BEHAVIOR OF SUCKING DISKS UNDER VERTICAL AND TANGENTIAL LOAD

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ABSTRACT

The behavior of sucking disks, used to stabilize human tissue during surgeries, was investigated using conventional plastic sucking disks. The contact load to control a sustainable tangential load was calculated from the pressure and area of the internal cavity and the normal load. We observed an interesting phenomenon wherein the more the disk was pulled, the more it was pressed against the counter-surface. We also investigated the maximum tangential frictional force for several pre-loads applied perpendicularly to clarify the potential for sticking. We found that higher the pre-load, the lower was the maximum tangential friction force obtained.

1. INTRODUCTION

To achieve better quality-of-life for patients, the demand for minimally invasive surgery is increasing. For these surgeries, the invasive area is localized and greater skill is required than ever on the part of Surgeons. To assist Surgeons during such operations, several surgical robots and manipulators [1] are currently under development. However, for these systems to perform properly, it is necessary to track or stabilize the targets, since human tissues are mostly flexible and are also constantly moving because of aspiration or heartbeats.

There are several stabilizers even for the beating heart during coronary-artery bypass surgery [2], and the ones that use sucking disks seem to be the most promising in terms of minimizing tissue damage. Stabilizers currently use a negative pressure line in the operation room. Therefore, the sucking force that controls the contact pressure and the sustainable tangential load are constant and are always a maximum whether or not this is necessary.

In this work, we investigated the possibility of reducing tissue damage by using flexible sucking disks that generate contact pressure as required. However, neither the contact pressure generated by the flexible disk nor the tangential force that the disk can sustain is currently well understood.

2. MATERIALS AND METHODS

We used a glass plate as the sticking surface to observe the contact area and the cavity through the transparent plate. The glass has a 2 mm diameter hole at the center and a pressure gauge is inserted from the sticking face of the plate and fixed to form the flush surface to the glass.

Two experiments were performed in the study. The first was a “pulling down” experiment and the second was a “tangential pulling” experiment. The disk, which measured 40mm in diameter, was first pressed to the glass and the cavity in the contact area was squeezed out prior to each experiment except for the central one. The disk was pulled down, and the force of pulling was measured using a load transducer attached to the disk clamp. The movement of the disk was restricted by the linear guide to which the clamp was fixed. The glass holder has a self-aligning system made of a large bore thrust ball bearing. The tangential load was applied by pulling the glass plate tangentially with respect to the disk, and the force was measured by a load transducer attached to the glass holder. The pre-loads applied were 0, 10, 20, 30, and 40N.

The contact and cavity areas were monitored by a video camera positioned at a 45-degree glancing angle and illumination was provided by a flat illuminating panel placed at 45 degrees so that the direct reflection image of the glass surface could be observed.

Since the sucking disk was made of clear polyvinyl chloride (PVC) whose refractive index is over 1, the contact area was observed as a dark area, while the cavity was observed as a bright region. The areas of contact and the cavity were analyzed using image analysis software off-line and correlated with the force data.

3. RESULTS AND DISCUSSION

Figure 1 shows an image of the cavity area, and an image of a disk peeling from the glass plate. Figure 2 shows typical evolutions of pressure and cavity area as a function of the
displacement. As can be seen in Fig. 2, pulling the disk increased the area of the cavity (A) and reduced the internal pressure (P). The contact load (L) is calculated by the following equation.

\[ L = A(P_a - P) - F \]  

(1)

Where \( P_a \) is the atmospheric pressure and \( F \) is the force to pull the disk. As shown in Fig. 3, the contact load increased with increasing displacement. In other words, the more the disk was pulled, the more it was pressed to the surface.

In spite of the higher contact loads at higher pre-loads, the maximum tangential force decreased with increasing pre-loading (Fig. 4). For pre-loads of over 20N, the maximum tangential force was proportional to the contact load and area, indicating that the normal adhesive friction mechanism was at work.

On the other hand, at lower pre-loads, the tangential force was higher but less than the values expected from the contact area, suggesting that only a part of contact area contributed. However, this indicates that no vertical pressure on the disk is necessary to obtain sufficient tangential hold which is preferable and advantageous for minimizing tissue damage.

CONCLUSIONS

An interesting phenomenon was observed in the study wherein when a sucking disk was pulled, the contact was pressed to the surface.

The highest maximum tangential force was achieved for a zero pre-load condition in spite of the minimal initial contact load.

At elevated pre-loads, the maximum tangential force was proportional to the contact area and load.

This type of sucking disk may sustain a higher tangential force under a pulling force than disks that use a constant negative pressure.

Without the pulling force, this type of sucking disk generates very limited negative pressure. This reduces the possibility of tissue damage.

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REFERENCES


Figure 1. Left: Definition of cavity area from an image. Right: An image of a disk partially peeling.

Figure 2. Relationship between the displacement and internal pressure / area of cavity.

Figure 3. Evolution of pulling and sucking forces and the contact load with displacement.

Figure 4. Dependence of maximum tangential force on the pre-loading (left) and on the contact area of the disk (right).