Determination of Effective Evaluation Parameters on the Airway Management Training System WKA-1R

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***Abstract*—The emerging field of medical robotics is aiming in introducing intelligent tools to support surgeons to perform medical procedures with higher levels of accuracy which cannot be achieved by conventional methodologies. More recently, thanks to the innovations on robot technology, advanced medical training systems have been introduced. Up to now, the medical industry has contributed in developing training simulators that reproduces with high fidelity the human anatomy. However, such devices are not designed to provide any information about trainees' performance so that no objective assessment of training achievements can be obtained. However, thanks to the advances in Robot Technology (RT), more efficient training systems can be conceived. For this reason, our long-term research goal is focused on the development of a Patient Robot which nearly reproduces the human anatomy and physiology by embedding sensors and actuators into a human model. Due to the complexity of the development of such kind of training devices, as a first approach, we have proposed the development of an Airway Management Training System designed to provide quantitative information of the task as well as providing feedback to trainees. In this paper, we present the improvements achieved on the newest version, the Waseda-Kyotokagaku Airway No. 1 Refined (WKA-1R). This new version has improved the designing of the embedded sensors to measure better the applied forces while performing the task. A set of evaluation parameters are then proposed and experiments were carried out to determine their usefulness in detecting the differences among levels of expertise. From the experimental results, we could identify a significant difference on the proposed evaluation parameters between doctors and unskilled subjects while practicing with the WKA-1R**

Manuscript received May 3, 2008. This work was supported by the Knowledge Cluster Initiative, a project from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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I. INTRODUCTION

DURING last past decades, computer based simulations have been introduced into medical training in the form of interactive software leaning tools and anatomic instructional programs. Moreover, Virtual Reality (VR) techniques enhanced the complexity and realism of training simulators to new levels [2]. VR is an advanced human-computer interface that goes far beyond existing interfaces. It implies a three-dimensional computer-generated world that mimics the real world and allows trainees to interact with and navigate it, using components of their five senses in real time and become immersed. However, these advanced simulators have been scarcely applied to training programs [3]. In contrast, Augmented Reality (AR) is a relative new technology applied to medical applications. The idea of AR is inserting virtual objects into the normal field of view. The main strength of AR compared to VR is the perception of the real scene [4]. The system only overlays those pieces of information that are necessary. This eliminates the need for the trainee to immerse in a totally virtual environment and supports the intuitive integration of the information [5].

More recently, thanks to the introduction of Haptic Interfaces (HI), novel ways of medical and surgical training have been proposed. The research on HI is based on the study of the psychomotor experience of touch and is an essential component if a meaningful surgical experience is to be created [4]. Haptic feedback is becoming an integral component of numerous training systems, particularly those designed for teaching motor skills [6-9]. In particular, it has been reported that visuohaptic training significantly enhances the motor skill learning [8-10]. Even the promising results of HI-based training systems, further analysis should be performed due to the complexity of understanding the processes involved during the learning process.

Authors believe in the importance that an effective training system should be designed to provide active training [5-6]. An active training system must fulfill at least three conditions: reproduce the real-world condition of the task, provide objective assessments of the training progress and provide useful (multimodal) feedback information to trainees. Even that different kinds of active training systems have been proposed, most of them are designed to attach sensors on the medical instrument, which may affect the performance of trainees due to collisions between the tool and the patient model; as well as limit the freedom of motion of the surgical tool [10-13]. Furthermore; trainees may have difficulties while performing the same task with real surgical tools because they are trained with a modified tool (different weight, dimensions, etc.).

For that purpose, we have proposed a long-term project, since April 2004 at Waseda University, for the development of a patient robot that may be used as an active training system as well as an evaluation tool of surgical instruments and medical procedures. In order to fulfill the three basic principles of an effective training system [6], the Patient Robot should be designed to emulate the human body (both anatomy and physiology), embed sensors into the simulator (not on the instrument) and embed actuators to provide feedback. Due to the complexity of developing the Patient Robot, we have been developing at Waseda University as a first approaches the following training systems: a Suture/Ligature Training System [14] and an Airway Management Training System [15].

In this paper, we are presenting the details of the development of the Airway Management Training System. Airway management is a basic skill that it is provided during emergency situation such as: cardiopulmonary arrest, multiple injury, etc. In general, Airway management is not only managed in order to supply oxygen into the lung but also to prevent the lung from gastric foreign body and bleeding due to an external wound [16-18]. Even though it is a basic medical operation, different kinds of accidents may occur when an unskilled person provides it. As a result, emergency medical technicians and medical science students are required to practice airway management for several years.

Up to now, there are many airway management training mannequins which have been developed by many companies. These mannequins have no sensors to obtain quantitative information of the trainee, and no actuators to reproduce various cases of the patients and individual differences in anatomy. Consequently, mannequins are designed to provide reduced amounts of feedback information, to reproduce simple task conditions without providing objective assessments of the task performance.

As a result of our research, we have developed the Waseda-KyotoKagaku Airway No. 1 (WKA-1), which embedded an array of sensors into a conventional mannequin to acquire quantitative information of the task performance [19]. The anatomical design of the simulated organs of the mannequin was simplified. In particular, the WKA-1 consists of simulated organs (tongue, vocal cord, trachea, incisor teeth, head, neck and chest), a web-cam and an evaluation module (PC). In particular, three different kinds of embedded sensor arrays were proposed: Force Detection Sensor System (FDSS), Position Detection Sensor System (PDSS) and Distance Detection Sensor System (DDSS).

By performing experiments with the WKA-1, we detected problems on the design of the FDSS to measure the applied forces. Therefore; in this paper, we present the details of the improvements done on the Waseda-KyotoKagaku Airway No.1 Refined (WKA-1R). This new version has improved the design of the FDSS which are embedded into the trachea and incisor teeth. Thanks to such improvements, we could perform more detailed experiments with medical doctors and unskilled subjects to determine the evaluation parameters that should be considered for the evaluation function of the airway management task.

II. Waseda-Kyotokagaku Airway No.1 Refined

A. System Overview

In this year, we have developed the Waseda-Kyotokagaku Airway No. 1 Refined (WKA-1R). The WKA-1R is composed by a conventional mannequin, array of embedded sensors, webcam, and a personal computer (evaluation module). The conventional mannequin is designed to realistically reproducing the human anatomy. The mannequin is composed by seven main parts (Figure 1): head, neck, chest, incisor teeth, tongue, vocal cord, and trachea. The design of the simulated organs was simplified in order to enable the integration of the proposed arrays of sensors (FDSS, PDSS and DDSS). In particular, the following inner simulated organs were supplied by Kyotokagaku Co. Ltd.: upper trachea, vocal cord, epiglottis, tongue, and esophagus. In order to understand how the trainee is performing the task, we considered integrating the proposed arrays sensors based on the basic steps previously detailed. Basically, we have proposed to embed the following sensors into the WKA-1R as follows (please refer to Fig. 2 regarding the steps of the airway management procedure):

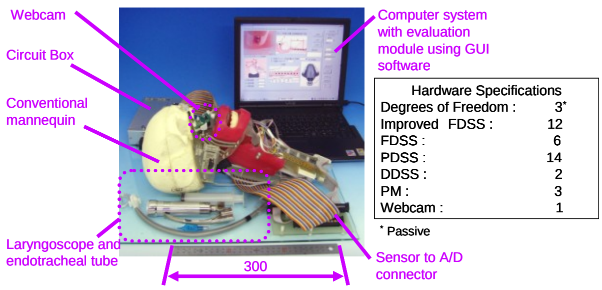

Fig. 1. System overview of the newest Waseda Kyotokagaku Airway No.1R (WKA-1R). This new version has improved the designing of the Force Detection Sensor System to measure better the applied forces while performing the task.

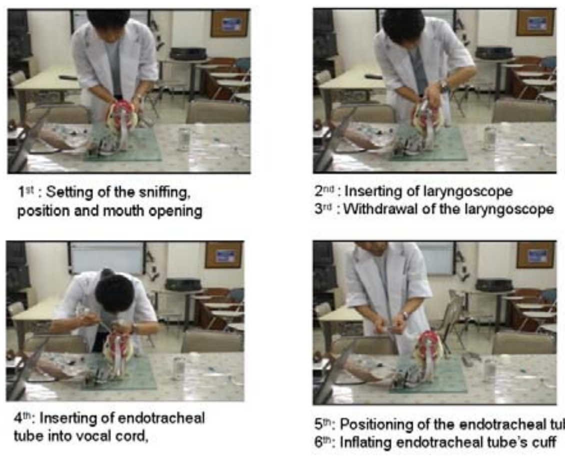

Fig. 2. The airway management procedure consists of six fundamental steps while using the WKA-1R. In order to understand better the training progress, different kinds of arrays of sensors were proposed to measure the applied forces, positions and distances of instruments [15].

- Three potentiometers (PM) were attached to measure the aperture of the mount, the degree of inclination of the head and the degree of inclination of the lower cervical spine. This sensor is used to measure the sniffing position and opening mouth (1st Step).
- One array of improved FDSS was embedded into the incisor teeth to measure the applied force on the tongue by the laryngoscope (2nd Step).
- Six arrays of FDSS were embedded on the tongue for measuring the force applied on the tongue during the withdrawal of the laryngoscope (3rd Step).
- Two arrays of DDSS were embedded on each side of the vocal cord to measure the applied forces by the endotracheal tube (4th Step).
- Thirteen arrays of PDSS were embedded on the trachea to measure the positioning of tip of the endotracheal tube (5th Step).
- Eleven arrays of improved FDSS were embedded inside the simulated trachea to measure the applied force due to the inflation of the tube's cuff (6th Step).

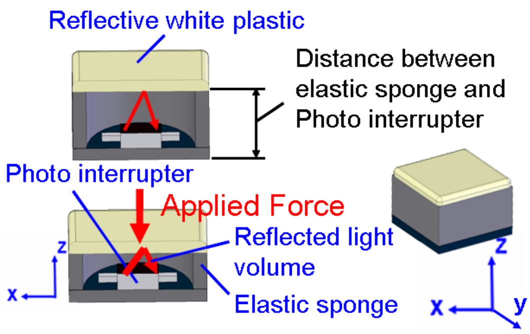

Fig. 3 Details of the Force Detection Sensor System designed for the WKA-1 [19].

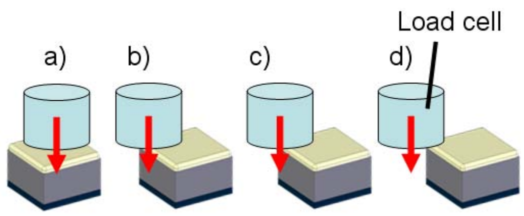

Fig. 4 Experimental conditions to determined the curve characteristics of the proposed FDSS designed for the WKA-1.

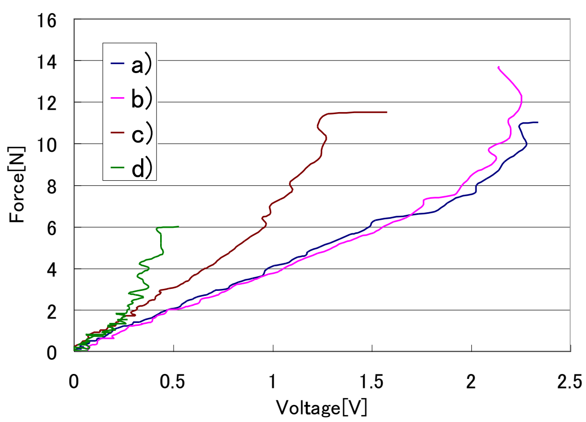

Fig. 5 Characteristic curves obtained by the FDSS while using the WKA-1 (a, b, c, and d are the different considered cases shown in Fig. 4).

B. *Improved Force Detection Sensor System*

The proposed Force Detection Sensor System (FDSS) on the WKA-1 has been designed to measure the applied forces along the z-axis [19]. In particular, such kinds of array of sensors were embedded into the incisor teeth, trachea and tongue. The FDSS consisted of 3 layers: elastic sponge, white reflective plastic, and photo interrupter as shown on Fig. 3. A high-sensitivity phototransistor has been selected with a dimension of 2.7mm x 3.2mm. By using such kind of sensor, we reduced the installation space and increase the two-point-discrimination threshold (TPDT) which is the minimum distance from which the human fingertip can detect.

However, while performing experiments with the FDSS designed for the WKA-1, we have found some problems while measuring the applied forces. In particular, we have performed experiments to obtain the characteristic curve of the FDSS. In particular, we have designed an experimental device at our laboratory to program the location of the applied forces on the FDSS. The experimental device is composed by a DC-motor, a mechanical link and a load cell attached to the end-effector. Such an experimental device was programmed to applied forces on the FDSS on different locations (Figure 4). The experimental results are shown in Fig. 5. As we may observe, depending on the location of the applied force, different characteristic curves are obtained. Such differences are mainly due to the use of the elastic sponge placed between reflective white plastic and the photo interrupter (Figure 3). In fact, depending of the direction of the applied force, the properties of the

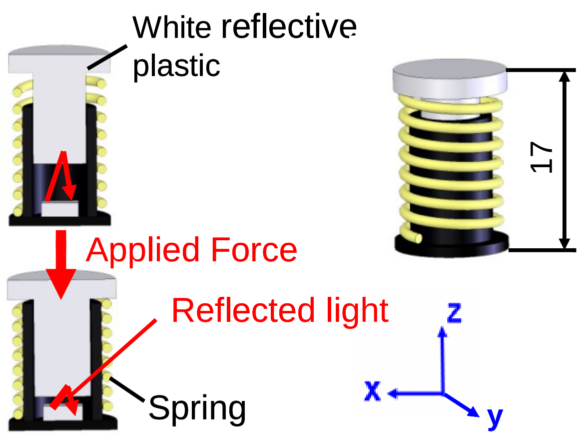

Fig. 6 Working principle of improved FDSS designed for the WKA-1R.

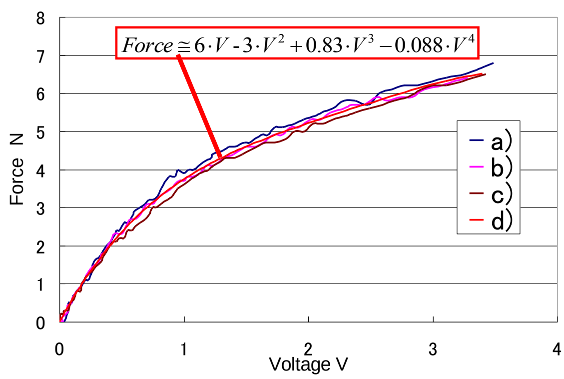

Fig. 7 Characteristic curves obtained by the improved FDSS designed for the WKA-1R (a, b, c, and d are the different considered cases shown in Fig. 4).

sponge considerably changes. Furthermore, the sponge required considerably time to recover its original shape after applying force.

Therefore, in this paper, we focused on developing an improved FDSS to obtain better performance on the measurement of the applied forces, in particular, on the incisor teeth and trachea. The improved FDSS of WKA-1R consists of four elements (Figure 6): a photo interrupter, white reflective, spring, and spring guide. The principle of the improved FDSS is basically the same as the previous FDSS; however, in order to avoid the non-linear properties of the sponge, a spring material was placed between the photo interrupter and the reflective material. By using such a design, regardless the location of the applied forces on the FDSS, the characteristic curve of the sensor is the same. The experimental results with the improved FDSS are shown in Fig. 7. As we may observe, a unique characteristic curve can be computed and depending on the spring's elastic coefficient, we can even modify the desired range of force.

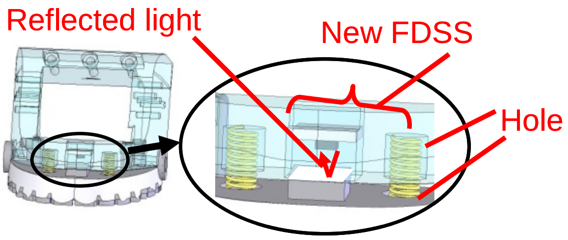

Fig. 8 Details of the redesigned incisor teeth of the WKA-1R in order to embed the improved FDSS.

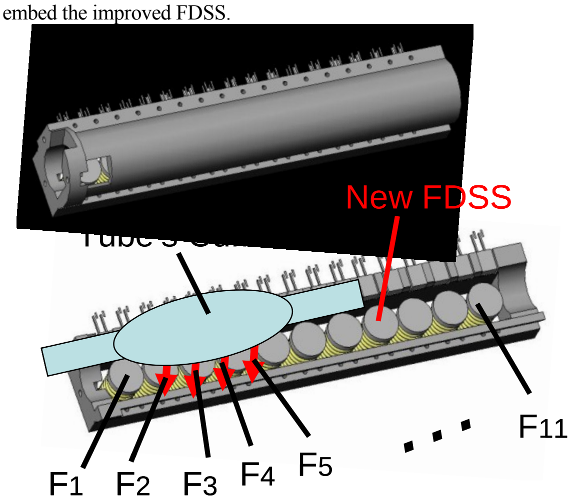

Fig. 9 Details of the redesigned trachea of the WKA-1R in order to embed the improved FDSS.

C. *Redesigned Trachea and Incisor Teeth*

As we have previously mentioned, the improved FDSS was embedded into the *Incisor Teeth* and the Trachea of the WKA-1R. Regarding the Incisor Teeth, the improved FDSS was embedded by attaching two springs on each side of the photo-interrupter as it is shown in Fig. 8. Therefore, the *Incisor Teeth* was redesigned in order to embed the springs of the improved FDSS. As a result, we may assure the preciseness of the measurement of the applied force by the laryngoscope while performing the airway management.

Regarding the *Trachea*; the improved FDSS was embedded into the WKA-1R as it is shown in Fig. 9. Basically, the trachea is composed by an array of eleven arrays of FDSS to measure the applied pressure on the trachea by the endotracheal tube's cuff. Each of the improved FDSS is composed by a photo-interrupter, a spring and a reflective material. Thanks to new design of the FDSS, a unique relationship between the applied force and pressure can be defined, as it is shown in Eq. 1. Moreover, the total applied force on the trachea can be computed by using Eq. 2; where F_{sensor} is the measured force on each of the embedded sensors on the trachea. Finally, by performing a calibration on the improved FDSS, the relation between force and the pressure can be also obtained.

$$P_{cuff} \cong k_{PF} \times F_{cuff} \quad ; \ (k_{PF} = 10) \qquad (1)$$

$$F_{cuff} = \sum_{i=1}^{N} F_{sensor[i]} \quad ; \ (N = 11) \qquad (2)$$

III. Experiments & Results

In 2006, we have performed preliminary experiments with the WKA-1 in order to determine the evaluation parameters. In particular, we have experimentally determined the following evaluation parameters as useful for determining the differences between surgeons and students [19] : *angle of the opening mouth*, *applied integral force on the incisor teeth*, *intubation time*, *applied force on the tongue*, and *displacement index of the left side of the vocal cord*. However, the WKA-1 presented problems on the measurement of the applied forces. As a result, some of the proposed evaluation parameters didn't present a significant difference between surgeons and students.

Thanks to the improvements on the measurement of the applied forces on the WKA-1R, now we can perform more detailed experiments on determining the evaluation parameters. Therefore; in this paper, we have proposed to perform experiments with the WKA-1R to determine the real effectiveness of the proposed evaluation parameters on detecting differences between levels of expertise. For this purpose, a total of six anesthetists and six unskilled were asked to perform the airway management while using the WKA-1R. Each of the subjects was asked to repeat the task three times. In the case of the unskilled subjects, we demonstrated to them how to perform the task by showing videos from experts' performances while performing airway management.

Regarding the experimental results obtained for *applied maximum force on the incisor teeth*, we found a significant difference between the doctors and unskilled subjects ($P<0.05$) as shown in Fig. 10. Medical literature states operators should not apply force on the incisor teeth by the blade of the laryngoscope. As we may observe, the unskilled group applied higher levels of force on the incisor teeth compared to the anesthetists while performing the 3rd step of the task (withdrawal of the laryngoscope).

On the other hand, we analyzed the *applied force on the tongue* during the withdrawal of the laryngoscope. The experimental results are shown in Fig. 11. As we may observe, a significant difference on the sensor #1 and #4 were detected (P<0.05). The medical literature states the operator should place the laryngoscope to the right side of the tongue, and lift up the right side of the base of the tongue by the laryngoscope during the 3rd step. Through the information obtained from the FDSS which is embedded into the tongue, doctors had a greater tendency to place the blade of the laryngoscope to the right side better than the unskilled subjects.

Finally, we have analyzed *cuff's pressure* parameters. In the last preliminary experiment on the WKA-1, we could not find a significant difference due to the sensor's problem. Thanks to the improved FDSS, we could obtain the information of the *cuff's pressure* parameters. From the experimental results with the WKA-1R, we found the significant difference on the *cuff's pressure* while comparing both groups (P<0.05) as shown in Fig. 12. Medical literature states the operator should inflate the *cuff's pressure* properly and with care. It causes the trachea's membrane to be traumatized. Analyzing the information obtained from the improved FDSS which is embedded into the trachea, unskilled subjects have a greater tendency to inflate the cuff's pressure strongly better than doctors.

IV. CONCLUSION & FUTURE WORK

In this paper, we have presented the details of the Waseda-KyotoKagaku Airway No. 1R (WKA-1R), which embeds an array of sensors in order to quantitatively acquire information from the performances of trainees. In particular, the details of the improved Force Detection Sensor System (FDSS) are given as well as the redesign of the incisor teeth and trachea in order to embed the improved FDSS. In addition, an experiment was proposed to confirm the effectiveness proposed evaluation parameters to detect differences on levels of expertise while performing the airway management with the WKA-1R. As a result from the experiments, we observed significant differences on *applied maximum force on the incisor teeth*, *applied force on the tongue* and *cuff's pressure.* Such parameters were actually not identified as significant while performing previous experiments with the WKA-1.

However, we recognized some difficulties while measuring the applied force on the tongue, and the angle of the opening mouth on the jaw due to some design problems. In the future, we are planning to refine the design of the tongue and the jaw of the conventional mannequin, develop the lung which embeds the sensor able of measuring an inflow rate of air, and embed several sensors into the other parts in order to determine evaluation parameters. As a result, more detailed experiments will be proposed to verify the effectiveness of the WKA-1R, and the evaluation parameters to detect changes on the motor skills during the training process. Thus, an evaluation function will be proposed to understand quantitatively how well trainees are improving their skills (learning curve).

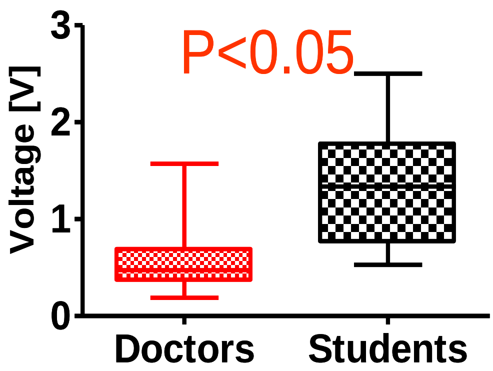

Fig. 10 Experimental results of the evaluation parameters: *Maximum applied force on the incisor teeth.*

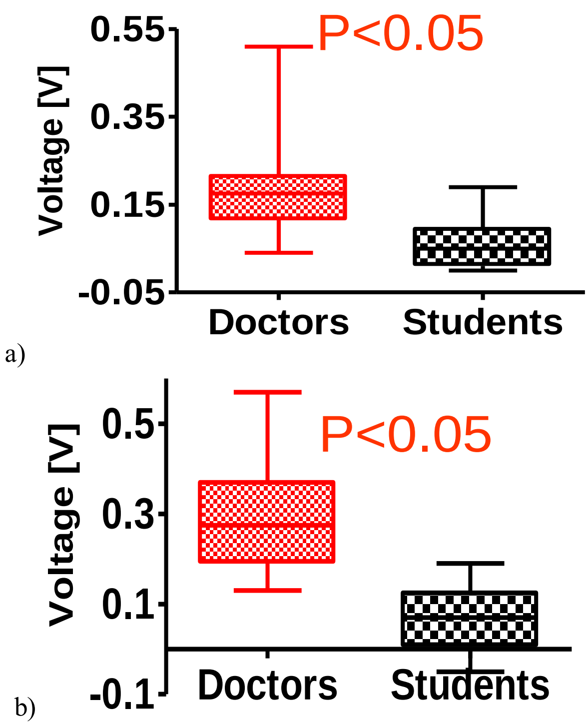

Fig. 11 Experimental results of the evaluation parameters: applied force on the tongue at: a) Sensor #1 and b) Sensor #4.

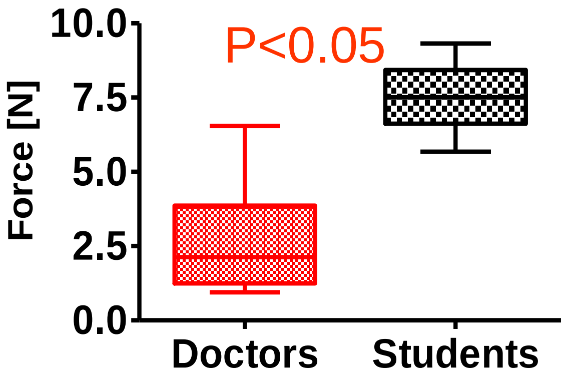

Fig. 12 Experimental results of the evaluation parameters: *Cuff Pressure* inner side of the trachea.

ACKNOWLEDGMENT

The authors would like to express special gratitude to Waseda University. The authors also would like to express gratitude to WABOT HOUSE in Gifu Prefecture and to SolidWorks Japan K.K for their support. Finally, we would like to thanks to the anesthetists from the Department of Anesthesiology at the Tokyo Women's Medical University for their valuable time to perform the experiments.

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