Verification of Validity of Assessment Items in Training System for Laparoscopic Surgery

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Abstract—In laparoscopic surgery, training is necessary for surgeons to enhance the safety of the surgery. In our training system, "the operating force of the forceps while knotting the suture thread (knotting procedure)" and "the angle of the left and the right wrists while twisting the suture thread around the forceps (twisting procedure)" are considered as possible assessment items for surgical operation of ligation. The purpose of this paper is to verify the validity of these two assessment items in the training system by comparing the measurement data which were obtained in past measurements for surgical operation of ligation performed by intern surgeons and skilled surgeons. As for the operating force of the forceps for knotting procedure, it was confirmed that there is a tendency of which intern surgeons pull the suture thread by applying large force more than the needed at the tip of the forceps. As for the angle of the left and the right wrists for twisting procedure, it was confirmed that the amount of twisting the wrists while twisting the suture thread around the forceps by intern surgeons is not as large as that of skilled surgeons. It is considered that the skilled surgeons intentionally twist their both hand's wrists largely in order to twist the suture thread around the forceps smoothly. Therefore, it is concluded that the proposed assessment items in training system are effective for improvement of a surgical skill.

Index Terms—laparoscopic surgery, training system, ligation, operating force of the forceps, angle of wrists

I. Introduction

Recently, medical treatment performed by laparoscopic surgery has been increasing. Laparoscopic surgery is minimally invasive surgical operation, however, surgeons must have considerable skills to perform laparoscopic surgery. Therefore, training is necessary for surgeons to enhance the safety of the laparoscopic surgery.

For training purposes in laparoscopic surgery, Augmented Reality (AR) or Virtual-Reality (VR) based Simulator training system and Box training system are generally used [1]–[3]. One of the advantages of the VR based Simulator training systems is in the fact that they have haptic feedback. An application of haptic technologies to medical simulations for laparoscopic surgical training has been discussed in [4]. In separate studies, a visualization of surgical training data such as force, position, rotation, and synchronized video for improving skill acquisition has been discussed in [5].

In the VR based Simulator training system, quantitative assessment for trainee's surgical operation is provided. However, the VR based Simulator training systems are very expensive. On the other hand, Box training systems are less expensive. However, in the Box training, trainee's skill is not improved without instruction from skilled surgeon during the training. Therefore, instruction from skilled surgeon is necessary in use of the Box training system.

Therefore, authors are developing an expensive training system that can assess trainee's surgical operation of ligation quantitatively so that trainees can train surgical operation of ligation by themselves without any instruction from skilled surgeon.

As for surgical procedures, in [6], it is reported that a difference arises between a skilled and an unskilled surgeon in the magnitude and direction of the handling force of the object, the manner of holding surgic instruments, and the surgeon's posture. In [7], whether the level of the trainee's surgical skills can be classified as experts or novice level was investigated based on force data during the suture task.

In our training system, as assessment items for trainee's surgical operation of ligation, "the operating force of the forceps while knotting the suture thread (knotting procedure)" and "the angle of the left and the right wrists while twisting the suture thread around the forceps (twisting procedure)" are listed.

The objectives of this paper are as follows. (1) To investigate the difference of the skill between skilled surgeons and intern surgeons in the operating force of the forceps during the knotting procedure and the angle of the wrists during the twisting procedure through all data which were obtained in past measurements for surgical operation of ligation performed by intern surgeons and skilled surgeons. (2) To verify the validity of these two assessment items in the training system by comparing the measurement data of intern surgeons and skilled surgeon.

II. Experimental Setup

A. Measurement Device

The measurement device used in this study is shown in Fig. 1, in which the needle holder FYP2009L-CNK made by Japan Polymer Technology Co., Ltd. is used as the

right hand side forceps and the needle holder EYP2009S CNK made by Japan Polymer Technology Co., Ltd. is used as the left hand side forceps. Each forceps is attached to PHANTOM Omni made by SensAble Technologies, Inc., and operation amount of the forceps is measured by the PHANTOM Omni.

In addition, as shown in Fig. 2, strain gauges are attached to the grip part and the rod of each forceps. Thus, the operating force of the forceps, which is grasp force and the force added to the tip of the forceps, can be measured. Angle of the left and the right wrists is measured using the developed wrist angle measuring device, in which 9 axis MEMS motion tracking sensor MPU-9250 is installed. The wrist angle is calculated from measured value of acceleration sensor and gyro sensor.

Inside of the training box of the measurement device, a rubber sheet of 1 mm thickness is installed. The image inside the training box taken by a web camera is projected on a central monitor. Looking at the monitor, trainee performs a surgical operation of ligation using the two forceps inserted into the inside of the training box through the trocar.
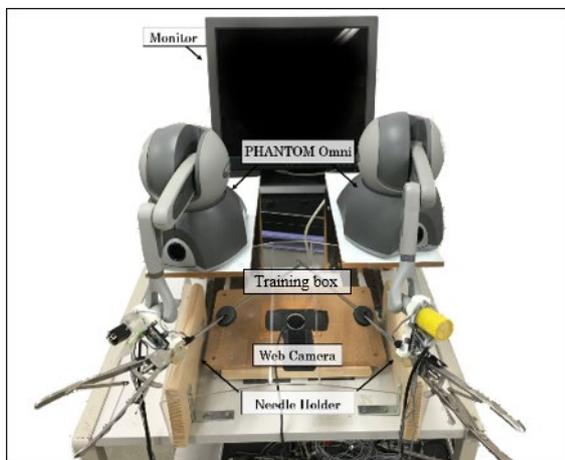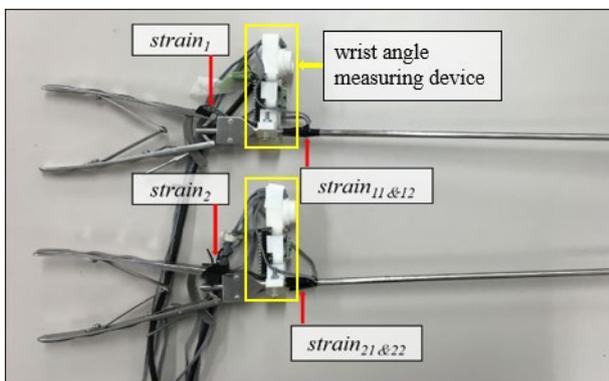

Figure 1. Measurement device.

Figure 2. Forceps with sensors.

B. Measurement Environment

In order to train surgical operation of ligation, there exist two viewpoints to see operation field, which are (a) Co-axial position and (b) Para-axial position. In co-axial position, the laparoscope is inserted between the left forceps and the right forceps, and in para-axial position,

the laparoscope is inserted from the direction which intersects perpendicularly to that of the co-axial position. The view of operation field from co-axial position and para-axial position is shown in Fig. 3. It is known that surgical operation under para-axial position is more difficult than that under co-axial position.
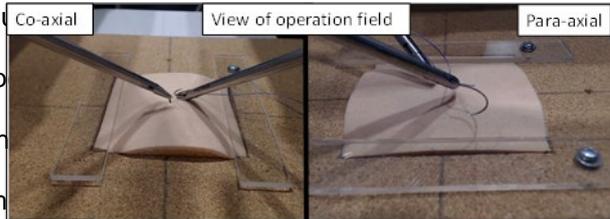

Figure 3. Co-axial position and Para-axial position

In the past measurements, manipulation data of the forceps for surgical operation of ligation was obtained in two environmental conditions, which are (c) Dry condition and (d) Wet condition. In dry condition, the data was measured under box-training using the measurement device shown in Fig. 1, and in wet condition, the data was measured under in vivo training in animal laboratory.

C. Operation of Ligation

Ligation is a part of surgical operation of suturing, and is procedure for knotting suture thread. Since ligation is a fundamental technique in surgical operation, in this study, ligation was targeted as operation for training. With taking a significance of the manipulation into consideration, the surgical operation of ligation is divided into 12 procedures, as shown in Fig. 4. The validity of this classification has been approved by the skilled surgeon of laparoscopic surgery.
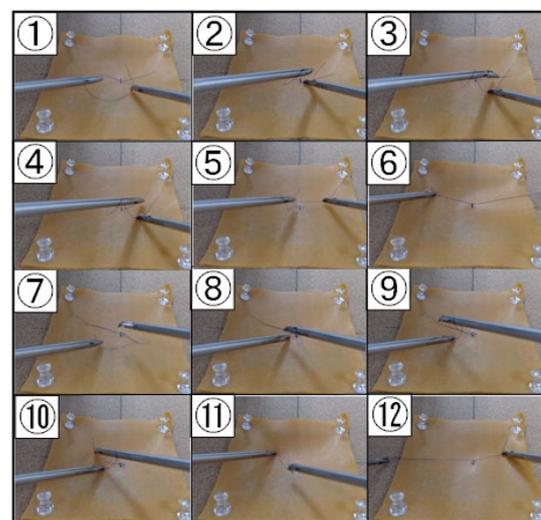

Figure 4. Classification for operation of ligation.

1. Grasping (right): Grasping the suture thread with the right forceps.
2. Twisting (left rod): Twisting the suture thread held by the right forceps around the rod of the left forceps.

3. Translation (left): Moving the left forceps to the opposite side of the suture thread.
4. Grasping both hands: Grasping the suture thread by both forceps.
5. Start knotting: Staring to pull the both forceps to outside to make a knot.
6. Knotting: Pulling the suture thread to make a knot tightly.
7. Grasping (left): Grasping the suture thread with the left forceps.
8. Twisting (right rod): Twisting the suture thread held by the left forceps around the rod of the right forceps.
9. Translation (right): Moving the right forceps to the opposite side of the suture thread.
10. Grasping both hands: Grasping the suture thread by both forceps.
11. Start knotting: Starting to pull the both forceps to outside to make a knot.
12. Knotting: Pulling the suture thread to make a knot tightly.

Generally, the procedures 1 to 6 is called "C-loop method" and the procedures 7 to 12 is called "Reversed C-loop method". In 1 set of ligation, C-loop, Reversed C-loop and C-loop procedures are performed in this order.

III. ASSESSMENT ITEMS

A. Operating Force of the Forceps

In the box training system, it is difficult for trainees to learn about proper operating force of the forceps while performing ligation. If the knotting of the suture thread is performed under improper operating force of the forceps, it may cause a failure of the sutures, which is very dangerous for patient. Therefore, in this study, as one of the assessment items in the training system for surgical operation of ligation, "the operating force of the forceps while knotting the suture thread (knotting procedure)" was chosen.

The operating force of the forceps is measured by the strain gauges attached to the forceps. The grasp force of the left forceps and the right forceps is obtained by the measured value $strain_{i1}$ and $strain_{i2}$ (i=1:right and i=2:left), respectively. While, the force added to the tip of the forceps S_i is calculated from the equation (1).

$$S_i = \sqrt{strain_{i1}^2 + strain_{i2}^2} \quad (i = 1, 2), \qquad (1)$$

where $strain_{i1}$ and $strain_{i2}$ (i=1:right and i=2:left) are measured values of the strain gauges attached to the upper part and side part of the forceps rod, respectively.

B. Angle of the Wrists

In surgical operation, coordination of the right and the left forceps is important. Therefore, first the difference of the surgical skill between skilled surgeons and intern surgeons was investigated by watching their forceps manipulation. As a result, it turned out that the amount of twisting the wrists while twisting the suture thread around

the forceps by intern surgeons is not as large as that of skilled surgeons. It is considered that the skilled surgeons intentionally twist their both hands' wrists to obtain an effective coordination of the right and the left forceps.

Thus, in this study, as another assessment items in the training system for surgical operation of ligation, "the angle of the left and the right wrists while twisting the suture thread around the forceps (twisting procedure)" was chosen. In addition, it was confirmed that the intern surgeons took more time to perform twisting procedure as compared with the skilled surgeons.

To verify the validity of wrist angle and operation time as the assessment item, in this study, distinction of skilled surgeon and intern surgeon is conducted on the basis of the difference of the wrist angle and the required time between skilled surgeon and intern surgeon while performing the twisting procedure.

The features x is defined as $x = [F_i, T]^T$, where F_i $(i = 1,2)$ is the variation of wrist angle of both hands and T is the required time for performing the twisting procedure.

Using the discriminant analysis method, discriminant function $f(x)$ was determined so as to classify forceps manipulations into skilled surgeon's region or intern surgeon's region. Then, regarding the obtained discriminant function $f(x)$ as threshold line, trainee's forceps manipulation is distinguished to either corresponding to skilled surgeon's manipulation or intern surgeon's manipulation.

IV. RESULTS

The list of the numbers of subjects (the numbers of skilled surgeon – the numbers of intern surgeon) in the past measurements of operating force of the forceps and angle of the wrists in dry and wet conditions, is shown in Table I. In each measurement, one excellent skilled surgeon, who has more than 25 years of career as surgeon, is involved. The measured operating force of the forceps of the excellent skilled surgeon is used as a target value for trainees, and the measured angle of the wrists of the excellent skilled surgeon is used as learning data to obtain a discriminant function, namely a threshold line.

TABLE I.   LIST OF DATA MEASURED IN THE PAST MEASUREMENT

Subjects	Operation force				Rotation of wrists			
	Dry		Wet		Dry		Wet	
	Co-axial	Para-axial	Co-axial	Para-axial	Co-axial	Para-axial	Co-axial	Para-axial
	Expert–Intern				Expert–Intern			
March, 2015	–	–	2–6	–	–	–	–	–
October, 2015	–	–	3–7	–	–	–	–	–
March, 2016	1–0	1–0	–	–	–	–	–	–
March, 2016	3–9	3–9	3–9	–	3–8	3–8	–	–
October, 2016	3–7	3–7	–	3–7	3–7	3–7	–	3–7
March, 2017	3–6	3–6	–	3–6	3–6	3–6	–	3–6

A. Operating Force of the Forceps

1) Dry condition

As an example, the average operating force of the forceps for 3 times of knotting procedure (C-loop, Reversed C-loop and C-loop), namely the average grasp force and the average force added to the tip of the forceps, measured in March, 2017 is shown in Table II.

TABLE II. OPERATING FORCE OF THE FORCEPS IN DRY CONDITION

| Subject | Voltage[mV] | | | | | | | |
| | Co-axial position | | | | Para-axial position | | | |
	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)
Expert-1	0.217	0.244	0.357	0.467	0.183	0.144	0.378	0.718
Expert-2	0.126	0.164	0.096	0.204	0.131	0.124	0.161	0.284
Expert-3	0.230	0.250	0.205	0.215	0.257	0.244	0.209	0.335
Intern-1	0.087	0.224	0.647	0.737	0.190	0.262	0.631	1.025
Intern-2	0.094	0.276	0.434	0.416	0.115	0.133	0.380	0.556
Intern-3	0.262	0.169	0.224	0.232	0.241	0.181	0.206	0.178
Intern-4	0.194	0.164	0.421	0.249	0.288	0.424	0.303	0.288
Intern-5	0.186	0.158	0.410	0.173	0.188	0.157	0.509	0.438
Intern-6	0.207	0.386	0.483	0.362	0.212	0.212	0.309	0.166

When comparing the operating force of the forceps between co-axial position and para-axial position, remarkable difference is not seen in both skilled surgeons and intern surgeons. Therefore, common target value is adopted in both co-axial position and para-axial position.

The excellent skilled surgeon (Expert-2 in Table II) is technically superior to other skilled surgeons, and he performs knotting procedure with stable operating force of the forceps. Therefore, the target value of the operating force of the forceps is determined as the average value of each operating force of the forceps, namely the grasp force of the right and the left forceps and the force added to the tip of the right and the left forceps, obtained from the excellent skilled surgeon for knotting procedure under dry condition in past 8 times measurement. The obtained target value is shown in Table III.

TABLE III. TARGET VALUE OF OPERATING FORCE IN DRY CONDITION

	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)
Target value [mV]	0.109	0.173	0.169	0.234

From the target value, the error rate of each operating force of the forceps is defined by the following equation.

$$\text{Error ratio} = \frac{\text{Measured value} - \text{Target value}}{\text{Target value}} \times 100 \qquad (2)$$

In the case where the error rate is 100%, this means that the operating force of the forceps is twice as large as the excellent skilled surgeon. Error rate of each operating force of the forceps and their absolute average are shown in Table IV.

TABLE IV. ERROR RATE OF OPERATING FORCE IN DRY CONDITION

| Subject | Error rate[%] | | | | | | | | | |
| | Co-axial position | | | | | Para-axial position | | | | |
	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)	absolute ave.	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)	absolute ave.
Expert-1	98.8	41.1	110.5	99.2	87.4	67.7	-16.5	123.1	206.3	103.4
Expert-2	15.5	-5.1	-43.6	-12.9	19.3	20.3	-28.5	-5.3	21.0	18.8
Expert-3	110.3	44.7	21.2	-8.5	46.2	135.4	40.8	23.3	43.1	60.6
Intern-1	-20.6	29.6	281.8	214.3	136.6	73.8	51.6	272.6	337.3	183.8
Intern-2	-14.0	59.6	155.9	77.4	76.7	4.8	-23.1	124.3	137.4	72.4
Intern-3	140.2	-2.3	32.2	-1.2	44.0	120.4	4.5	21.8	-24.0	42.7
Intern-4	77.6	-5.3	148.4	6.1	59.3	163.5	144.9	78.8	22.7	102.5
Intern-5	70.2	-8.5	142.1	-26.2	61.8	72.1	-9.2	200.7	86.9	92.2
Intern-6	89.0	123.0	184.9	54.5	112.9	94.4	22.4	82.2	-29.1	57.0

In Table IV, 3 intern surgeons who pull the suture thread by the force exceeding 100% of the average of the error rate in co-axial position or para-axial position are seen. Although there exists a skilled surgeon Expert-1 who has applied large force at the tip of the forceps, it was confirmed that there is a tendency which especially intern surgeons pull the suture thread by applying very large force at the tip of the forceps.

When the knotting procedure is performed by applying large force more than needed at the tip of a forceps, a suture thread may escape from the forceps and there is a danger that the forceps will damage surrounding internal organs. Therefore, it can be said that to adopt "the operating force of the forceps while knotting the suture thread" as the assessment item of training system is effective for improvement of a surgical skill.

2) Wet condition

As an example, the average operating forces of the forceps measured under co-axial position in March, 2016 and under para-axial position in March, 2017 are shown in Table V and Table VI, respectively.

TABLE V. OPERATING FORCE IN WET CONDITION (CO-AXIAL)

| Subject | Voltage[mV] | | | |
| | Co-axial position | | | |
	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)
Expert-1	0.053	0.101	1.032	0.360
Expert-2	0.096	0.098	0.305	0.242
Expert-3	0.098	0.132	0.641	0.189
Intern-1	0.038	0.258	0.833	0.218
Intern-2	0.112	0.176	1.156	0.173
Intern-3	0.069	0.124	1.229	0.641
Intern-4	0.047	0.143	0.845	0.224
Intern-5	0.048	0.102	0.429	0.372
Intern-6	0.098	0.156	0.919	0.440
Intern-7	0.047	0.262	0.637	0.574
Intern-8	0.109	0.137	1.137	0.524
Intern-9	0.101	0.157	0.620	0.376

TABLE VI. OPERATING FORCE IN WET CONDITION (PARA-AXIAL)

| Subject | Voltage[mV] | | | |
| | Para-axial position | | | |
	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)
Expert-1	0.070	0.104	0.445	0.402
Expert-2	0.053	0.049	0.242	0.151
Expert-3	0.069	0.066	0.414	0.291
Intern-1	0.057	0.162	1.049	0.616
Intern-2	0.084	0.052	0.509	0.526
Intern-3	0.109	0.058	0.687	0.769
Intern-4	0.090	0.032	0.435	0.324
Intern-5	0.058	0.065	0.729	0.439
Intern-6	0.190	0.099	0.652	0.374

Also in wet condition, when comparing the operating force of the forceps between co-axial position and para-axial position, remarkable difference is not seen in both skilled surgeons and intern surgeons. Therefore, common target value is adopted in both co-axial position and para-axial position.

Thus, as the same way of dry condition, the target value of the operating force of the forceps is determined as the average value of each operating force of the forceps obtained from the excellent skilled surgeon for knotting procedure under wet condition in past 5 times measurements. The obtained target value is shown in Table VII.

TABLE VII. TARGET VALUE OF OPERATING FORCE IN WET CONDITION

	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)
Target value [mV]	0.046	0.066	0.198	0.175

When comparing Table VII to Table III, the forces added to the tip of the forceps are same degree between

the wet condition and the dry condition. However, the grasp forces under the wet condition are smaller than those under the dry condition. This is considered to be caused by the following reason. Since frictional force of the suture thread under the wet condition is lower than that under the dry condition, in the wet condition, surgical operation of ligation can be performed under small grasp force as compared with the dry condition.

From the target value, as the same way of dry condition, the error rate of each operating force of the forceps was calculated. As an example, the error rate of each operating force of the forceps and their absolute average calculated from the data measured under para-axial position in March, 2017 is shown in Table VIII.

TABLE VIII. ERROR RATE OF OPERATING FORCE IN WET CONDITION (PARA-AXIAL)

Subject	Error rate [%]				
	Para-axial position				
	Grasping(R)	Grasping(L)	Tip load(R)	Tip load(L)	absolute ave.
Expert-1	51.6	58.5	124.7	130.2	91.2
Expert-2	15.2	-24.9	22.0	-13.6	18.9
Expert-3	50.8	0.4	109.4	66.5	56.8
Intern-1	25.3	146.5	430.2	252.2	213.5
Intern-2	83.9	-20.9	157.4	200.9	115.8
Intern-3	138.3	-11.2	247.2	339.5	184.1
Intern-4	96.8	-51.7	119.7	85.0	88.3
Intern-5	26.2	-1.0	268.5	151.0	111.7
Intern-6	313.6	51.5	229.6	113.6	177.1

It was confirmed that 20 of 35 intern surgeons and 5 of 14 skilled surgeons exceeded 100% of the absolute average of the error rate either in-axial position or para-axial position through all the measurement data measured under wet condition.

When focusing on the force added to the tip of the forceps of intern surgeons, it was confirmed that 26 of 35 intern surgeons exceeded 100% and moreover, 09 of 26 intern surgeons exceeded 200% of the absolute average of the error rate. From this fact, also in the wet condition, it was confirmed that there is a tendency which intern surgeons pull the suture thread by applying very large force at the tip of the forceps.

3) 100% excess rate of the absolute average error rate

The ratio that the absolute average of the error rate exceeded 100% under the dry environment and the wet environment was calculated for intern surgeon and skilled surgeon, respectively. They are shown in TABLE IX.

TABLE IX. 100% EXCESS RATE OF ABSOLUTE AVERAGE OF ERROR RATE

	Percentage [%]	
	Dry condition	Wet condition
Expert	33.3	35.7
Intern	54.5	57.1

From Table IX, the difference of the 100% excess rate between skilled surgeon and intern surgeon was 21.2 points in the dry condition and was 21.4 points in the wet condition. Thus, it can be said that the difference between skilled surgeon and intern surgeon in the dry condition and that in the wet condition are same degree.

In addition, when focusing on the force added to the tip of the forceps, in the wet condition, the rate of the intern surgeon who exceeded 200% of the absolute average of the error rate increased as compared with the dry condition. Moreover, the maximum value of the absolute average of the error rate also increased from 404.0% under the dry condition to 521.0% under the wet condition.

This is considered to be caused by the following reason. Since the surgical operation of ligation under the wet condition is more difficult than that under the dry condition, the difference of the skill of the intern surgeons and of the skilled surgeons appeared clearly.

B. Angle of the Wrists

Along the distinction method described in section III B, distinction rate of skilled surgeon and intern surgeon was calculated, respectively.

1) Co-axial position under dry condition

First, angle of the left and the right wrists for the twisting procedure under dry condition of co-axial position measured in past 3 times measurements from March, 2016 to March, 2017, was used to find a discriminant function, namely a threshold line. In more detail, the threshold line was determined so as to classify the measurement data into skilled surgeon's region or intern surgeon's region using all the measurement data obtained from the excellent skilled surgeon and 21 times of the measurement data obtained from 20 intern surgeons. Here, extremely different measurement data was excepted as an abnormal value.

Next, using 10 times of the measurement data obtained from 7 skilled surgeons and 21 times of the measurement data obtained from 20 intern surgeons, the distinction rate of which the measurement data is classified correctly according to the determined threshold line was calculated. Distinction result is shown in Fig. 5, and the distinction rate is shown in Table X.
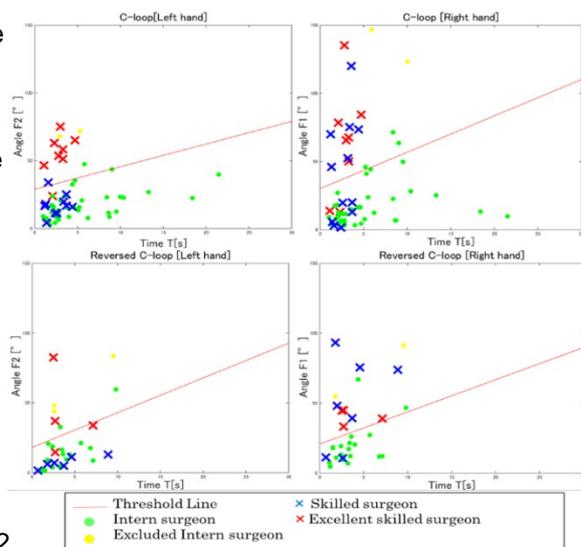

Figure 5. Distinction result for co-axial position in dry condition

For the skilled surgeon, the case where their measurement data is mapped to the skilled surgeon's

region is regarded as a success, and for the intern surgeon, the case where their measurement data is mapped to the intern surgeon's region is regarded as a success. Then, the distinction rate is calculated on the basis of the numbers of the success.

obtained for the intern surgeon. Thus, it is expected that the intern surgeon is distinguishable with high distinction rate also under the para-axial position.

TABLE X.   DISTINCTION RATE FOR CO-AXIAL POSITION IN DRY CONDITION

skilled surgeon	C-loop		Reversed C-loop		Ave.
	forceps		forceps		
	left	right	left	right	
count	8/18	12/20	2/10	9/11	31/59
Rate[%]	44.4	60.0	20.0	81.8	52.5
Intern surgeon	C-loop		Reversed C-loop		Ave.
	forceps		forceps		
	left	right	left	right	
count	37/40	37/42	17/22	19/23	111/127
Rate[%]	92.5	88.1	77.3	82.6	84.4

From TABLE X, the distinction rate of at least 20% and at most 81.8% was obtained for the skilled surgeon. The distinction rate of the skilled surgeon varies and is not stable. This is considered to be caused by the following reason. Since surgical skill of the excellent skilled surgeon is too high as compared with other skilled surgeons, other surgeon's measurement data was mapped to the intern surgeon's region occasionally and was incorrectly distinguished.

While, the distinction rate of at least 77.3% and at most 92.5% was obtained for the intern surgeon. Since overall, high distinction rate was obtained, the possibility that intern surgeon will be accidentally distinguished to skilled surgeon is low. Therefore, it can be said that to adopt "the angle of the wrists while twisting the suture thread around the forceps" as the assessment item of training system is effective for improvement of a surgical skill.

2) Para-axial position under dry condition

As the same way of the co-axial position, first, angle of the left and the right wrists for the twisting procedure under dry condition of para-axial position measured in past 3 times measurements from March, 2016 to March, 2017, was used to define a discriminant function, namely a threshold line. The threshold line was determined using all the measurement data obtained from the excellent skilled surgeon and 21 times of the measurement data obtained from 20 intern surgeons. Here, extremely different measurement data was excepted as an abnormal value.

Next, using 10 times of the measurement data obtained from 7 skilled surgeons and 21 times of the measurement data obtained from 20 intern surgeons, the distinction rate of which the measurement data is classified correctly according to the determined threshold line was calculated. Distinction result is shown in Fig. 6, and the distinction rate is shown in Table XI.

From Table XI, the distinction rate of at least 81.8% and at most 94.4% was obtained for the intern surgeon. In addition, the average distinction rate of 88.3% was
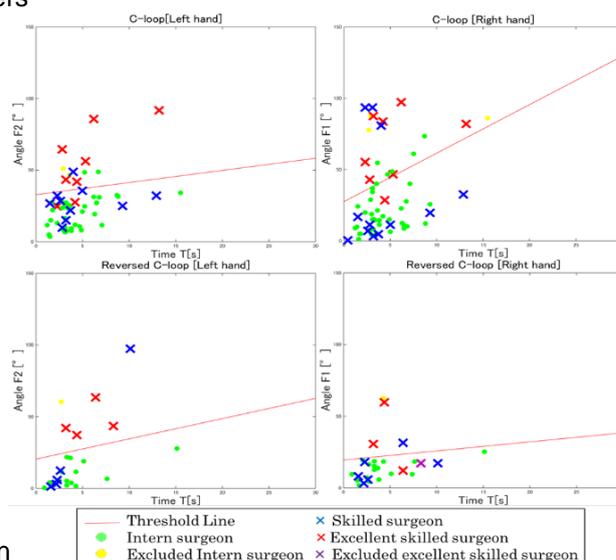

Figure 6.   Distinction result for para-axial position in dry condition

TABLE XI.   DISTINCTION RATE FOR PARA-AXIAL POSITION IN DRY CONDITION

skilled surgeon	C-loop		Reversed C-loop		Ave.
	forceps		forceps		
	left	right	left	right	
count	7/18	10/20	5/9	3/10	25/57
Rate[%]	38.9	50.0	55.6	30.0	43.9
Intern surgeon	C-loop		Reversed C-loop		Ave.
	forceps		forceps		
	left	right	left	right	
count	37/41	36/44	16/17	17/18	106/120
Rate[%]	90.2	81.8	94.1	94.4	88.3

As for the distinction rate of the left hand in reversed C-loop, it was the worst in the co-axial position but was the best in the para-axial position. This is considered to be caused by the following reason. Since the difficulty of surgical operation in para-axial position is higher than co-axial position, the difference of the skill between the intern surgeons and the skilled surgeons appeared clearly.

3) Para-axial position under wet condition

First, angle of the left and the right wrists for the twisting procedure under wet condition of para-axial position measured in past 2 times measurements from October, 2016 to March, 2017, was used to define a threshold line. Since the numbers of the measurement data under wet condition are few, the threshold line was determined using all the measurement data obtained from 8 skilled surgeons and 9 times of the measurement data obtained from 9 intern surgeons.

Next, the distinction rate of which the measurement data is classified correctly according to the determined threshold line was calculated based on the substitution method. Distinction result is shown in Fig. 7, and the distinction rate is shown in Table XII.
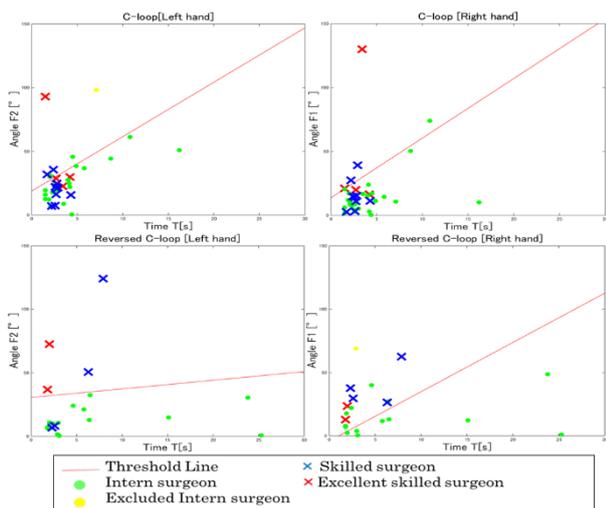
Figure 7. Distinction result for para-axial position in wet condition.

TABLE XII. DISTINCTION RATE FOR PARA-AXIAL POSITION IN WET CONDITION

skilled surgeon	C-loop		Reversed C-loop		Ave.
	forceps		forceps		
	left	right	left	right	
count	3/13	4/13	4/6	6/6	17/38
Rate[%]	23.1	30.8	66.7	100.0	44.7
Intern surgeon	C-loop		Reversed C-loop		Ave.
	forceps		forceps		
	left	right	left	right	
count	21/24	23/24	15/15	8/15	67/78
Rate[%]	87.5	95.8	100.0	53.3	85.9

It was confirmed that in the wet condition, the difference of the skill between the skilled surgeon and the intern surgeon appeared notably as compared with the dry condition. Especially, the difference appeared in the required time for performing the twisting procedure, and many intern surgeons required longer time for performing the twisting procedure under the wet condition than that under the dry condition.

From TABLE XII, the distinction rate of at least 53.3% and at most 100% was obtained for the intern surgeons. As for the distinction rate of the right hand in reversed C loop, it was the worst for the intern surgeons but was the best for the skilled surgeon. Therefore, it is necessary to increase the number of measurement data under the wet condition. If the measurement data of the excellent skilled surgeon is increased, it is expected that more accurate threshold line can be obtained.

V. CONCLUSIONS

In this paper, the difference of the skill of the skilled surgeon and of the intern surgeon was verified through all of past measurement data for surgical operation of ligation performed by intern surgeons and skilled surgeons.

In particular, as possible assessment items of surgical training system, "the operating force of the forceps while knotting the suture thread" and "the angle of the left and the right wrists while twisting the suture thread around the forceps" were investigated.

As for the operating force of the forceps for knotting procedure, the difference of the operating force of the forceps between skilled surgeons and intern surgeons was confirmed in both dry condition and wet condition. Especially, it was confirmed that there is a tendency of which intern surgeons pull the suture thread by applying large force more than the needed at the tip of the forceps. Therefore, it is concluded that it is effective to adopt "the operating force of the forceps while knotting the suture thread" as assessment item of training system.

As for the angle of the left and the right wrists for twisting procedure, the difference of angle of the wrists between skilled surgeons and intern surgeons was confirmed in co-axial position and para-axial position under dry condition and in para-axial position under wet condition.

It was confirmed that the amount of twisting the wrists while twisting the suture thread around the forceps by intern surgeons is not as large as that of skilled surgeons. It is considered that the skilled surgeons intentionally twist their both hands' wrists largely in order to twist the suture thread around the forceps smoothly with an effective coordination of the right and the left forceps.

In addition, using the features composed of variation of the wrists angle and the required time for performing the twisting procedure, a tendency of which intern surgeon can be distinguished with high distinction rate was confirmed. Therefore, it is concluded that it is effective to adopt "the angle of the wrists while twisting the suture thread around the forceps" as assessment item of training system.

However, even if the angle of the wrists is large, technically correct surgical operation has not necessarily been performed. As a future work, it is necessary to analyze the correlation of the excellent skilled surgeon's left wrist angle and right wrist angle and to investigate the relation of technically correct surgical operation with the angle of the wrists.

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