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Experimental Testing of Single and Double Medical Gloves Static Friction with Surgical Scalpel for Studying the Safety of Manipulation During Surgery

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Abstract:

In conventional surgeries, protection of surgeon and his team from infection, due to patient blood exposure, is a significant issue. Using gloves is a common barrier technique which prevents patient bacteria or viruses permeating the surgeon's hand. However, using sharp surgical tools led to gloves perforation which stimulates surgeons to wear double gloves to offer extra protection. Nevertheless, many clinicians are reluctant for donning double gloves as it may affect tactile sensation and manipulation skills. One objective of this study is to compare between single and double gloves friction with a surgical scalpel, where static friction can affect the gripping and manipulating process. Tests were carried out using single and double latex gloves sliding over four scalpel surface topologies and in different contact conditions (dry, wet, blood and blood diluted by water). Donning double gloves was found to raise the static friction coefficient in all conditions. Experiments using water and blood-wet conditions indicated that water would increase the friction higher than that observed in the dry condition as it increases the electrostatic charge between surfaces and consequently the adhesion between them. Blood increases the friction over dry and wet conditions because of coagulation which forms a blood clot that withstands the finger movement. Serrated surface gave the highest friction coefficient which makes it efficient for gripping and manipulating.

Keywords:

Single and Double Gloves, Gloves perforation, Scalpel Surface Topology

1. Introduction

By the 1889s, surgical gloves were firstly used intraoperatively by William S. Halsted whose nurse had exposed to phenol, and mercuric chloride, which is commonly used as disinfectants in surgeries, and her hands were infected with exacerbation dermatitis, [1]. Dr. Joseph Bloodgood, who was the head of surgical pathology in Hopkins University, began to use gloves himself in hernia operations in

1896. In 1899, Joseph reported that over 450 hernia operations, the infection rate dropped to 100% using gloves, [2]. Consequently, the effectiveness of using gloves in surgeries has been reported in surgical, [3,4,5] and dental literature, [6,7].

Despite all the reports that discussed the benefits of surgical gloves as a barrier technique, there are many shortcomings which need to be considered. The incidence of perforations in the surgical gloves, intraoperatively, may transmit Pathogens from patients to surgeons. Moreover, it does not offer enough protection for the patient from wound sepsis due to blood-borne infections, [8]. Perforation of surgical gloves is a common event that occurs by sharp instruments; a needle prick is the most popular cause of perforation. Bacteriologic studies have illustrated that the presence of a perforation in a surgical glove leads to the great recolonization of the surgeon's hands, [9]. In the presence of such reports, as well as concerns of exposure human immunodeficiency virus, surgeons have started the routine of donning double gloves.

Donning two pairs of surgical gloves is considered as a robust barrier against post-operative or blood-borne infections and further decrease the danger of contamination, [10]. Tanner et al. [10] studied the effect of using double and triple gloving in reducing the number of pinholes in the innermost pair of surgical gloves. They found that adding a second pair of gloves significantly decreases pinholes in the innermost gloves and the same occurs with the triple gloving. Gabriel et al. [9] performed a prospective study which compares the visibility of blood on hands of surgeons donning single and double gloves during operations. They found that the percentage of blood visibility for the usage of the single glove was 38% whereas visible blood for double gloving was 2%. Accordingly, It was recommended to wear two gloves on each hand when handling infected tissues or operating on high-risk patients[8].

Many surgeons and clinicians are reluctant for donning double gloves, and they claim that such a practice reduces tactile sensation and affect manipulation skills which will not be accurate enough, [11]. Tactile sensing is an essential property in medical practice. It enables surgeons to identify abnormal areas in soft tissues and is a critical part of both treatment and diagnosis, [12]. Tactile feedback plays a significant role in grasping and manipulation surgical tools, allowing surgeons to apply the suitable forces to tissues and to grasp medical instruments with appropriate force, [13]. The friction coefficient of contacting surfaces can control the safety of medical tools handling through increasing the gripping force. Consequently, the coefficient of friction of tactile sensor was investigated, [14]. Carre et al. [15] studied the influence of medical gloves on the friction which expresses the surgeon feel. They examined the levels of friction for contact surfaces in different conditions (steel/glass; dry/wet) in case of bare-state, and a latex glove donned. The researchers found that wearing gloves increases the coefficient of friction in a dry state, and vice versa occurred in wet conditions. Lewis et al. [16] studied finger friction against materials used in fabricating jars and bottles. Experiments were carried out using two types of gloves and bare-finger in dry, wet and oil conditions. Results illustrated that gloves increase the friction, and adding a small amount of water increases the friction over the dry condition. On the contrary, the similar amount of oil led to a significant decrease in the coefficient of friction. Gloves friction coefficient have been investigated when sliding against different materials, steel, glass and wood sheets, in order to study the safety of handling such materials, [17]. Experiments have been conducted in various conditions, dry, water and detergent wet. Results illustrated that polyester, polyamide and polyethylene glycol gloves are appropriate for handling steel sheets. Polyethylene glycol and aniline formal resin coated gloves are suitable for handling glass sheets while wood sheets can be handled safely using polyethylene glycol and polyamide gloves. Mahmoud [18] measured the friction coefficient of eight gloves of different materials when sliding against glass sheet at various contact conditions (dry, water and oil). He found that latex gloves, which is used as surgical gloves, can be used in case of dry conditions due to the high coefficient of friction. However, a dramatic friction decrease occurred in case of water and oil conditions which prevent using such gloves in handling glass in these conditions.

The current study aimed to carry out friction tests under different conditions to determine latex gloves friction against surgical scalpel and to examine the safety of use double gloves in manipulating surgical scalpel. The surgical scalpel was selected as it needs a high accuracy in manipulating and applying sufficient, not excessive, force intraoperatively. Latex gloves were selected due to its fame of transmitting most of the tactile sensation to surgeon hands, [19]. Experiments were conducted using a single glove and double gloves against four surfaces topology, namely flat, grooved, serrated and grooved-serrated surfaces, in different contact conditions dry, wet, blood and blood mixed water (water 50% - blood 50%). Electrostatic charge analysis was conducted in order to clarify the mutual relationship between the friction coefficient and the electrostatic charge generated during the tests.

2. Finger Friction Experiments

2.1. Test Procedure

The current work investigated the measurement of friction coefficient in case of sliding single and double latex gloves (fabricated from approximately 55-65% water and 30-40% of rubber material) against surgical scalpel surfaces (Stainless Steel Individually sleeved 6061 1's; Ra = 0.783 μm). Commercial surgical scalpel consists of a handle and an expendable assembly which is exchanged after each surgery or as necessary. The scalpel handle surface can be divided into four structure topologies namely flat, grooved, serrated and grooved-serrated surfaces as shown in Figure 1. At the beginning of the operation, the contact between surgeon hands and the scalpel is dry, and during surgery, the surgeon's hand is exposed to patient blood. In order to remove debris during the operation to assist the surgeon in the visual examination and to reduce the surgical site infection, [20], a process called wound irrigation is used. In this process, a steady flow of water with 0.05% CHG pass across the open wound to have wound hydration, [20]. Therefore, experiments were carried out in dry, wet, blood (animal blood) and blood mixed water (water 50% + blood 50%) conditions to study their effect on the friction coefficient between gloves and scalpel's surfaces. The blood mixed water was produced based on 50% water and 50% blood (volume), they were mixed using mechanical stirrer to achieve a homogenous solution. In case of water, blood and blood mixed water, the scalpel surfaces have been sprayed before each test to achieve a fully wetted state.

The rig was designed and manufactured for measuring the friction coefficient, as shown in Figure 2. It basically consists of two incorporated load cells and a plate to hold the counter face of the surgical scalpel. The surgical scalpel was assembled on the plate of the test rig, and the load was applied on the scalpel in the normal direction, finger position was approximately 45o to achieve constant contact area. Once the experiment starts, the researcher sought to slide his finger very slowly as he can, in order to identify clear static friction coefficient. In other words, the gripping process does not mean that the finger has to move, this technique was successfully proved by Lewis et al. [16]. Once the finger starts to move on the scalpel surface, the normal force and the friction force are recorded, and the friction coefficient values were calculated by dividing friction force by normal force. Tests were carried out ten times for each surface topology with single and double gloves, then the friction coefficient average and the standard error were calculated. The average of the calculated friction coefficient is calculated, based on an acceptable standard error did not exceed ±3% to ensure accurate results. Tests were conducted in temperature 21oC and 60% humidity.

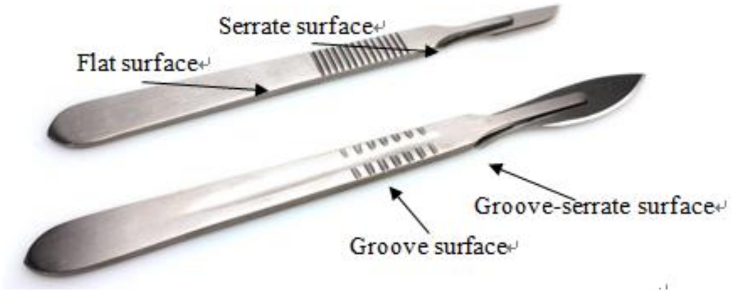

Figure 1. *Surgical scalpel surface structures.*

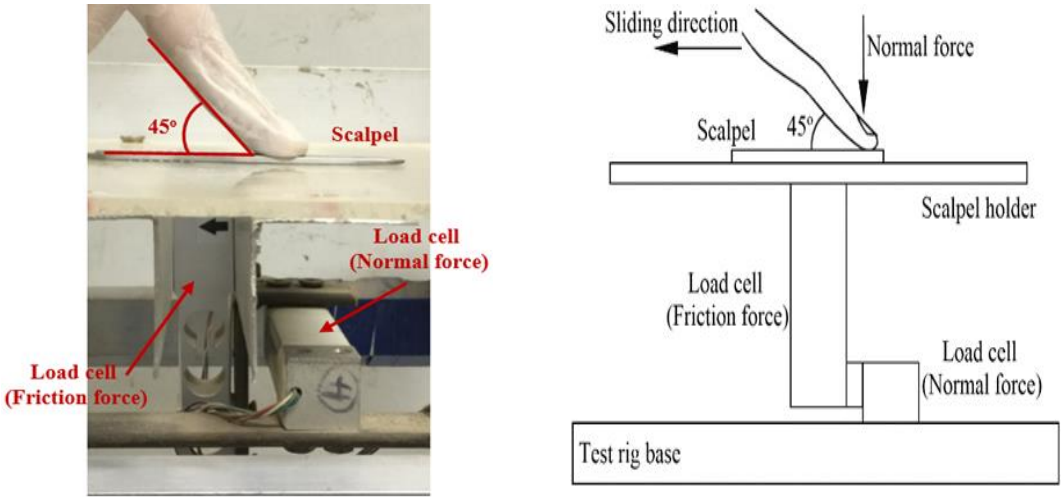

Figure 2. *The test rig and a schematic of the friction measurement process.*

2.2. Data Processing

Figure 3 illustrates an example of the measured forces, normal and friction force, during an experiment. Once movement did occur, the normal and friction forces were recorded. Fluctuations in forces reading are due to the stick and slip phenomena. The friction force increases until the overcome of static coefficient of friction; then the finger slides very fast down the scalpel counterface. The high velocity of sliding before sticking again can be attributed to the increase of friction at low sliding speeds [21]. Figure 4 shows the change in the friction coefficient during the experiment. Each peak value can indicate the static friction coefficient before sliding as shown.

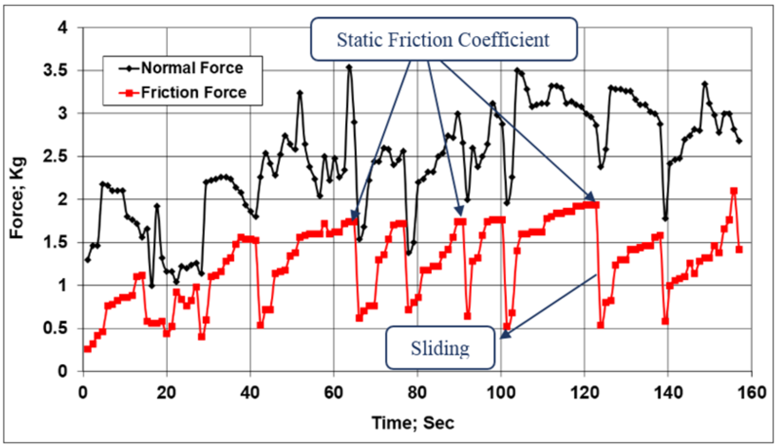

Figure 3. *Data from the normal and friction force load cells.*

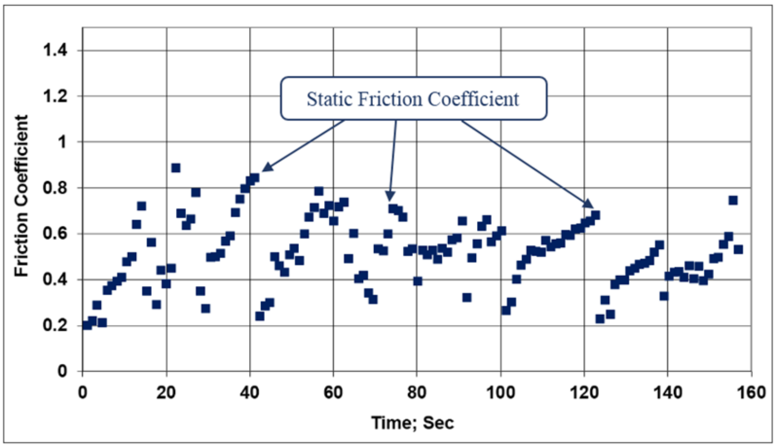

Figure 4. *Coefficient of friction against time.*

2.3. Results and Discussion

The static coefficient of friction was calculated for different surfaces structure, as shown in Figure 5. With different surface topologies, the double gloves gave an increase in the static friction coefficient which reached 3.8% for the flat surface. This can be interpreted on the basis of triboelectrification, where inducing an electrostatic charge between two sliding bodies raises the attractive force between the surfaces. As a result, the adhesion force increases and consequently the friction increases. Friction coefficient at nano- and macroscale increases when surfaces are tribocharged, [22]. The generation of electrostatic charge from the dry sliding of latex single and double gloves against polymer surfaces was investigated, [23]. Authors found that double gloving gained relatively higher charge than that obtained using a single glove. They attributed the reason to the fact that the two layers of gloves can form voids which trap the electrostatic charge formed on their internal surfaces. Consequently, the increase in friction coefficient in double gloving was due to the increase in electrostatic charge. Furthermore, a double layer glove system is thicker and softer than a single glove and could thus increase friction and adhesion by providing a greater real contact area on the microscopic scale.

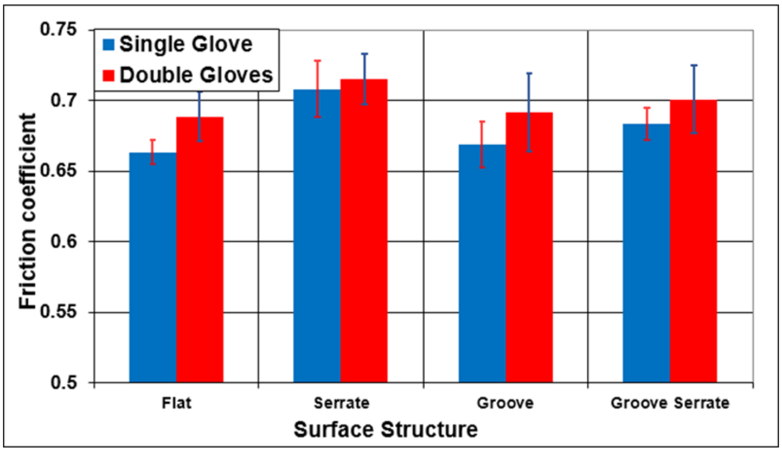

Figure 5. *Static friction coefficients for single and double gloves in case of the dry condition.*

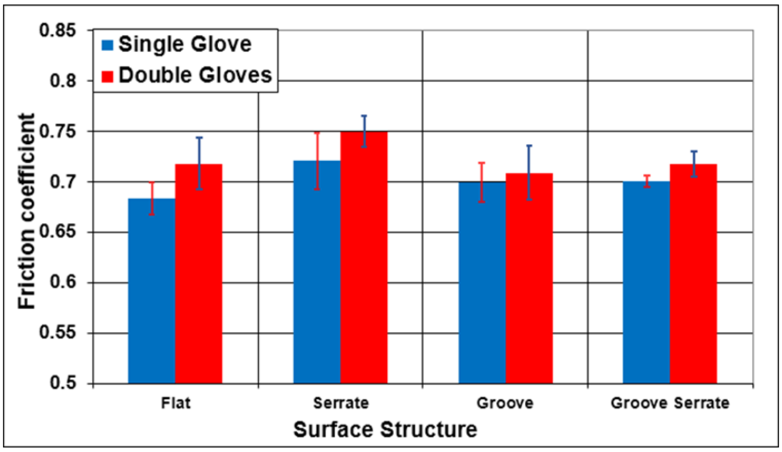

Figure 6. *Static friction coefficients for single and double gloves in case of wet condition.*

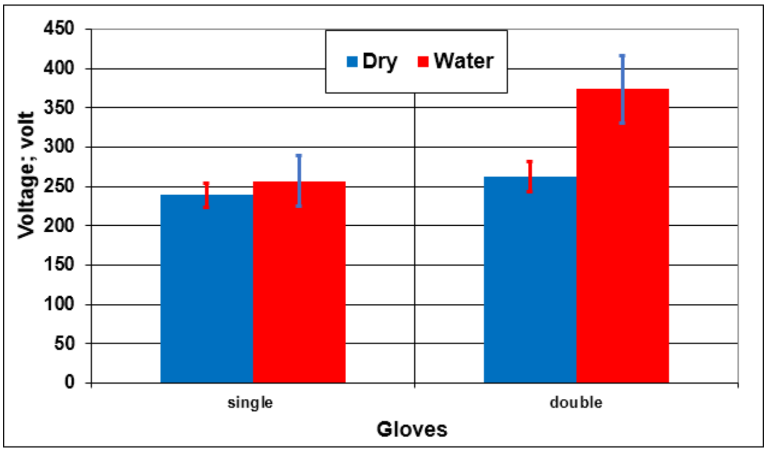

Figure 7. *Electrostatic charge generated on the scalpel surface during single and double gloves sliding in dry and wet conditions.*

Figure 6 illustrates the friction coefficient after adding a film of water to the contact surface. It is obvious that friction coefficient of double gloves against scalpel is higher than single glove which is the same behaviour of the dry condition and reached 5% for the flat surface. Adding a film of water increases the friction coefficient compared to the dry condition; reached 4.8% for the serrate surface. Increasing of friction coefficient in wet condition was interpreted [24]. They claimed that water forms liquid bridges between the counterface of bodies and the finger in which it increases the viscous shearing effect. Moreover, other researchers attributed this increase to the fact that water is an electrolyte during friction. Therefore, the effect of electrostatic charges plays a significant role in the hydrodynamic lubrication which generates attractive force between surfaces [25]. Consequently, the electrostatic charge was measured in voltage in case of single and double gloves in dry and wet conditions to investigate its effect on the static coefficient of friction. Once the test starts equal electrostatic charges are generated on the contact surfaces with different signs. The electrostatic charge (voltage) was measured using ULTRA STABLE SURFACE DC VOLTMETER. The device measuring range varies from 1/10 volt on a surface, and up to 20 000 volts (20 kV). Measurements were conducted ten times for each surface, then the average electrostatic charge and the standard error were calculated. Figure 7 illustrates that adding a film of water increases the electrostatic charge in case of single and double gloves by 7.5% and 42.3% respectively. Furthermore, the electrostatic charge generated due to double gloves sliding on scalpel is higher than that in single glove in the dry and wet conditions by 9.7% and 45.3 respectively, which clarifies the results in Figure 5 and Figure 6. The electrostatic charge increases the attractive force and adhesion between gloves and scalpel surfaces and subsequently the friction increases.

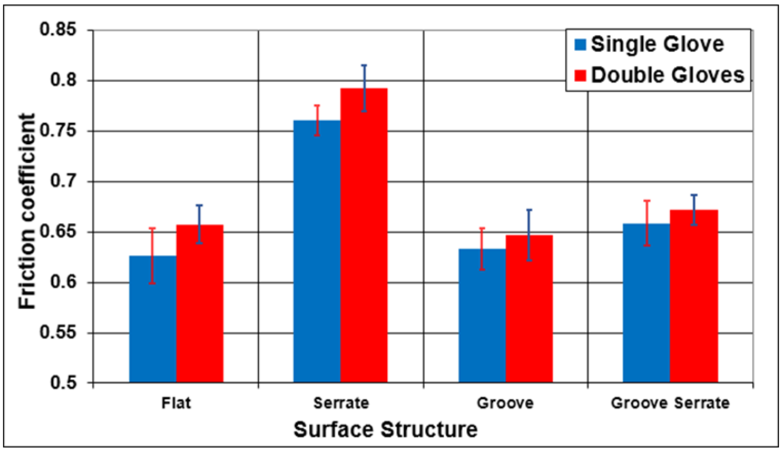

Figure 8. *Static friction coefficients for single and double gloves in case of a blood condition.*

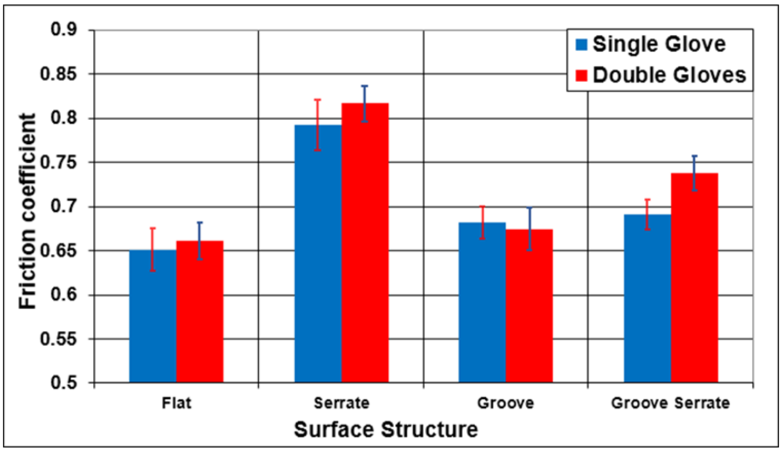

Figure 9. *Static friction coefficients for single and double gloves in case of blood mixed water condition.*

Figure 8 and 9 show the measured friction coefficient in case of blood and blood diluted by water. Animal blood was used in order to investigate the effect of blood film between gloves and scalpel. Then a mixture of 50 wt.% blood with 50 wt.% water is used to simulate the blood mixing water during surgery. Similar to dry and wet cases, double gloves friction coefficient with a scalpel was higher than a single glove. For the blood the friction coefficient increases by 4.9% (flat surface) and for blood mixed water increased by 6.8% (Groove-Serrate surface). The static coefficient of friction in case of blood increases compared to water and dry condition. This behaviour occurs due to coagulation in which the blood changes its phase from liquid to gel forming a blood clot which resists finger motion, and consequently, friction increased. In case of blood mixed water, the friction coefficient recorded the highest value, as mentioned before the presence of water increases electrostatic charge and with the blood clot, the friction remarkably increases.

Figure 5, Figure 6, Figure 8 and Figure 9 show that the serrated surface usually has higher friction coefficient in case of single or double gloves than in different working conditions. In case of double gloves; compared to flat surface, serrate surface increases the friction coefficient by 20.5% and 23.5% for blood and blood mixed water, respectively. Then, the grooved-serrated surface come in the second degree followed by grooved surface and finally, the flat one. Based on the previous results, using double gloves during surgery in handling scalpel does not affect the tactile sensing of the surgeon, and it allows him to use and manipulate scalpels without fear of scalpel slipping.

3. Conclusions

This paper presents a study on the effect of donning double gloves instead of single glove on the friction coefficient between latex gloves and surgical scalpel. Sliding gloved finger experiments were carried out in different working conditions, dry, water, blood and blood mixed water which are the stages of contact between gloved finger and scalpel during the surgery. Experiments were conducted on different scalpel surface topologies namely flat, serrated, grooved and grooved-serrated surfaces. Findings showed that sliding double gloves against various scalpel surface topologies in all conditions (dry, wet, blood, blood mixed water) gave a relative increase in the friction coefficient compared to donning a single glove. This increase was explained as wearing double gloves creates internal voids that trap the charge between the gloves internal surfaces. As the electrostatic charge increases, the adhesion between surfaces increases and consequently friction increases. Results showed that using of latex gloves in wet condition increased the friction relative to dry conditions. This increase occurs due to the rise of the electrostatic charge and the increase of viscous shear effect as a result of water brides between surfaces. The friction increased also in cases of blood and blood wet surfaces due to coagulation which forms a blood clot prevents sliding of a gloved finger against the scalpel surface. Eventually, findings illustrated that serrated surface gave the highest friction coefficient relative to the other three surfaces.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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