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Force application of laparoscopic surgeons under the impact of heavy personal protective equipment during COVID-19 pandemic

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A R T I C L E I N F O

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A B S T R A C T

Objective: Surgeons are required to wear heavy personal protective equipment while delivering care to patients during the COVID-19 pandemic. We examined the impact of wearing double gloves on surgeons' performance in laparoscopic surgery.

Methods: Eleven surgeons-in-training at the Surgical Simulation Research Lab of the University of Alberta were recruited to perform laparoscopic cutting tasks in simulation while wearing none, one pair, and two pairs of surgical gloves. Forces applied to laparoscopic instruments were measured.

Results: Wearing gloves prolonged task times (one pair of gloves: 301.6 ± 61.7 s; two pairs of gloves: 295.8 ± 65.3 s) compared with no gloves (241.7 ± 46.9 s; $p = 0.043$). Wearing double gloves increased cutting errors (20.4 ± 5.1 mm^2) compared with wearing one pair of gloves (16.9 ± 5.5 mm^2) and no gloves (14.4 ± 4.6 mm^2; $p = 0.030$). Wearing gloves reduced the peak force (one pair of gloves: 2.4 ± 0.7 N; two pairs of gloves: 2.7 ± 0.6 N; no gloves: 3.4 ± 1.4 N; $p = 0.049$), and the total force (one pair of gloves: 10.1 ± 2.8 N; two pairs of gloves: 10.3 ± 2.6 N; no glove: 12.6 ± 1.9 N; $p = 0.048$) delivered onto laparoscopic scissors compared with wearing no glove.

Conclusion: The combined effects of wearing heavy gloves and using tools reduced the touching sensation, which limited the surgeons' confidence in performing surgical tasks. Increasing practice in simulation is suggested to allow surgeons to overcome difficulties brought by personal protective equipment.

1. Introduction

During the COVID-19 pandemic, wearing heavy personal protective equipment (PPE) is strictly required to prevent healthcare providers from being attacked by the virus while providing services to patients.[1–5] The PPE for COVID-19 care includes heavy protective clothes, masks, hats, eye-shear and multilayer gloves.[6] A recent survey on surgeons in over 26 countries reported that wearing PPE hampered surgical performance due to visual impairment and communication impediments; surgeons' capabilities in making a decision, controlling surgical instruments, and building team collaboration were affected during their surgical procedures[7].

Performing a surgical procedure requires surgeons to use intricate instruments and control force precisely.[8–12] For example, in laparoscopic procedures, a robotic and image-guided surgical procedure is performed in the abdominal area. Surgeons need to reach the surgical site using long-shafted instruments with multiple hinges. Surgeons will undergo a long training phase to take in the mechanical properties of tools to their motor control system before they can confidently perform the task.[10,13,14] Thousands of receptors under the skin of a surgeon's hands and inside their muscles and joints work together, regulating their movements and force deliveries.[15] These sensorimotor pathways may be disturbed while a surgeon wears multilayer gloves.

Glove-wearing is a necessary measure to prevent two-way transmission of pathogens between patients and healthcare providers.[16–18] However, wearing heavy gloves may significantly hinder the adoption process with surgical instruments. The elastic property of medical gloves creates an uneven pressure on different areas of the hand, which may disturb the kinesthetic pathways and affect the natural perception of touching.[16,17,19–21] Wearing heavy gloves may affect a surgeon's control of the instrument and further affect the hand dexterity and movement coordination built

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between eyes, hands, and tools.[1,19,20] In this controlled laboratory study, we particularly investigate the impact of wearing multilayer gloves on the performance of surgical tasks performed using complex tools.

2. Methods

2.1. Participants

Eleven surgical trainees and students working at the Surgical Simulation Research Lab of the University of Alberta were recruited for this study. None of our participants had adopted formal robotic and laparoscopic training before the study. Information and objectives were explained to the participants prior to their participation in the study.

2.2. Data measurement

We measured the force delivery during a laparoscopic surgical procedure in the simulation environment. Specifically, we set up a laparoscopic task under a simulation environment where participants were asked to perform a task bimanually three times: with no gloves, wearing one pair and two pairs of gloves (*Fischer Nitrile* gloves, Fischer Scientific, Ottawa, Canada). The data of task performance (task time, number of cutting, cutting errors) and force profiles (peak force, time to peak force, and total force) were measured and collected.

2.3. Apparatus & task

A specific training box (30 cm × 30 cm × 20 cm) was set up to simulate a human abdominal cavity (Fig. 1). Multiple ports were created on the wall of this training box to allow surgical cameras and instruments to enter the box. A piece of white fabric was attached to the bottom of this training box. Participants were required to cut off a circle (4 cm in diameter) drawn to the centre of this fabric using a pair of laparoscopic scissors (Ethicon Endo-Surgery, Cincinnati, OH, USA) held in their dominant hand. To support the cutting, participants needed to manipulate and stabilize the fabric using a laparoscopic grasper (Ethicon Endo-Surgery, Cincinnati, OH, USA) held in their non-dominant hand. The cutting site was video captured by a digital camera (Stryker 0-degree endoscope, San Jose, California, United States) and displayed in a 19-inch high definition monitor. The digital camera processor, the lighting source and cables were located on a standard laparoscopic tower (Stryker Endoscopy, San Jose, California, United States), where the training box was placed in front.

Each individual was able to choose his or her preferred glove size (small, medium, or large). Depending on the participant's comfort, they were allowed to mix and match glove sizes for the double-glove condition.

Before beginning the tasks, we demonstrated the proper usage of a laparoscopic grasper and scissors to each participant. They were allowed one trial to familiarize themselves with the laparoscopic setting and the task procedure. The study began after this practice trial. Participants were instructed to complete the task as fast and as precisely as possible. To minimize any learning effect, the order of the glove/hand condition was counterbalanced among participants.

2.4. Cutting & force profiles

The FingerTPS (Pressure Profile Systems, Inc., Los Angeles, CA) force sensor (1.2 cm × 1.8 cm) was placed on the distal phalanx of the thumb of the dominant hand (the one holding the scissors). The exact place of the force sensor was adjusted among individuals so that the thumb ring of the laparoscopic scissors could firmly touch the sensor. The FingerTPS device was calibrated for each participant to ensure that the data were collected in a standardized manner.

Each participant completed the circle cutting task by constantly adjusting the positions of the grasper and the scissors and performing a number of cutting attempts. We reported the number of cuttings for each trial. In this study, we only examined the force application in one cutting attempt, when cutting was applied to the right apex of the circle (marked in red dot in Fig. 1). Around this point, participants should be comfortable in giving a full range of cutting movement as the scissors were held in a position aligning well to their right arms. For left-handed people, cutting action applied to the left apex of the circle was used for analysis. The extracted force data were exported to MATLAB (Mathworks, Palo Alto, CA) where force profiles were created for further analysis (Fig. 2).

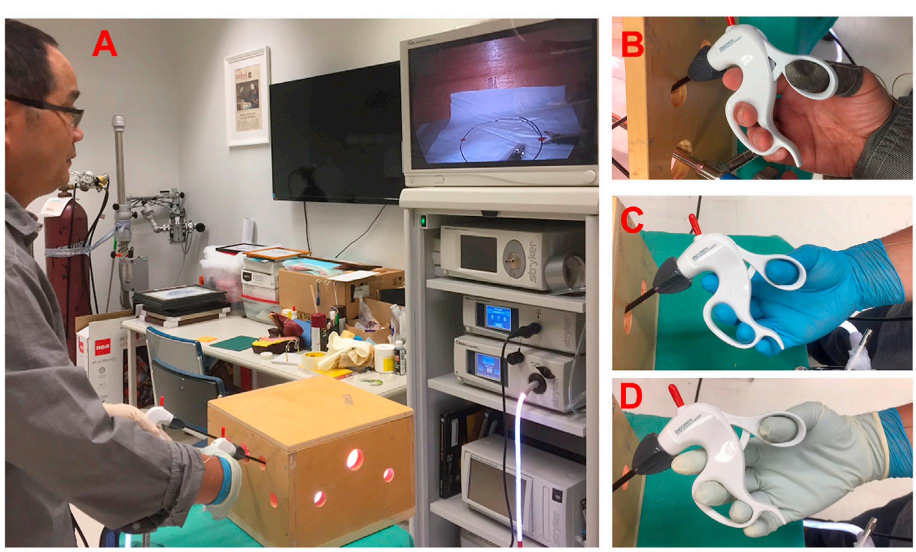

Fig. 1 Experimental setting images
A, A training box is placed in front of the laparoscopic tower. B-D, The subject needed to perform the cutting task using naked hands, wearing one pair and two pairs of gloves.

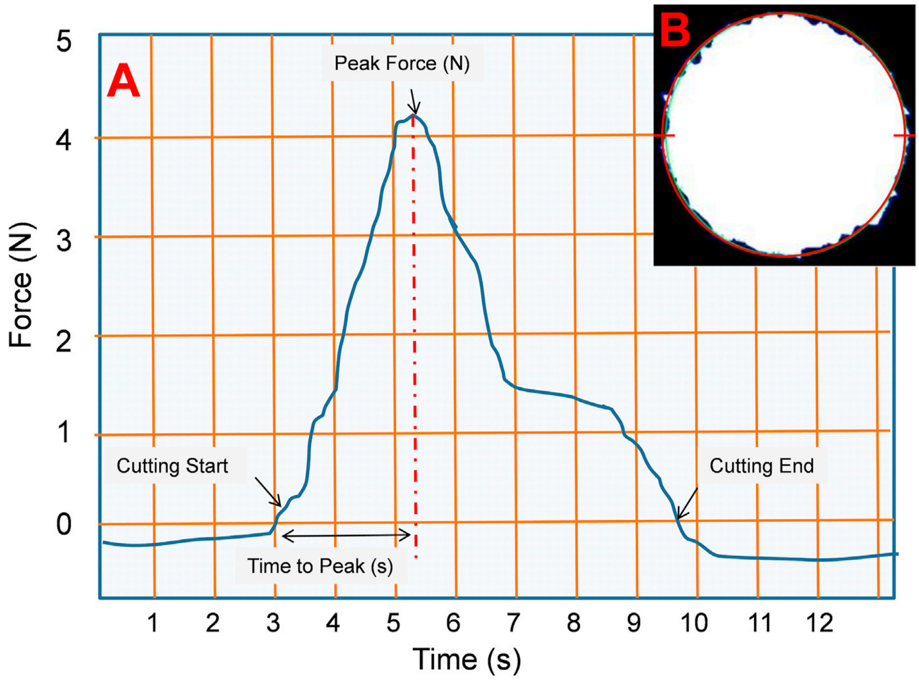

Fig. 2 Image of force profile
A, The force profile shows the starting and ending moments of the cutting, as well as the peak force and the time to peak force. The area covered by the force curve is reported as the total force. B, The cut-off fabric is scanned and compared with the predefined line. The deviation is reported as cutting errors.

The start of the trial was defined as the moment when the force exceeded 0.2 N and the end as the moment when the force dropped to 0.0 N. On each force profile, we reported the task time in seconds (s), the peak force in Newtons (N), the time to the peak force in seconds (s), and the total force in Newtons (N). The total force was calculated by measuring the area under the force curve (Fig. 2).

2.5. Cutting errors

The cut-off circle from each trial was collected and later scanned into the computer. The scanned images were transformed into binary (black and white) images to define the cutting edge. The cutting edge was then overlapped with the circumference of a 4 cm circle (predefined line). The deviation from the actual cutting line to the predefined circumference was reported as cutting errors, reported in the accumulated areas (mm^2).

2.6. Statistical analysis

Variables on task performance (task time, number of cutting, cutting errors) and force profiles (peak force, time to peak force, and total force) of each trial were compared over the three glove/hand groups using one-way ANOVA (Analysis of Variance) with SPSS 22.0 (IBM Corporation, New York, United States). Differences between groups are reported as the mean ± standard deviation, where $p < 0.05$ was considered statistically significant. *Post-hoc* analysis was also completed (*Fisher's Least Significant Difference*) when needed.

3. Results

The one-way ANOVA reported significant differences among the no gloves, one pair and two pairs of gloves groups in task time ($F = 3.507$, $p = 0.043$, $\eta^2 = 0.19$), cutting errors ($F = 3.940$, $p = 0.030$, $\eta^2 = 0.21$), total force ($F = 3.364$, $p = 0.048$, $\eta^2 = 0.18$) and peak force ($F = 3.314$, $p = 0.049$, $\eta^2 = 0.18$); no significant differences appeared in the number of cuttings ($F = 2.613$, $p = 0.090$, $\eta^2 = 0.15$) or the time to peak force ($F = 0.586$, $p = 0.563$, $\eta^2 = 0.04$) (see Table 1).

For task time, the *post-hoc* analysis revealed significant differences between the groups of no gloves and one pair of gloves ($p = 0.023$), and the groups of no gloves and two pairs of gloves ($p = 0.038$); but there were no significant differences between the one and two pairs of gloves groups ($p = 0.817$; Fig. 3A).

The *post-hoc* analysis on cutting errors revealed significant differences between the groups of no gloves and two pairs of gloves only ($p = 0.009$); the differences were not significant between groups of no gloves and one pair of gloves ($p = 0.245$) or one pair and two pairs of gloves ($p = 0.118$; Fig. 3B).

Table 1
Task performance compared over three groups

	No gloves	One pair of gloves	Two pairs of gloves	*F* value	*p* value	η^2
Task time, mean ± SD, s	241.7 ± 46.9	301.6 ± 61.7	295.8 ± 65.3	3.507	0.043[a]	0.19
No. of cutting, mean ± SD	18.7 ± 4.4	23.8 ± 6.2	23.5 ± 6.6	2.613	0.090	0.15
Cutting errors, mean ± SD, mm^2	14.4 ± 4.6	16.9 ± 5.5	20.4 ± 5.1	3.940	0.030[a]	0.21
Total force, mean ± SD, N	12.6 ± 1.9	10.1 ± 2.8	10.3 ± 2.6	3.364	0.048[a]	0.18
Peak force, mean ± SD, N	3.4 ± 1.4	2.4 ± 0.7	2.7 ± 0.6	3.314	0.049[a]	0.18
Time to peak, mean ± SD, s	3.8 ± 1.3	4.1 ± 1.5	4.5 ± 1.6	0.586	0.563	0.04

[a] Statistically significant.

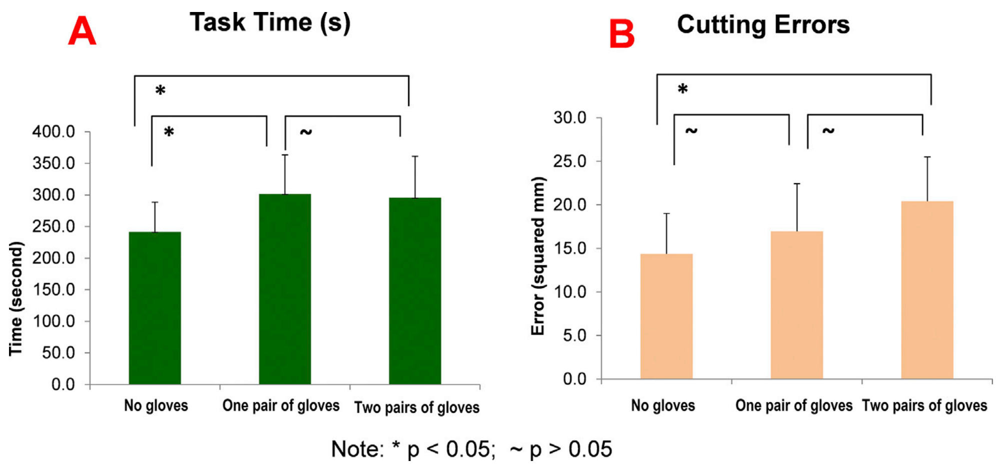

Fig. 3 Post-hoc analysis of task time and cutting errors among different groups
A, Task time is compared among different hand and gloving conditions. B, Cutting errors are compared among different hand and gloving conditions.

For force analysis, the *post-hoc* analysis on the total force revealed significant differences between the groups of no gloves and one pair of gloves ($p = 0.026$), as well as two pairs of gloves ($p = 0.041$); however, the difference was not significant between the one and two pairs of gloves groups ($p = 0.844$; Fig. 4). When examining the peak force, we only found a significant difference between no gloves and one pair of gloves groups ($p = 0.020$); but not between the groups of no gloves and two pairs of gloves ($p = 0.066$), or one pair and two pairs of gloves groups ($p = 0.591$; Fig. 4).

4. Discussion

Wearing heavy PPE is inevitable during the COVID-19 pandemic. Previous studies with survey data reported that wearing PPE degrades surgical performance.[7] Evidences from this study specifically reveal that wearing thick gloves does affect task performance.

Research done by Johansson in 1979 reported that the density of subcutaneous receptors at the fingertip can be as high as 250 units/cm^2, about five times denser than at the palm of the hand.[15] These mechanical receptors detect changes in force in the hands. Tactile pathways from these receptors are used for regulating the force generation in hands to control the scissors.[22] Wearing gloves, either one or two pairs, alter the sensitivities of those receptors. The results from this study indicated that, when wearing gloves, participants were less confident in controlling the scissors; they reduced the peak force and the total force during cuttings, and performed smaller cuttings compared to using hands directly. Even though they were taking these precautionary measures, the impact of glove-wearing was still measurable. Wearing gloves prolonged task times and was associated with more cutting errors.

Demonstrating the negative impact of glove-wearing on health performance is not our ultimate purpose. We are more interested in finding the solution. We believe that training is required when healthcare providers need to wear heavy PPE.[19,22] When practicing with gloves, health personnel can readjust their physiological properties to those receptors, reinstall the sensitivities in hands, and regain the precise control over tools.[7,21] The knowledge gained from this study can be applied to the battel with COVID-19. We strongly suggest giving healthcare providers sufficient training opportunities to practice skills with PPE before they deliver care to patients.[2,21] We intend to address such training using simulation to minimize the side damage done to patients at the early phase of practice.

This study has some limitations. First, the subjects included surgical trainees with limited experience in laparoscopic training. Physicians, surgeons, and nurses with extensive experience wearing gloves may produce different outcomes. Second, the circle-cutting task is a simple task that cannot fully represent the true surgical procedure performed by surgeons in caring for COVID-19 patients.[1,4,7] Precaution will also be needed when applying our findings to real surgical procedures performed by a team of healthcare providers.

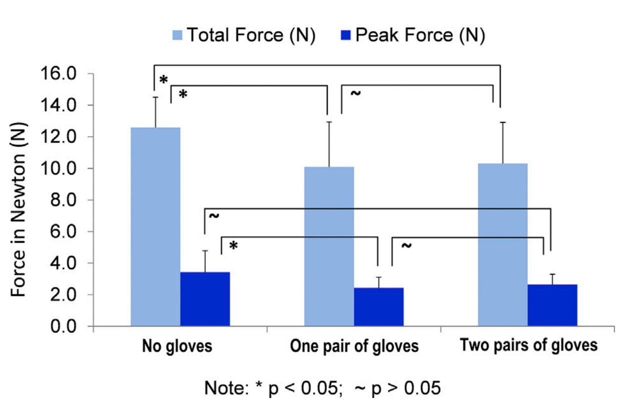

Fig. 4 Post-hoc analysis of total force and peak force among different hand and gloving conditions

5. Conclusion

In summary, the results from this study demonstrate the impact of glove-wearing on the performance of surgery when using complex surgical instruments. Participants with heavy PPE often reduce their control force over the tools when delivering surgical tasks to patients. Increased practice in simulation is suggested to facilitate healthcare providers to adapt to the altered sensation and regain confidence when performing healthcare procedures.

Conflict of interest

The authors declare no conflicts of interest.

Ethics approval

The methods used in the study were reviewed and approved by the University of Alberta Health Ethics Review Board. All participants gave consent to participate in the study.

Consent for publication

Written consent was obtained from all the participants for the publication of data and images.

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