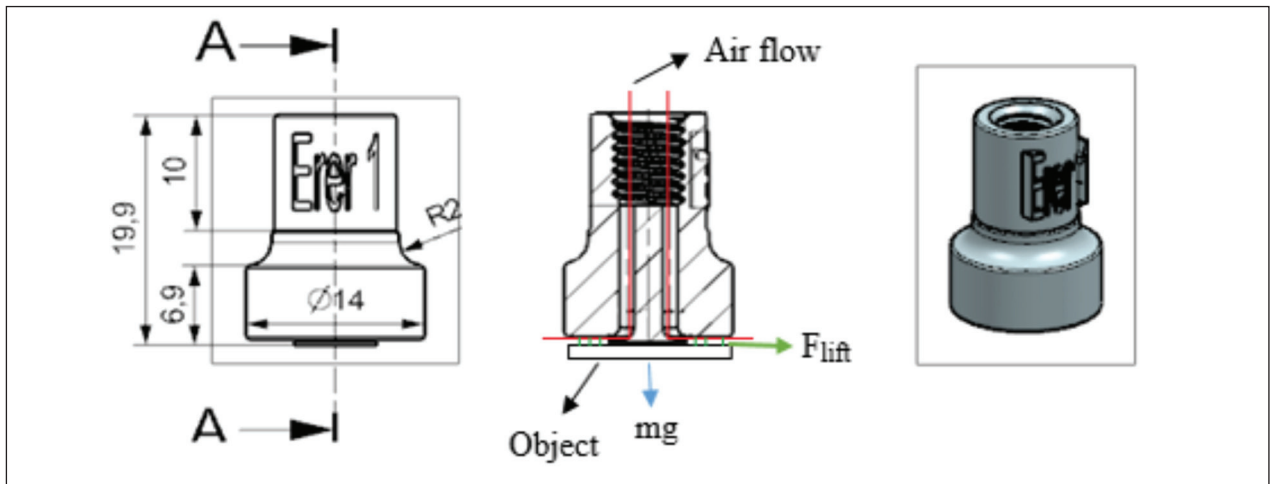


Figure 2. Non-contact gripper with deflector based on Bernoulli principle (a) front view, (b) sectional view, (c) Cad design

principle produce a reduction in the air pressure above the object. The resultant pressure differential between the upper and lower surface of the object generates an attractive force between the gripper and the object.

Due to compressed air flow hits the object directly, in this form the gripper is not capable of handling very delicate materials such as soft tissues. Therefore a deflector was used to protect the flexible delicate tissues from the strong air flow as can be seen Figure 1. In this case air travels down the central channel and is forced by the deflector to flow laterally across the face of the gripper. The result of this is when the gripper approaches an object, the lateral flow passes over the surface and generates an attractive force as previously but without the central repulsive force. As the object is pulled towards the gripper its central section comes into contact with the deflector and no lift is generated at this point. However, the remainder of the object is supported on a cushion of air as previously. As there is minimal contact between the gripped object and the gripper there is very little friction to hold it in place.

Application of Bernoulli principle into object lifting

Bernoulli principle can be applied in object lifting. For example, an airplane wings are lifted with Bernoulli's equation. Bernoulli showed that as the velocity of fluid flow increases, its pressure decreases. The speed of airstream is greater at above the wing, hence

the air pressure above the wing is less than the pressure below the wing, resulting in a net upward force. Similar principle is applied for lifting chicken tissues by Bernoulli gripper. A compressed air is applied to the gripper plate through the central channel with a circular cross section as can be seen Figure 2 (b). The air flows down this channel until hits the deflector and forced by the deflector to flow lateral across the surface of the gripper. Due to round nature of the gripper, the air diffuses in all directions far from the central channel. This causes the air to travel across the upper surface of the lifted object and in line with Bernoulli principle to produce a reduction in the air pressure above the object. The resultant pressure difference in the middle of the upper and the lower surfaces of the object caused an attractive force between the gripper and object. As the object is pulled towards the gripper, deflector comes into contact with the object and no lift generated at this point. However, the remainder of the object is supported on a cushion of air as previously. The gap between the object to be lifted and the gripper is reduced, as the gripper is brought nearer to the upper surface of the object. When the lifting force become larger than the gravity effect on the object, the gripper lifts the objects and pulls it towards the surface of the gripper. As the object continues to get closer, the attractive force further increase. Eventually the object will reach an equilibrium point and it is securely grasped without making any contact with the gripper.

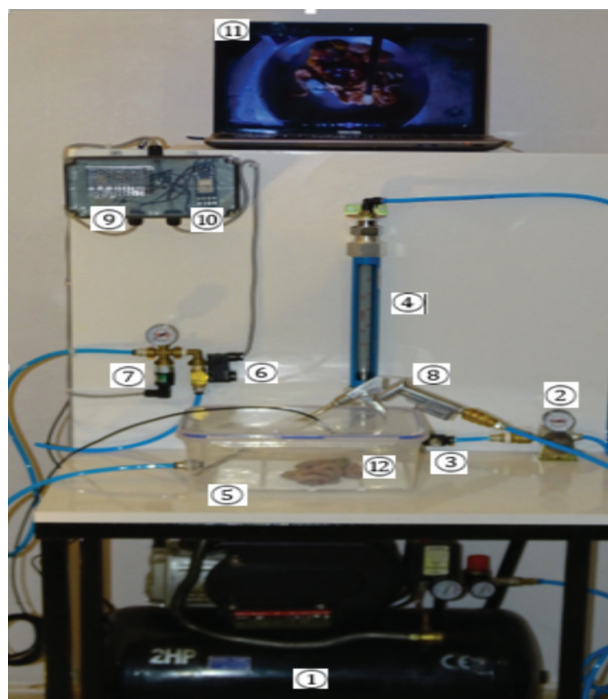


Figure 3. Experimental setup for handling chicken tissues (1) Air compressor, (2) Pressure regulator, (3) Flow control valve, (4) Flow meter, (5) Laparoscopic training box, (6) Selenoid valve, (7) Pressure sensor, (8) Compressed air hammer, (9) Adaptor, (10) Relay, (11) Monitor

Experiments

An experimental setting was used to manipulate healthy chicken tissues via non-contact gripper. During the experiments, a simple manipulation was per-

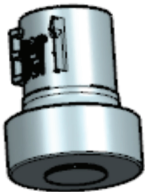
formed with prototype. The prototype was constructed such that fit through a 15 mm trocar. It had two control options, grasping tissue and releasing tissue. To grasp tissue, the nozzle was placed on the tissue surface and air opened manually by means of a finger. The tissue was lifted towards the nozzle surface. To release grasped tissue, air flow closed and decreased the vacuum level, causing tissue slip out of the nozzle. For tissue manipulation the tissue was grasped and lifted 90° upward 200 mm as seen Figure 5 and repeated 10 times with prototype at air flow level between 2 m³/h and 2,4 m³/h. Totally 50 manipulations were accessed and all effects of the manipulations were macroscopically assessed in terms of tissue damage and visible damage can not find on all tissues. A schematic description of the experimental setup of non-contact gripper for lifting chicken tissues is shown in Figure 3.

The size, shape, weight and surface structure of tissues are the most important characteristics for gripping and invariably have to be considered when testing gripper's capability in handling tissues. Different chicken tissues with various sizes, shapes, and weights are tested with the gripper as can be seen Table 1.

Conclusions

In this study, the goal was to explore the possibility of applying Bernoulli principle to a gripper for tissue manipulation during Minimally invasive surgery. The gripper was able to grip flexible chicken tissues

Table 1. Non-contact gripper test conditions

Gripper	Number	Tissues name	Tissues weight (gr)	Fluid pressure (bar)	Fluid velocity (m ³ /h)	Lifting height (mm)	Levitation time (sn)	Retries
	1	Liver	14,80	2	2	200	15	10
	2	Lung	6,78	2	2	200	15	10
	3	Hearth	9,35	2	2,4	200	15	10
	4	Gizzard	20,82	3	2,4	200	15	10
	5	Skin	9,54	3	2,4	200	15	10

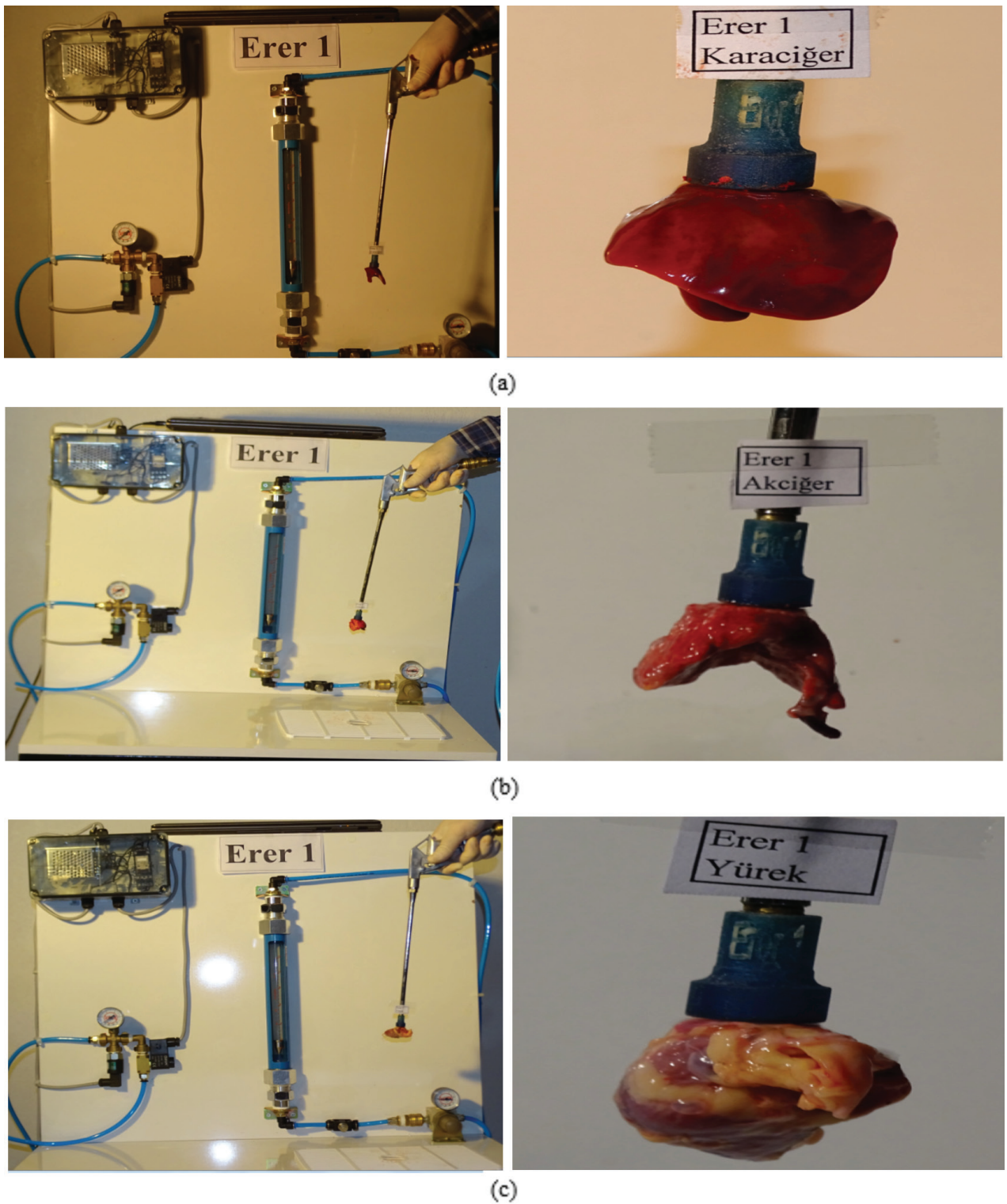


Figure 4 a-c. The gripper is handling (a) Liver, (b) Lung, (c) Hearth

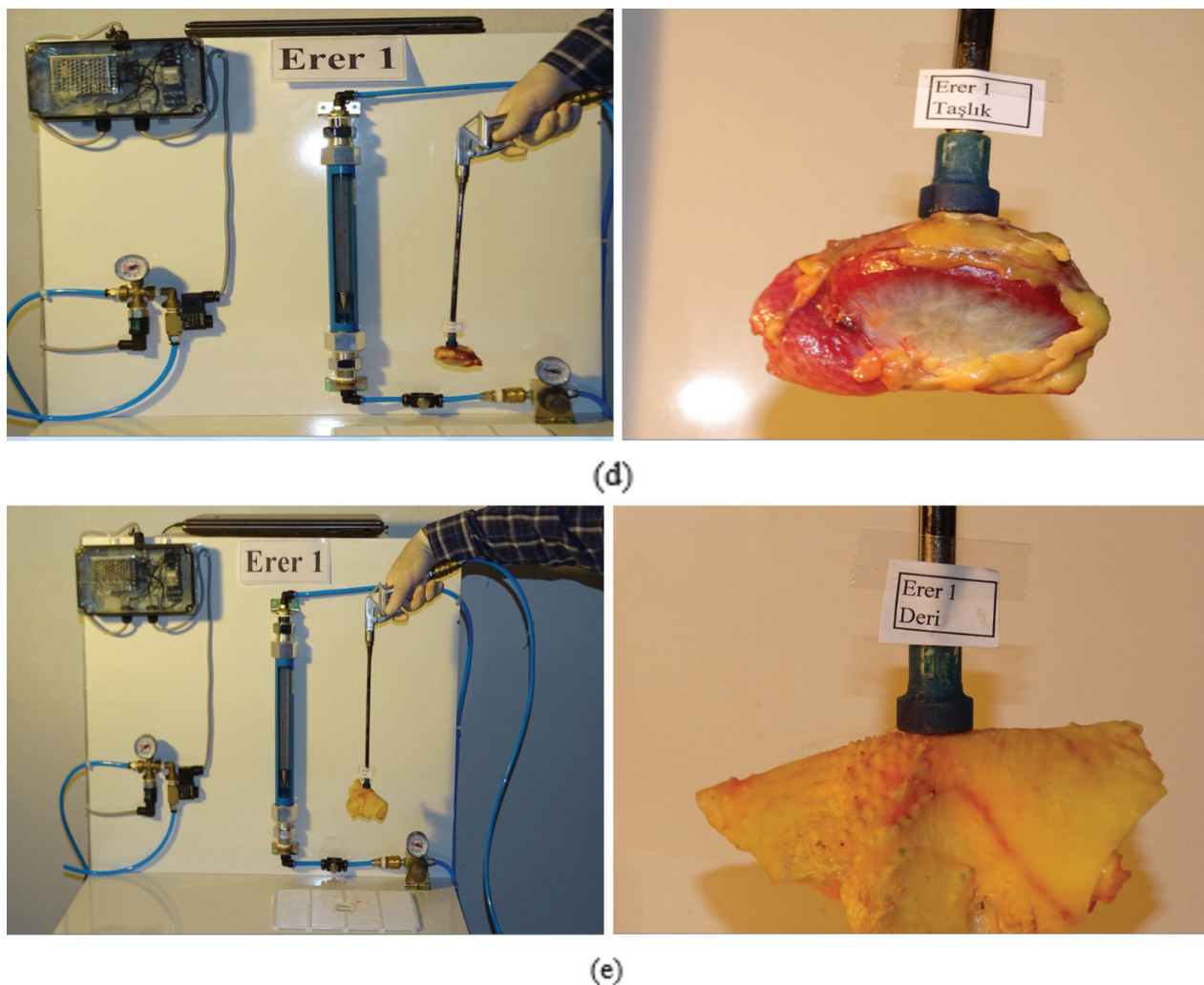


Figure 4 d-e. The gripper is handling (d) Gizzarg, (e) Skin with close views

without damaged. The gripper is not completely contactless, but it had minimal contact with the tissue due to deflector, which prevent the tissue from damage due to air flow. However, the rapid air flow over the surface of the tissues causes dehydration and vibrations. To prevent this, a moisturized low air flow can be used. Chicken bowel tissues were used for the experiments. The physical principles of the non-contact grasper prototype allowed chicken tissues to be grasped safely. No torn tissue layers or tissue perforations were observed. The forces that grasp and hold the tissue are determined by the level of air flow, preset at a constant level independently of the user. The manipulations on all

types of tissue resulted in no visible organ damages. These tests indicate that a non-contact gripper based on the Bernoulli principle can be used to grasp without causing damage to these types of tissue.

Conflict of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

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