Development and Validation of a Measurement System for Laparoscopic Surgical Procedures

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Abstract: This paper presents details of the development and validation of a measurement system for laparoscopic surgical procedures. An individual marker set is attached to each surgical instrument, and hence the developed system can simultaneously track multiple surgical instruments. The tracked surgical instruments can be exchanged during an operation. The movements of surgical instruments such as grasping forceps, scissors forceps, clip applicers, and needle holders are measured, and their tip positions, opening ratios, gripper rotation angles, and orientations are calculated online. Two strain gauges are attached to the gripper of the grasping forceps to measure the grasping point and force. In validation experiments, data from 46 cases of lymphadenectomy and renal parenchyma suturing using porcine cadaver organs performed by 44 subjects were acquired by measurement, and the movements of the surgical instruments used were recorded. A questionnaire survey regarding the operational feel about the surgical instruments was conducted, and the results show that this system has little impact on the operational feel.

Key Words: laparoscopic surgery training, motion capture system, skill evaluation, grasping force measurement.

1. Introduction

Laparoscopic surgery is one of the surgical techniques for operations within the abdominal or pelvic cavities. In laparoscopic surgery, surgical instruments such as an endoscope and forceps are inserted into the patient’s abdomen through trocars, which are used as portals for surgical instruments. Surgeons use these instruments to remove an organ or lesion. Compared to conventional laparotomy surgery, which often generates large incisions, laparoscopic surgery generates few and small incisions; hence, this method is less invasive, and as a result, patients suffer less inconvenience. Because of the reduced invasiveness, postoperative pain and the likelihood of contracting infectious diseases are reduced, and the recovery period is shortened. Owing to those advantages, laparoscopic surgery has become popular.

However, in laparoscopic surgeries, surgeons have to use advanced techniques. The operation is conducted by referring to the laparoscopy view of the abdominal cavity, which is displayed on a two-dimensional laparoscopic monitor. The visual information is limited because of the loss of the three-dimensional effect and the limited field of view. Furthermore, surgeons must familiarize themselves with specific surgical instruments which are longer than usual and also cope with the inconsistency of hand-eye coordination [1]. Efficient laparoscopic training for novice surgeons is important, especially because improper manipulation of forceps may cause complications such as organ damage and bleeding [2].

There are many types of training methods for laparoscopic surgical operations, such as the dry lab, wet lab, and virtual reality (VR) surgery simulator. The dry lab uses human organ models fabricated from plastic or rubber, and the wet lab uses animal cadaver organs. However, surgical skills are evaluated using simple criteria such as the task completion time of the training, and the skills are not quantified well. Furthermore, there is variability in the skills acquired through training, and skill transmission from experts to novices has mainly been achieved by imitating demonstrations by experts. Therefore, it takes time for novices to master surgical operations. To improve the skill transmission efficiency, an objective surgical skill evaluation method is an urgent necessity.

In laparoscopic surgical operations, there are basic operations such as forceps handling and cooperative movement of both hands, and applied operations such as dissection and suturing. To measure these operations, several systems have been developed. The Hiroshima University endoscopic surgical assessment device (HUESAD) [3] and the tracking endoscope (TrEndo) [4],[5] measure the basic operations of surgical instruments. Both systems measure the tip position of surgical instruments. Takayasu et al. measured the upper body position of surgeons in the suturing operation and analyzed the posture patterns of surgeons with two different skill levels using a motion capture (Mocap) system [6]. The Imperial College Surgical Assessment Device (ICSAD) [7],[8] has been developed to measure the hand motion of surgeons using an electromagnetic

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tracking system. The grasping force of forceps is an important index used to analyze the skill levels of surgeons. Yoshida et al. developed a system to measure the force on the tip of forceps by using a 3DoF force sensor, and carried out measurement experiments on wet lab training for dissection procedures [9]. Kuwana et al. developed grasping forceps with a 3DoF MEMS tactile sensor and quantified the stress generated in organs [10]. Kowalowski et al. developed a laparoscopic surgery training system, iSurgeon, in which markers were attached to surgical instruments (forceps and dissector), and their movements were tracked by a Mocap system [11].

However, HUESAD [3] and TrEndo [4],[5] do not support surgical instrument exchange during the operation because these systems measure the movement of forceps by sensors attached to the trocar, and the forceps are constrained by the measurement system. Human motion capturing systems (e.g., [6]–[8]) cannot recognize which surgical instrument is currently being used because these systems track only human motion and do not capture the movement of surgical instruments. Because the surgeon’s hand movements depend greatly on the surgical instrument, it is desirable for the measurement system to recognize the surgical instrument used by the surgeon. In iSurgeon [11], the surgical instruments are exchangeable in principle; however, tasks are limited to laparoscopic suturing and knot tying on a standardized silicone suture pad, and exchange of surgical instruments is not considered. Furthermore, the opening ratio and grasping force of forceps are not measured in iSurgeon.

Motivated by this background, the authors developed a laparoscopic surgery training system in which measurements of multiple surgical instruments are tracked [12]. Unlike HUESAD [3] and TrEndo [4],[5], because forceps are not constrained by the measurement system, this system supports exchange of surgical instruments during the operation. Furthermore, unlike the human motion capturing systems (e.g., [6]–[8]), this system can identify the surgical instruments used by the surgeon. This system not only measures the tip position and orientation but also the opening ratio and grasping force of surgical instruments. In addition, the developed system can record surgical operations involving dissection and suturing tasks in wet lab (animal) training. This is considered to be an advantage of the system over iSurgeon [11], which can record only the suturing task in the dry lab.

However, in this system [12], because the tip position and the opening ratio were calculated based on the individual marker coordinates, there was a problem with the measurement accuracy when occlusion occurred. In addition, the tip position and the opening ratio of the forceps were calculated off-line, and hence those data could not be used online. To analyze the difference between the surgical skills of expert and novice surgeons, not only the grasping force but also the grasping point was considered as a key index. In a discussion with expert urologists on the skill difference between expert and novice surgeons, the authors hypothesized that expert surgeons tend to grasp tissues with the forceps at the tip of the gripper, whereas novices tend to grasp them with the whole surface of the gripper. In addition, the former system [12] measured the grasping force using only one strain gauge, assuming that the grasping point was the middle of the gripper, and therefore the measured force was not always accurate.

### Table 1: Specification of OptiTrack Prime41 camera [13].

| Parameter             | Value                  |
|-----------------------|------------------------|
| Frame Rate            | 30 fps to 180 fps      |
| Image Resolution      | 2048 × 2048            |
| Latency               | 5.5 ms                 |
| Shutter Type          | Global                 |
| FOV                   | 51°                    |
| Minimum Shutter Speed | 10 μs                  |

This paper describes an improved measurement system for laparoscopic surgery procedures that supports online processing and measurement of the grasping point. In addition, the results of a questionnaire survey completed by the subjects of the measurement experiments on the operational feel of the developed system are reported.

## 2. Measurement System

### 2.1 System Components

In the measurement system, an optical Mocap system, OptiTrack, supplied by NaturalPoint Inc. (USA), is used to capture the forceps movement. The specifications of the Mocap camera Prime41, which is used in the system, are shown in Table 1. In this work, the frame rate of the cameras is set to 30 fps. The tip position, gripper opening ratio, gripper rotation angle, and orientation of the forceps are calculated by the position and orientation of two marker sets attached to the surgical instruments. The grasping force and point are measured by two strain gauges attached to the backside of the gripper of the grasping forceps. A microcomputer, Arduino Pro Mini, is used to read the sensor output and transmit the data to the PC via ZigBee wireless communication. The sensor measurement unit is installed near the training box used for wet lab training. The configuration of the system is shown in Fig. 1.

### 2.2 Support for Online Processing

The Mocap system used in the system is capable of interprocess communication and real-time measurement data streaming via a LAN. In the former system [12], 3D positions of every marker were transmitted to the PC, and the tip position was calculated off-line based on the marker positions. In the improved system presented in this paper, the marker set is registered as a RigidBody with the Mocap system, only the centroid and orientation of the RigidBody are transmitted to the PC, and the tip position is calculated online based on the centroid and the ori-
2.3 Measurement Method for Forceps Behavior

In this work, a grasping forceps (KARL STORZ non-windowed grasping forceps, insert: K33310DY, sheath: K33300, handle: K33131), scissors forceps (OLYMPUS scissors forceps, scissors unit: A64810, sheath: A60800, handle: A60201), and clip applier (Weck Hem-o-lok Polymer Locking Ligation System Applier size L) were used for the dissection task, and two needle holders (Japan Polymer Technology Co. Ltd. EYP2009S-CN, EYP2009LCNK) were used for the suturing task. The infrared reflective markers were attached to the surgical instrument using a jig fabricated from ABS resin manufactured by a 3D printer. In laparoscopic surgery, the tip of the surgical instrument is hidden because the instrument is inserted into the patient’s abdomen, and the tip position and opening ratio cannot be measured directly. Therefore, the tip position and opening ratio are calculated by the positional relationship of the two marker sets attached to the forceps sheath and handle.

2.3.1 Tip position

As described above, the marker sets are registered as Rigid-Body with the Mocap system, and their centroids and orientations are computed in the Mocap system. The forceps tip position is obtained with respect to the local coordinate system $\Sigma_l$ with the rigid body centroid coordinate $v_{Lo}$ as the origin, and then converted to the global coordinate system using the orientation and centroid of the rigid body. Figure 2 shows the positional relationship between the marker set and the coordinate system. Because the orientation representation on the Mocap system employs zyx Euler angles, the forceps tip position $v_{Gtip}$ in the global coordinate system $\Sigma_G$ in Fig. 2 can be expressed as follows in terms of the forceps tip position $v_{Ltip}$ in the local coordinate system of the marker set:

$$v_{Gtip} = R_z(\gamma)R_y(\beta)R_x(\alpha)v_{Ltip} + v_{Lo}. \quad (1)$$

Here, $R_z(\gamma), R_y(\beta), R_x(\alpha)$ are the rotation matrix around the x, y, and z axes, respectively, and $\gamma, \beta, \alpha (\circ)$ are the rotation angles of these conversions. The forceps tip position $v_{Ltip}$ with respect to the local coordinate system of the marker set was obtained in advance. This system calculates the forceps tip position from the centroid position $v_{Lo}$ and the orientation obtained from the Mocap system. To remove the noise included in the centroid data of the marker sets, the Savitzky–Golay filter [14] was used. The polynomial order of the filter was set to 3, and the number of sampling frames of the filter was set to 31. The Mocap sampling rate was set to 30 fps (frames per second).

2.3.2 Accuracy evaluation test of tip position

The accuracy evaluation test of the tip position was carried out by comparing the tip position calculated by Eq. (1) and the actual tip position. The actual tip position was measured by the Mocap system by tracking the marker attached to the tip of the gripper of the forceps. Evaluation tests were conducted for the grasping forceps, scissors forceps, clip applier, and needle holders. In the evaluation tests, each forceps was moved upward and downward, left and right, and backward and forward, and the positional error between the estimated tip position $v_{est}$ and the actual tip position $v_{act}$ was calculated. The positional error $\Delta v$ can be expressed as follows:

$$\Delta v = \|v_{est} - v_{act}\|. \quad (2)$$

The results of the accuracy tests are shown in Fig. 3. As shown in the figure, the positional errors of each forceps were less than 2 mm. The offset errors in Fig. 3 are considered to be due to the gap between the position of the attached tip marker and the estimated tip position. Therefore, if the offset errors are excluded, the error variation range is within 1 mm in each forceps. The error variation range of the former system was 2 mm to 4 mm [12]. In addition, instead of individual marker positions, this system calculates the tip position by using the centroid position and the orientation of a marker set, and therefore it is more robust against occlusion.

2.3.3 Opening ratio

In this system, the opening ratios of the grasping forceps, scissors forceps, and clip applier are calculated to count the operation times of the scissors. As with the tip position of a forceps, the opening ratio cannot be measured directly because the forceps is inserted into the patient’s abdomen in laparoscopic
surgery. Therefore, the opening ratio is calculated by the positional relationship between two marker sets on the forceps (see Fig. 4). One marker set is attached to the handle, and the other is attached to the sheath of the forceps. As shown in Fig. 4, the opening ratio is calculated by the distance between $p_h$ and $p_o$. As well as the tip position, the position vectors $p_h$ and $p_o$ are calculated by converting from the local coordinate system to the global coordinate system. The distance $d$ between $p_h$ and $p_o$ can be expressed as follows:

$$d = \|p_h - p_o\|.$$  

(3)

The forceps opening ratio $A$ can be expressed as follows:

$$A = 100 \left(1 - \frac{d - d_{\min}}{d_{\max} - d_{\min}}\right) \%,$$  

(4)

where $d_{\max}$, $d_{\min}$ are the maximum and the minimum distances between $p_h$ and $p_o$, respectively. When the gripper is closed, the opening ratio is 0%, and when the gripper is open, the opening ratio is greater than 0. As shown in Fig. 4, the position vector $p_h$ draws an arc trajectory around the rotational joint of a handle, and the relative motion of $p_o$ for $p_h$ is not linear. However, in this system, the variation range of the distance $d$ is at most 2 cm, and the error due to approximation to a straight trajectory is sufficiently small. Therefore, to simplify the model, the opening ratio is calculated from the distance $d$. In addition, there is a dead zone called the backlash in each forceps that does not contribute to the open/closed state of the tip even if the handle is operated. Therefore, for the grasping forceps, scissors forceps, and clip applier, a calibration test was performed to obtain a threshold by measuring the actual opening ratio. Through this experiment, the threshold for reducing the influence of the backlash was determined.

### 2.3.4 Gripper rotation angle and representation of orientation

The gripper of the forceps can rotate around the axis of the forceps with respect to the handle. The gripper rotation angle is calculated from the relative rotation between the marker set attached to the handle and that attached to the sheath [12]. Note that the endpoint of the needle holder does not rotate around the axis, and therefore the gripper rotation angles are calculated only for the grasping forceps, scissors forceps, and clip applier. The orientations (roll, pitch, yaw) of each forceps are also measured in this system by using the measurement data of the Mocap system. Figure 5 shows an overview of the gripper rotation angle and a representation of the orientation of the forceps. Note that the roll, pitch, and yaw defined in Fig. 5 are different from $\alpha$, $\beta$, and $\gamma$ used in Eq. (1). The roll, pitch, and yaw represent the orientation of the handle, whereas $\alpha$, $\beta$, and $\gamma$ represent the orientation of the gripper after rotating around the axis of the forceps.

### 2.4 Measurement of Grasping Force and Point

The grasping force and point are calculated by measuring the strain of the gripper of the grasping forceps by using strain gauges attached to the backside of the gripper. In this system, strain gauge BF350-3AAN [15] produced by Elecrow Technology Co. Ltd. (China) and a strain amplifier module that uses the amplifier chip TP09 [16] produced by 3PEAK Inc. (China) were used. The measured strains are amplified and read by a microcomputer board (Arduino Pro Mini). The strains are transmitted from the Arduino Pro Mini to the PC via the ZigBee-based wireless communication module XBee S1 supplied by Digi International Inc. (USA) and recorded on the PC. The amplifier, microcomputer, battery, and wireless transmitter are packed in a housing fabricated from ABS resin (see Fig. 1). Figure 6 shows the configuration of the grasping force/point measurement system.

#### 2.4.1 Forceps with strain gauges

In this measurement system, a non-windowed grasping forceps was used. To attach the strain gauges, the back of the gripper of the forceps was flattened, and two strain gauges were installed. Figure 7(a) shows the position of the strain gauge
attached to the gripper of the forceps. Because waterproofness and mechanical strength are required, the strain gauges and the wiring part were covered with a photo-curing resin. Figure 7 (b) shows an overview of the gripper of the grasping forceps with strain gauges.

2.4.2 Calculation method for grasping force and point

As shown in Fig. 8, the strain gauges were attached to the fixed beam of the gripper of the forceps, which has a cantilever structure. By approximating the gripper of the forceps as a cantilever beam, the grasping force and point can be calculated from the strains. When a bending moment $M$ is applied to a cantilever, $M$ can be expressed as follows:

$$M = \frac{EI}{y} \epsilon_x,$$

where $E$ is Young’s modulus, $I$ is the section modulus, $y$ is the distance from the neutral axis, and $\epsilon_x$ is the strain generated along the x-axis (see Fig. 8).

Let $L_1$ and $L_2$ be the distances between the loading point (grasping point) and the center of the tip gauge, and between the loading point and the center of the root gauge, respectively, as illustrated in Fig. 8. When a load $W$ is applied to the loading point, bending moments $M_1 = WL_1$ and $M_2 = WL_2$ will be generated at the tip gauge and the root gauge, respectively. The output of the strain gauge is amplified by the Wheatstone bridge and strain amplifier. The output of the strain amplifier is converted from an analog signal (0 V to 5 V) to a digital signal (0 to 1023). The zero point (output at the no-load condition) can be adjusted by a variable register of the strain amplifier. Because the grasping force is unidirectional, the zero point is adjusted to 20 at the digital signal level. Let $S_1$ and $S_2$ be the digitized output of the tip gauge and the root gauge, respectively. Note that $S_1$ and $S_2$ are deviations from the zero point offset (i.e., 20). Equation (5) can be rewritten as follows:

$$WL_i = k_iS_i \quad (i = 1, 2).$$

From these discussions, to calculate the load $W$ and loading point $L$, strain gauge calibration tests to obtain the coefficients $k_i$ were carried out.

2.4.3 Strain gauge calibration tests

Strain gauge calibration tests were conducted by suspending a weight using a wire at the gripper of a forceps, and the outputs of the strain gauges were recorded. Fifteen different loads from 0 g to 750 g at 50 g intervals were applied to the gripper. The load was applied at six different points: 3 mm, 6 mm, 9 mm, 12 mm, 13.5 mm, and 15 mm from the center of the root gauge toward the distal end of the gripper. The experimental settings and loading points are shown in Fig. 9. After the experiment, the product $WL$ of the load and the load point was plotted against the digitized outputs of the tip and root strain gauges, and the regression line was calculated (see Fig. 10). From the results plotted in Fig. 10, the coefficients $k_1$ and $k_2$ in Eq. (6) were identified as $k_1 = 61.9 \text{ g/mm}$ and $k_2 = 51.4 \text{ g/mm}$.

The relationship between $L_1$ and $L_2$ is given by $L_1 = L_2 - 7.5$ (see Fig. 7 (a)). From the relationship, the load $W$ and the loading point $L_2$ can be calculated from $E_1$ and $E_2$ as follows:

$$\begin{cases} W = 6.9S_2 - 8.3S_1 \\ L_2 = \frac{51.4S_2}{6.9S_2 - 8.3S_1} \end{cases}$$

Note that when the loading point (grasping point) is between the two strain gauges ($L_2 < 7.5 \text{ mm}$), the output of the tip gauge $S_1$ will be zero. In this case, $W$ and $L_2$ cannot be independently obtained from Eq. (7), and hence $W$ is estimated by assuming...
that the loading point is at the middle of the two gauges ($L_2 = 3.8$ mm).

### 2.4.4 Accuracy evaluation

Accuracy evaluation of the load and loading point was carried out by using the data obtained in the strain gauge calibration tests described above. The estimated loads and points were calculated using Eq. (7) from the strain gauge measurement values $S_1$ and $S_2$ in the calibration tests (Section 2.4.3). The results of the test are shown in Fig. 11.

As shown in Fig. 11, when the loading point is between the two strain gauges ($L_2 = 3$ mm, or 6 mm), the accuracy of both the load and the point deteriorates. This is because the output of the tip gauge becomes zero ($S_1 = 0$) in this situation, and the load point is assumed to be $L = 3.8$ mm as described above. On the other hand, when the loading point is at the distal side of the tip gauge ($L_2 = 9$ mm, 12 mm, 13.5 mm, or 15 mm), there are no large errors in both the load and point. In laparoscopic surgery, it is observed that experts tend to grasp organs near the distal end of the forceps. Therefore, the grasping force and point are expected to be detectable with sufficient accuracy in most cases.

### 3. Measurement Experiment

#### 3.1 Experiment Environment Setup

Measurement experiments were performed under the revised measurement system. Figure 12 shows the experiment environment, and Fig. 13 shows the arrangement of the Mocap cameras. Six Mocap cameras were used, and the Mocap frame rate was set to 30 fps. The experiments were recorded with a video camera, and the endoscopic camera image was also recorded by a PC connected to the endoscopic camera system.
3.3 Experiment Results

Among the obtained measurement data of 46 cases, the data of a urologist are presented as a typical result in this section. Figure 14 shows a snapshot of the lymphadenectomy task, and Fig. 15 shows the trajectories of each forceps tip position in the task. These trajectories are smoothed by the Savitzky–Golay filter. The opening ratios of the grasping/scissors forceps and clip appliers during the lymphadenectomy task are plotted in Fig. 16. The roll, pitch, and yaw angles of the forceps and clip applier during the lymphadenectomy are plotted in Fig. 17. In the tip position trajectory shown in Fig. 15, the trajectory that lies outside the training box is excluded. The tip position of a surgical instrument exits the training box when it is exchanged for another instrument. The exchange between the scissors forceps and the clip applier frequently occurred in the lymphadenectomy task. In addition, as shown in Fig. 17, the clip applier was inserted two or three times when it was being used. This is because the surgeon must apply two clips when cutting blood vessels, to arrest bleeding in the lymphadenectomy task. The grasping force and point are shown in Fig. 18. When a forceps does not grasp anything, the grasping point data are not reliable. Therefore, those data are excluded from Fig. 18. Among these results, the fluctuation in the grasping force corresponding to the actual grasping motion was confirmed, and the grasping point was also confirmed as generally correct by comparison with the endoscopic camera image during the experiment. It is confirmed that the developed system measures the tip position and opening ratio of the forceps robustly against the occlusion and disturbances.

To evaluate surgical skills, the following indices are considered in this work:

(a). Task complication time.

(b). Average velocity \(v\), acceleration \(\dot{v}\), jerk \(\ddot{v}\) of the surgical instruments.

(c). Path length \(D\) of the tip trajectory of the surgical instruments.

(d). The number \(N_o\) of open/close iterations of the gripper.

(e). Average attitude angles (roll, pitch, and yaw).

(f). Average grasping force \(f\) of the grasping forceps.

(g). Average grasping point \(L_2\) on the surface of the gripper.

The indices (b) and (c) are calculated from the tip trajectories plotted in Fig. 15. The index (d) is calculated from the opening ratio plotted in Fig. 16. The index (e) is calculated from the attitude data plotted in Fig. 17. The indices (f) and (g) are calculated from the grasping force/point data plotted in Fig. 18. The calculated indices of the urologist are shown in Table 2, and the task complication time of the surgeon is 807.6 s. As described in the Introduction, skill measurement systems developed so far could not detect the exchange of surgical instruments, and hence the indices (a)–(g) for multiple instruments could not be obtained. As presented in Figs. 16 (b) and 17 (b), the developed system detects the exchange between the scissors forceps and the clip appliers, recognizes the surgical instruments, and captures the movements of them. The developed system enables the skill evaluation based on the indices (a)–(g) for multiple instruments. The measurement data of all 44 subjects are now being analyzed, and the results will be reported soon.

### 3.4 Operational Feel Evaluation

To capture/measure the forceps motion and grasping force/point, infrared reflective marker sets and strain gauges were attached to the surgical instruments. To analyze surgeons’ skill, it is desirable that these instruments have the same usual operational feel. However, these attachments may adversely affect the operational feel of the forceps. Therefore, to validate the impact of the attachments, a questionnaire survey was conducted on the operational feel of the forceps with markers and strain gauges for 46 cases (44 subjects) after the measurement experiment. The questions were as follows:
1. With respect to the forceps used in lymphadenectomy, whether the attached markers disturbed the surgical operation or not.
   (a) Grasping forceps
   (b) Scissors forceps
   (c) Clip applier

2. With respect to the forceps used in renal parenchyma suturing, whether the attached markers disturbed the surgical operation or not.
   (a) Suturing needles (right)
   (b) Suturing needles (left)

3. With respect to the grasping forceps with strain gauges used in the grasping force measurement:
   (a) Whether the strain gauges attached to the tip of the forceps disturbed the forceps operation or not (e.g., moving the forceps).
   (b) Whether the strain gauges attached to the tip of the forceps disturbed the grasping operation or not.
   (c) Whether the cable that was wired to the measurement unit disturbed the forceps operation or not.
   (d) Whether any difficulty was felt in grasping with windowless forceps or not (only for subjects of the previous experiment using windowed forceps, \( N = 19 \)).

For these items, the responses at a five-point evaluation (1: I do not think that it was at all disturbing, 2: I do not think that it was disturbing, 3: Average, 4: I agree that it was disturbing, 5: I strongly agree that it was disturbing) are summarized in Fig. 19. Table 3 shows the average value of each question.

As shown in Table 3, each evaluation is less than 2. Therefore, it is considered that forceps with markers have little impact on the operational feel. In addition, for the grasping force/point measurement system, each evaluation is less than 2, confirming that this system has little impact on the forceps operation. From these results, the improved system has little impact on the forceps operations, and surgeons are able to perform operations in the same way. This is considered to be an advantage for analyzing the surgeons’ skill with this system.
4. Conclusion

In this paper, the development and validation of a measurement system for laparoscopic procedures are presented. Measurement experiments and questionnaire surveys on the operational feel of forceps were carried out for 46 cases, and it was confirmed that this system has little impact on the operational feel of the forceps. The analytical results of the measurement data and the results of the skill evaluation will be reported soon. It is expected that the developed system will be applied to online skill evaluation for surgery training, and to computer-assisted surgery (CAS).

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