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Research Article

## Design and Feasibility Tests of A New Laparoscopic Gripper for Grasping Soft Tissues of Variable Shape Without Clamping Force

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### ABSTRACT

Surgeons use grippers for grasping and moving soft tissues during Laparoscopic surgery. The grasping jaws of these grippers have different toothed structures to prevent tissues from slipping. As a result of clamping tissues between grasping jaws, there is a risk of tissue damage. In this study, to eliminate this risk, a new Laparoscopic gripper that works on the Bernoulli principle and can lift tissues without clamping force was designed and produced, and its applicability tests were carried out with an experimental study. The gripper works by creating a vacuum with a high airflow rate with the Bernoulli principle between itself and the tissue. To not damage the lifted tissue by the strong air jet, a deflector was placed onto the center of the grasping surface to change the flowing direction of the air flowing in the axial direction. The study showed that a gripper working with the Bernoulli principle could be applicable to lift and move soft and flexible tissues without clamping force.

**Keywords:** Laparoscopic gripper, Bernoulli principle, Minimally invasive surgery

## Sıkma Kuvveti Uygulamadan Değişken Şekilli Yumuşak Dokuların Kavranması İçin Yeni Bir Laparoskopik Tutucu Tasarımı ve Uygulanabilirlik Testleri

### ÖZET

Cerrahlar, Laparoskopik cerrahi sırasında yumuşak dokuları tutmak ve hareket ettirmek için tutucular kullanmaktadır. Bu tutucuların kavrama çeneleri, dokuların kaymaması için değişik yapılarda dişli yapıya sahiptirler. Dokuların tutucu çeneler arasında sıkıştırılması sonucunda doku hasarı riski oluşmaktadır. Bu çalışmada bu riskin ortadan kaldırılması için Bernoulli prensibi kullanılarak çalışan, dokuları sıkmadan kaldırabilen yeni bir Laparoskopik tutucu tasarlanıp üretilerek deneysel çalışma ile uygulanabilirlik testleri yapılmıştır. Tutucu, doku ile arasında Bernoulli prensibi ile yüksek hava akış hızı ile vakum oluşturularak çalışmaktadır. Kaldırılan dokuların kuvvetli hava jetinden zarar görmemesi için eksenal yönde akan havanın akış yönünü değiştirmek amacıyla tutucu yüzey merkezine deflektör yerleştirilmiştir. Çalışma, Bernoulli prensibi ile çalışan bir tutucunun yumuşak ve esnek dokuların sıkıştırılmadan kaldırılması ve hareketi için uygulanabileceğini göstermiştir.

**Anahtar Kelimeler:** Laparoskopik tutucu, Bernoulli prensibi, Laparoskopik cerrahi

## **I. INTRODUCTION**

In laparoscopic surgery, specially designed grippers are needed to safely hold and move internal organs [1-4]. To introduce grippers into the abdominal cavity without making large incisions on the skin, small incisions are made. As a result of small incisions, small injuries are formed. As a result of this, less pain is formed in the patient during the surgery, and times of hospitalization and recovery are shortened. Additionally, a smaller scar is left in the patient aesthetically in comparison to open surgery. This is why Laparoscopic surgery is an advantage for the patient. As human tissues have different shapes and sizes and wet, sensitive, and soft surfaces, they are highly challenging to grasp with grippers.

In Laparoscopic surgery, grippers are used to hold and move organs and tissues during surgery [5]. For tissues to be grasped without slipping, these grippers usually have jaws with a toothed profile structure. The distribution of the clamping force between these jaws and the tissue is not uniform [6]. In the process of clamping and moving tissues with conventional Laparoscopic grippers, tissue damages occur due to high pressure [7]. As a result of tissue damage caused by grippers during Laparoscopic surgery, severe lesions may occur in the patient.

In this study, for holding, lifting, and moving tissues without applying clamping force in Laparoscopic surgery, it was aimed to introduce a gripper prototype working with the Bernoulli principle by using air and test is on inanimate animal tissues. Grippers working with the Bernoulli principles are used in the industry and being investigated in academic studies. With this technique, successful lifting was achieved for thin silicone plates by Brun [8], textile fabrics by Özçelik [9, 10], jelly blocks by Erzincanlı [11], sliced vegetables by Davis [12], skin layers by Dini [13], inanimate animal tissues by Ertürk [14] and fruits by Sam [15].

In this study, a gripper working with air was developed to prevent tissue damage originating from grippers in Laparoscopic surgery, and its applicability was assessed by experimental studies.

## **II. DESIGN AND EXPERIMENTAL DETAILS**

The design of a gripper working with the Bernoulli principle to be used in Laparoscopic surgery that was made in this study is shown in Fig. 1. The gripper consists of a circular channel where the fluid flows at the center, an air deflector, and a grasping surface.

The air deflector was placed onto the center of the grasping surface so that it would change the direction of the pressurized air flowing through the central channel without hitting the object to be lifted. With the help of an air deflector, when the gripper is brought close to the object to be lifted, no repelling force that would get the object away from the grasping surface is formed. Additionally, with the same deflector, harming the object to be lifted is also prevented as the pressurized air does not directly hit the object [16].

As per the Bernoulli principle, as seen in Fig. 1, the pressurized air flows along the circular channel found at the center of the gripper. The air deflected with the help of the deflector flows into the atmosphere through the shape of the grasping surface from the narrow gap between the surface and the object to be lifted.

According to the Bernoulli principle, when the velocity of the fluid in the zone between the grasping surface and the object increases, the pressure in the zone decreases, and this forms an attracting force on the object. The Bernoulli principle is shown in (1):

$$\left(\frac{1}{2}\rho v^2 + P\right)_1 = \left(\frac{1}{2}\rho v^2 + P\right)_2 \quad (1)$$

$\rho$ : air density,  $v$ : velocity,  $P$ : the pressure of the fluid. The total lifting force on the object is equal to the difference between the attracting force and the repelling force. The formula of the total lifting force is given in (2).

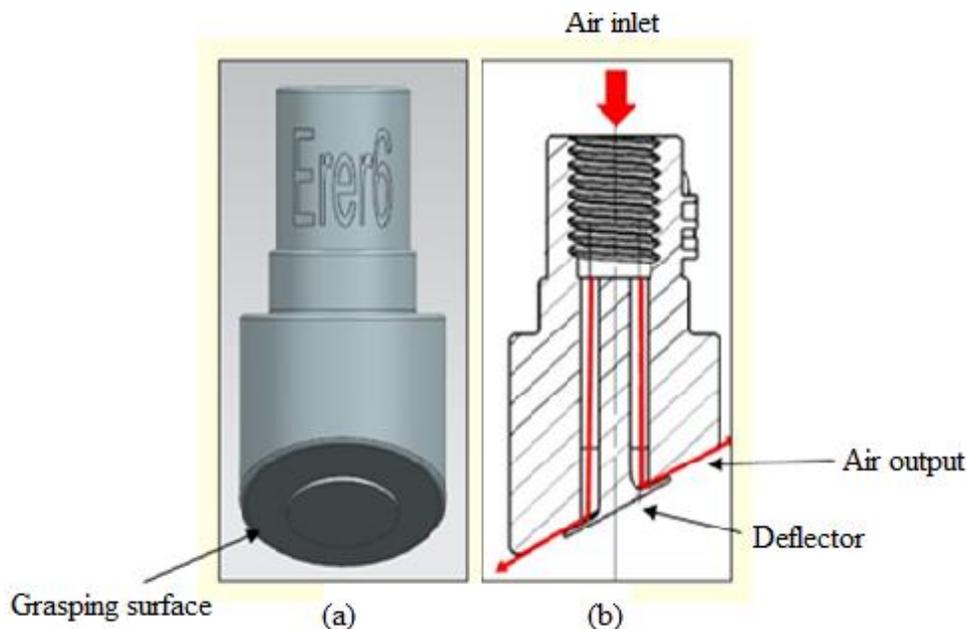
$$F_{total} = F_{att} - F_{rep} \quad (2)$$

While pressurized air flows down to ~~from~~ the channel at the center of the gripper, it hits the deflector without hitting the object to be lifted, and so, it is forced to flow horizontally. For this reason, no repelling force occurs on the object to be lifted, but only an attracting force occurs. The attracting force is calculated by the formula below.

$$F_{att} = \frac{1}{2} \rho \frac{Q^2}{2\pi h^2} \left[ \ln\left(\frac{r_{ext}}{r_{int}}\right) - \frac{1}{2} \left(\frac{r_{ext}}{r_{int}}\right)^2 \right] \quad (3)$$

$Q$ : volumetric flow rate,  $h$ : the distance between the grasping surface and the object that is grasped,  $r_{ext}$ : radius of the grasping surface,  $r_{int}$ : hole radius of the gripper.

The gripper prototype was designed as seen in Fig. 1 with a 3D printer from a biocompatible material and in a way that it would fit in a 15-mm trocar. The grasping surface area is 164 mm<sup>2</sup>, while the deflector area is 42 mm<sup>2</sup>. The Bernoulli effect occurs in places where the air flows. As there is no airflow on the deflector, no Bernoulli effect is seen on the 42-mm<sup>2</sup> deflector area. Therefore, the tissues that are lifted partly contact the deflector. The advantage of this contact is the prevention of slipping in the horizontal direction with the effect of air during lifting. The area where the Bernoulli effect takes place is the 122 mm<sup>2</sup> of the area, which is the difference between the area of the grasping surface and the deflector area. No external stopper was used to prevent the organ from slipping in the horizontal direction during lifting with the effect of the air. Slipping of the organ from the grasping surface is prevented by the deflector. For grasping and moving liver, lung, heart, gizzard and skin among inanimate chicken tissues with the designed gripper, an experimental setup was prepared as seen in Fig. 2.



**Figure 1. (a) Laparoscopic gripper solid model and (b) Cross-section**

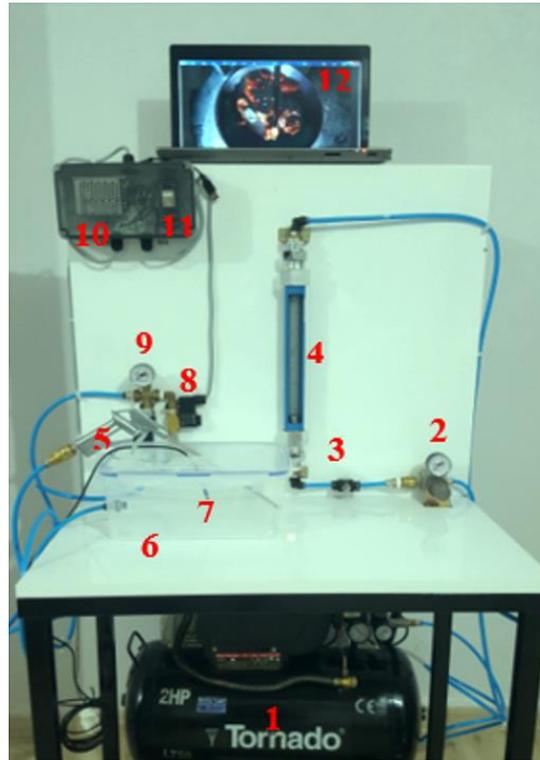


Figure 2. Experimental setup

In Fig. 2, 1: Air compressor, 2: Pressure regulator, 3: One-way flow control valve, 4: Flowmeter, 5: Air gun, 6: Laparoscopic experiment box, 7: Laparoscopic camera, 8: Solenoid valve, 9: Pressure sensor, 10: Adapter, 11: Relay and 12: Computer.

The pressured air that is needed for the experiment system to work and tissues to be lifted is produced by a Tornado HM2050F model compressor. The pressure of the air is set with a Vema brand (0-10 bar) pressure regulating valve, while its flow rate is set with a flow control valve. The set flow rate is measured by a VA10S-15 1.2-12m<sup>3</sup>/h model flowmeter. The gripper is connected to the air gun that can be turned on and off manually. With the help of the pressure sensor in the system, the air pressure in the laparoscopic box that represents the abdominal cavity can be controlled, and the excess pressure that is harmful to the tissues during lifting is evacuated into the atmosphere by the solenoid valve.

### **III. FEASIBILITY TESTS OF THE GRIPPER ON THE SOFT TISSUES**

Table 1 shows the experimental data that were used to lift liver, lung, heart, gizzard, and skin among inanimate chicken tissues by using the gripper that works with the Bernoulli principle.

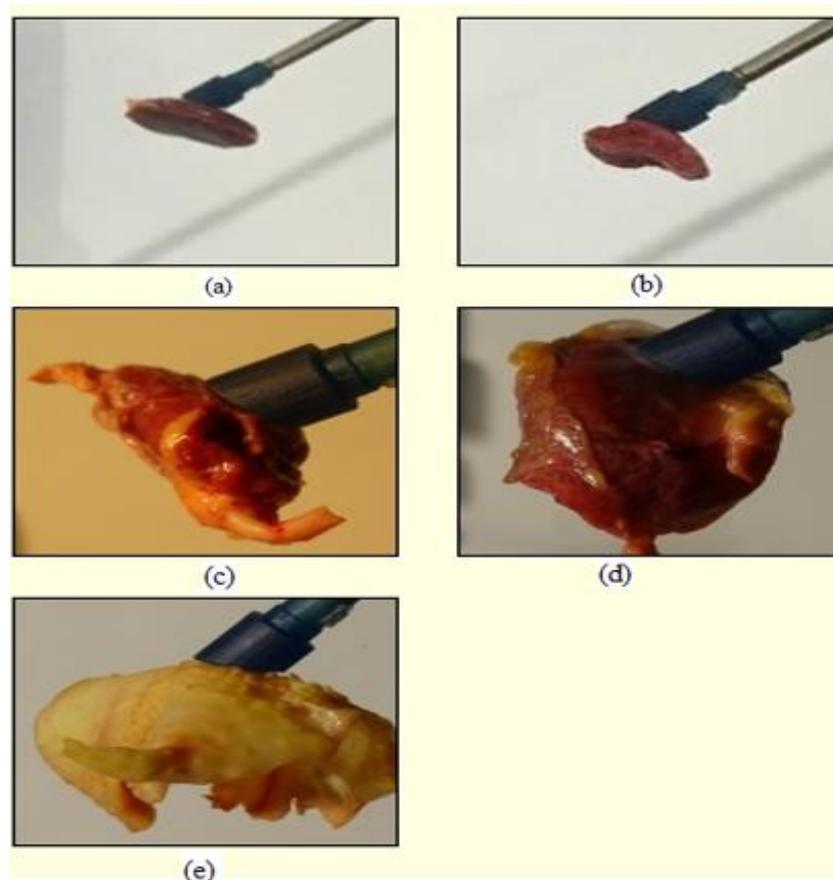
Table 1. Experimental data

Gripper Name	Experiment Order	Organ Name	Weight (gr)	Air Pressure (bar)	Air Flow Rate (m <sup>3</sup> /h)	Lifting Height (mm)
Erer 6	1	Liver	8	3	1.4	200
	2	Lung	5.27	2	1.4	200
	3	Heart	8.64	3	1.8	200
	4	Gizzard	13.93	3	1.8	200
	5	Skin	6.28	3	1.8	200

The organs that were used in the experimental study were subjected to grasping and lifting tests with the gripper starting with low pressure and flow rate values. The pressure and flow rate were gradually increased, and the optimum pressure and flow rate values that did not allow the organ to drop without harming it were determined. The physical and surface characteristics of these tissues are different. Tissues such as the liver and lung are delicate and easily damageable. As per the structures of the organs such as gizzard, heart, and skin, more pressure and flow rate are required for lifting. As each tissue that was used in the study had a unique surface structure, the optimal pressure and flow rate values were selected for the experiments. The gripper has two control options as grasping and releasing the tissue. To grasp the tissue, the gripper was brought closer to the surface of the tissue, and the air was manually introduced by a finger. To release the lifted tissue, the air was manually closed off, and the tissue was allowed to slip from the gripper.

In each tissue lifting experiment, it was ensured that the air pressure coming to the system stayed constant at the value set with the pressure regulator. Afterwards, with the flow control valve, the airflow rate was adjusted based on the weight and characteristics of the tissue to be lifted. For the lifted tissue to stay in balance without slipping on the grasping surface, the air deflector that was placed at the center of the gripper was utilized. During the experiments, the tissues to be lifted were held fixed, the gripper was brought closer to the tissues, the air was introduced, and the tissues were lifted. The airflow was measured by a flowmeter, the air passing through the flowmeter went into the atmosphere by horizontally changing its direction with the deflector without hitting directly on the tissue surface, and this way, the lifting gap between the gripper surface and the tissue occurred by itself.

Fig. 3 shows the lifting of (a) Liver, (b) Lung, (c) Heart (d) Gizzard (e) Skin tissues among inanimate chicken organs with the gripper using air that works with the Bernoulli principle designed and produced in this study.



*Figure 3. Lifting of soft tissues*

## **IV. EVALUATION OF EXPERIMENTAL RESULTS**

This study is the first study on lifting liver, lung, heart, gizzard, and skin among inanimate chicken organs with a flexible and delicate structure instead of real human organs by using radial flow with the Bernoulli principle for a gripper working with air.

The following information was reached as a result of the experimental study.

- With the gripper, the chicken organs with different weights and characteristics were successfully grasped and lifted at the determined optimum pressure and flow rate.
- During the experiments, as the pressurized air was prevented from directly hitting the tissue to be lifted with a deflector, the lifted tissues were not damaged by the pressurized air. The deflector was at the output of the central hole, and it led the direction of the air coming axially to deflect to a radial direction without hitting the tissue.
- In addition to changing the airflow direction, the deflector was also seen to prevent the tissues from slipping in the horizontal direction.
- As air did not flow on the deflector surface, there was no Bernoulli effect here, and therefore, the lifted organs contacted the deflector partially.
- In the case that the gap between the grasping surface where the air flows and the object is reduced, as a result of increased airflow and even more decreased pressure, heavier objects can be lifted.
- During the lifting of flexible tissues, as a result of the diminishing effect of the lifting force starting with the parts outside the grasping surface, hanging downwards could be clearly seen.

## **V. CONCLUSION**

The results that were obtained in the study may be listed as follows:

- This study developed a new medical gripper working with air using the Bernoulli principle to move tissues in Laparoscopic surgery without applying a clamping force or even touching.
- In the experiments, a gripper suitable for the standard trocar diameters for grippers to be introduced into the abdominal cavity in Laparoscopic surgery was designed and produced by using a three-dimensional printer.
- To prevent tissue damage that could occur as a result of the direct hitting of the airflow on the grasped tissue, an air deflector was used in the gripper to change the direction of airflow. The air flowing from the central channel of the gripper changes its direction radially without hitting the object to be lifted.
- The experiment results showed that a non-contact gripper working with the Bernoulli principle could lift chicken liver, lung, heart, gizzard and skin tissues without harming them.
- The experiments showed that it could be possible to use grippers working with the Bernoulli principle to lift flexible tissues.
- It is believed that the gripper that was designed and experimentally tested in this study, which is significant for Laparoscopic surgery, will be a reference for similar studies.

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