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Dental Patient Robot

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1. Introduction

Conventional robotics research in medicine is usually related to supporting surgical procedures and doctor's questions to patients during interviews [1]. However, there are not many examples on the development of patient robots for supporting clinical training of medical staff such as doctors and nurses. It is commonplace to use static models for therapeutic training in medicine. However, training based on the use of such models is inadequate due to differences between the models and actual patients [2]. Thus there are high expectations in the development of animated patient robots for use in medical training. Further, the development of simulators is being widely pursued in the field of dental therapy training but there are few examples of research on robots. The author has been developing patient robots for dental therapy training.

2. Practice in Dentistry

2.1 Dental school education

Recent dental school graduates of Japanese universities are said to lack clinical skills and experience in treating patients. The main reason is attributed to inadequate clinical training. Currently, so-called 'phantoms' (Fig. 1) consisting of a simple functional cephalic region and an arrangement of teeth are used for clinical training but these models are considerably different than actual patients. Until recently, clinical training was carried out on consenting volunteer patients. However, recent changes in ethical issues related to environmental studies, medicine and dentistry have made such clinical training difficult. Thus the potential danger of declining clinical skills is a problem in dental therapy training. Dental therapy skills often depend on the competence and ability of clinicians and it is necessary for them to have extensive experience using methods and models that accurately reflect actual treatment procedures and conditions.

2.2 Operating conditions

To become a dentist, it is necessary to graduate from dental school by passing a national examination in Japan. This examination is based on multiple choice (mark-sheet) questions. This method is used to reduce the possibility of unfair examinations that may result if tests were based on interviews and monitoring clinical ability. However, as described above, it can be said that in spite of the well known lack of skills of dental students, universities are still producing graduates based on knowledge instead of hands on, clinical ability. It is

known that there are many accidents in the first few years after graduating from dental school.

(a) Practice scenery   (b) Wrong method

Figure 1. Phantom for practical training

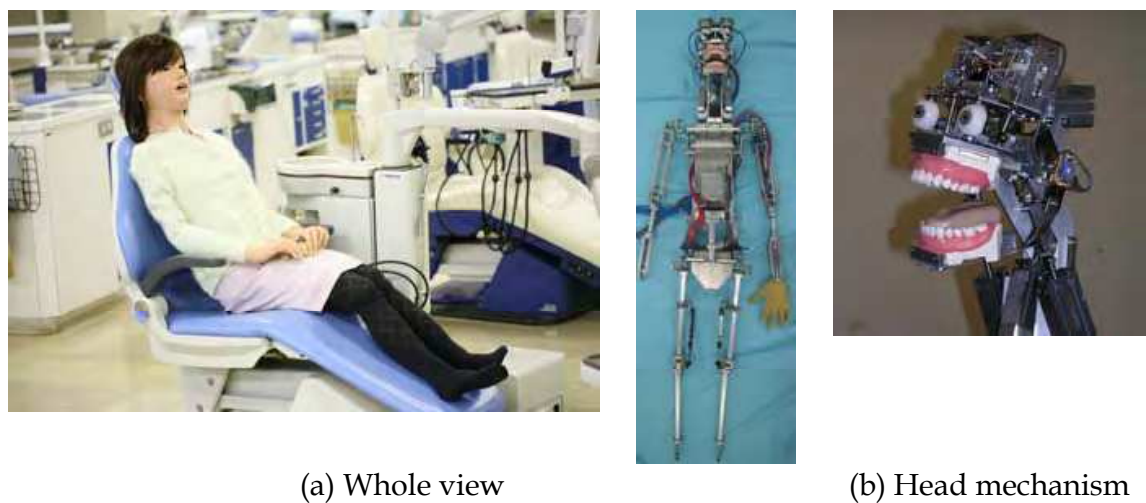(a) Whole view   (b) Head mechanism

Figure 2. Patient Robot

3. Specification of robot

3.1 External structure

The patient robot has a height of 165cm. The skeleton is made of metal and FRP is used for the skull (Fig. 2). The teeth in the conventional model used for direct therapy training, can be polished and can be easily replaced. The artificial outer skin is made from a special vinyl chloride based gum reproducing the form and sensation of actual skin. The robot has a total of 36 degrees of freedom (DOF), with patient movements being achieved by low pressure compressed air from an air cylinder as in Table 1. The other joints are passive components (Fig. 3). Further, by implementing almost human-like joints, it is possible to install the robot in an actual dental therapy unit[3][4].

3.2 Actuation system

An air cylinder is used in the drive sections. The main pressure is set at 0.7[MPa] and differential pressure to 0.35[MPa]. Further, blinking of the eyes and tongue movement are achieved by a diaphragm with a simple structure. Due to the high density of mechanical parts housed in the cephalic region, a wire is attached internally to the tongue which has 3-DOF, and the tongue is moved by pulling on the wire using a diaphragm attached to the body of the robot.

3.3 Control system

The patient robot is controlled by electro pneumatic regulators and electromagnetic valves using an air cylinder. Since it is possible to control the electro pneumatic regulator by minute changes in pressure, feedback from a PC enables fine movement of the neck and mouth. An electromagnetic valve is used for simple ON-OFF movements such as arms and eye lids. Feedback control is achieved by setting a potentiometer in parts where electro pneumatic regulators are used (Fig. 4).

3.4 Interface

The patient robot is controlled using a PC (Fig. 5). Position control of the patient robot's mouth and neck is achieved using voice recognition software that reacts to the trainee's instructions as in Fig. 6. Further, the supervising doctor can manipulate the interface to produce movements due to coughing and reactions to pain to which trainees as expected to respond. After the robot exhibits sudden movements, a five level point rating is displayed above the interface and the supervisor can grade the trainee's response in real time. A record of the type and timing of sudden movements and their evaluation is stored as a table. This table can be used in conjunction with video footage of training sessions by trainees to check their performance.

3.5 Image recoginition

The patient's eye is simulated by a small camera embedded into the patient robot's right eye. The camera has been successfully used to recognize and track trainees and instruments used during treatment. Imaging recognition is achieved using the RGB colors of video images where the color of the trainee's hair is electronically recognized and the robot's line of sight shown to the trainee (Fig. 7). By this procedure, it is possible to carry out therapy under conditions where the trainee is being watched by the patient.
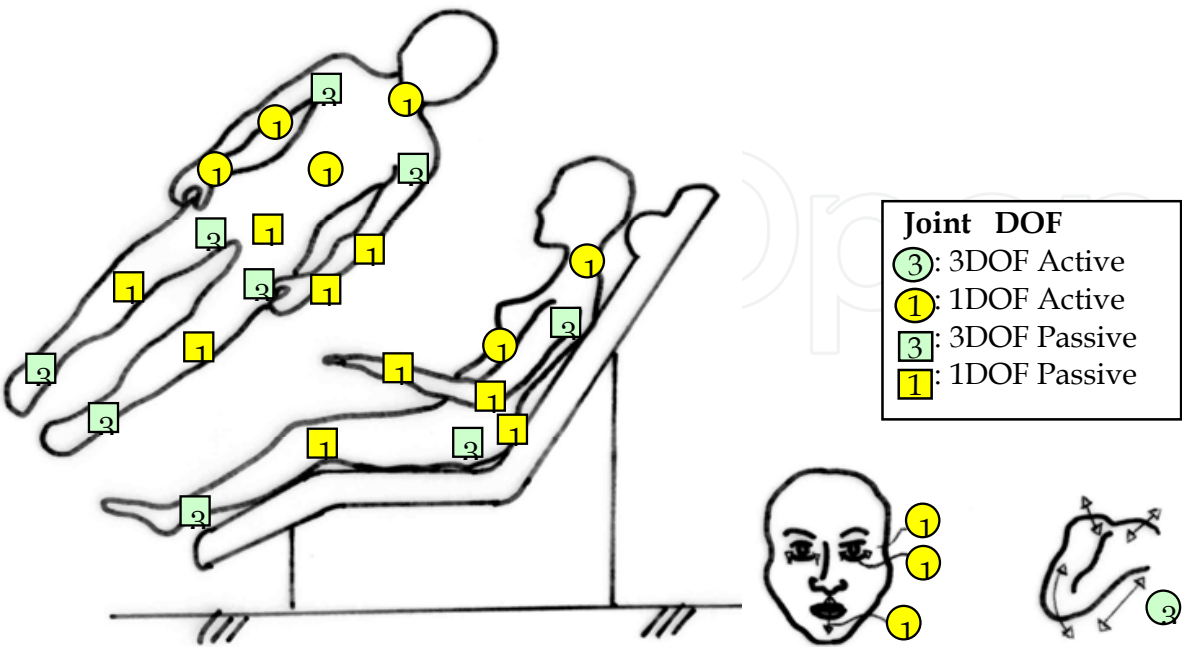

Figure 3. DOF of Patient Robot

Number	Item	DOF	Motion
1	Eyeball	1 (Active)	Right and Left
2	Eyelid	1 (Active)	Open and Close
3	Jaw	1 (Active)	Open and Close
4	Tongue	3 (Active)	Protrusion and Retraction
			Tip Up and Down
			Expansion
5	Throat	1 (Active)	Open and Close
6	Neck (Head)	3 (Active)	Nod
			Rotation
			Tilt
7	Chest	1 (Active)	Breath
8	Shoulder	3×2 (Passive)	
9	Right Elbow	1 (Active)	Bend and Stretch
10	Right Wrist	1 (Active)	Up and Down
11	Left Elbow	1 (Passive)	
12	Left Wrist	1 (Passive)	
13	Waist	1 (Passive)	
14	Hip Point	3×2 (Passive)	
15	Knee	1×2 (Passive)	
16	Ankle	3×2 (Passive)	

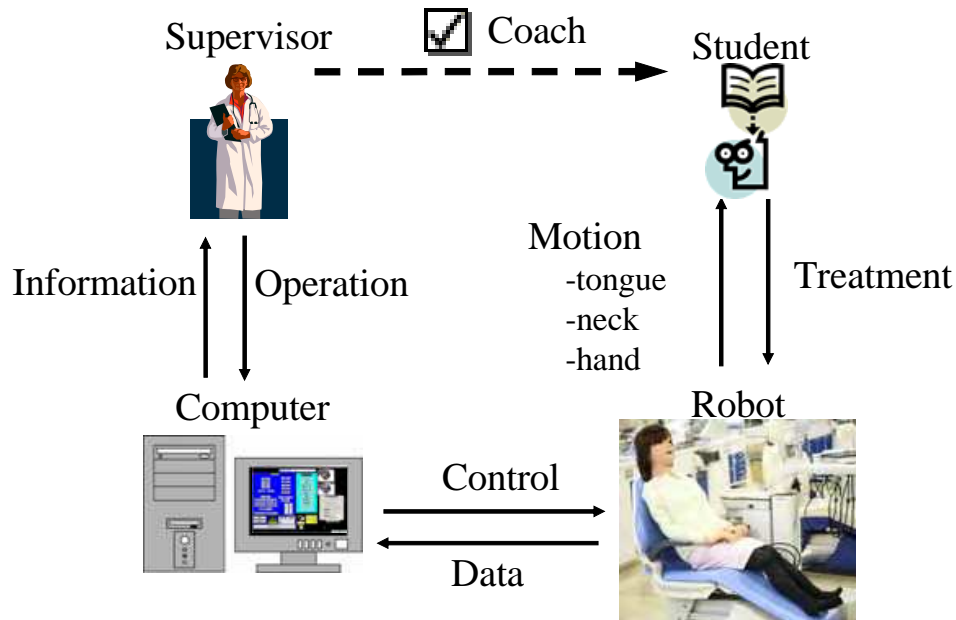Table 1. DOF configurations of patient robot

Figure 4. Control System

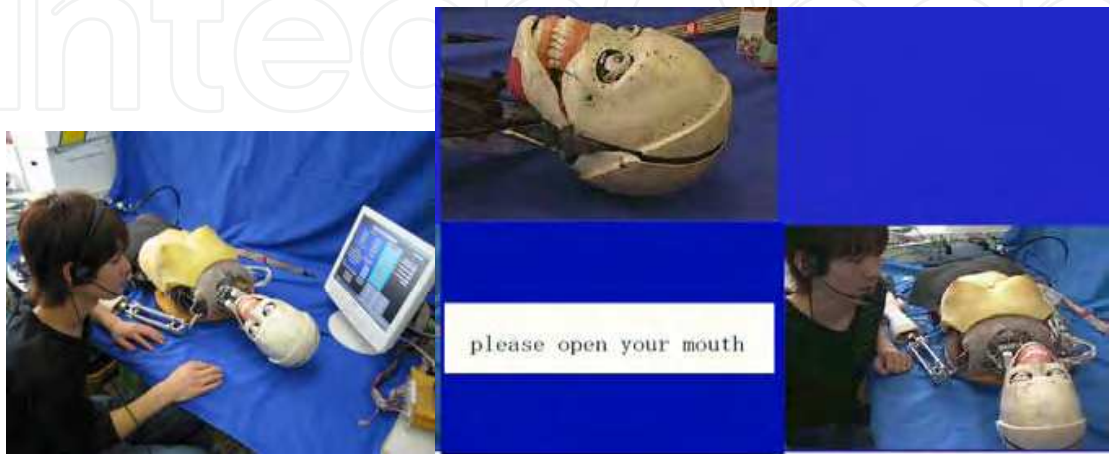Figure 5. Interface and Total System
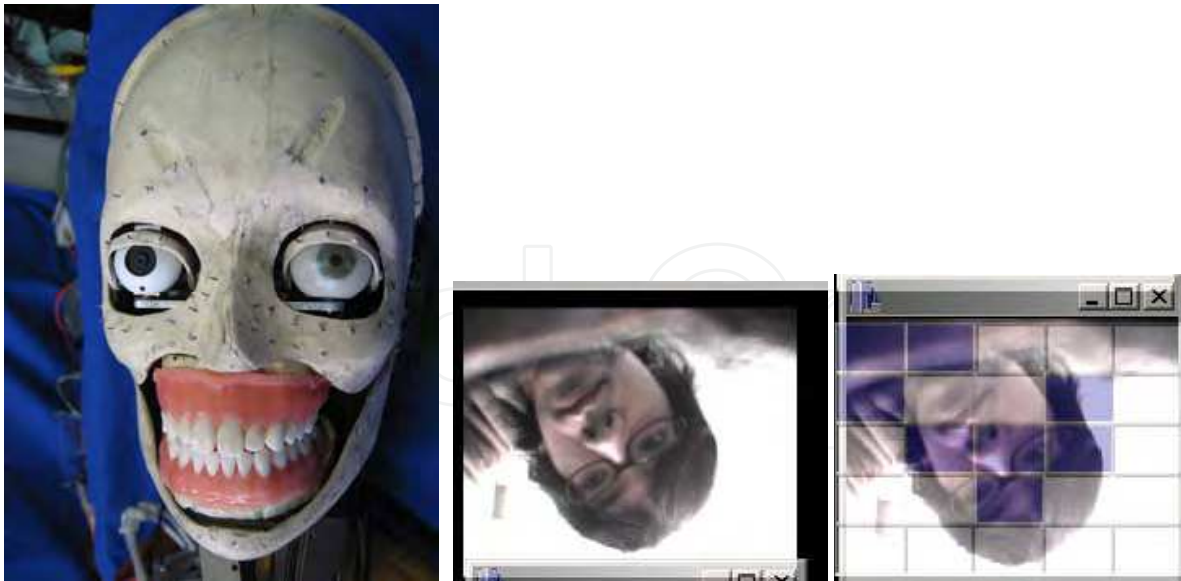

Figure 6. Voice recognition

Figure 7. Target tacking by camera

Also, the voice recognition software is useful for creating more realistic conditions to simulate actual conversation with patients during training [4]. Further, we also reproduced the psychologically induced backward movement of the head when endodontic instruments appear in the patient's line of sight. This was made possible by attaching a vinyl tape of a color not found in the treatment room.

4. Oral Cavity

4.1 Structure of the teeth

Starting from the outer surface, human teeth consist of enamel, dentine and pulp (Fig. 9). Enamel is the hardest outer surface of teeth. It is colorless and semi-transparent with a hardness equivalent to a Moha hardness of 6-7, which is comparable to that of quartz. Further, the thickness of teeth depends on their type, with molar teeth being typically 1.1~1.3[mm]. Dentine is covered with cement and produces the shape of teeth with the pulp inside. Further, dental tubules are 2~3[μm] diameters pipes, and are slightly harder than bones but have elasticity and are flexible. The pulp fills the pulp cavity at the center of teeth and serves to produce dentine and supply it nutrition; repair the dentine; protect it against bacterial infection; and transmit sensory perception.

4.2 Drilling teeth

Drilling enamel does not produce pain but pain does arise when the air turbine reaches the pulp. The body's tissue fluids circulate inside the dental tubule and intersect with the tooth pulp. During drilling, fluctuations arise in the tissue fluid of the pulp tubule which stimulate nerve ends and ultimately leads to the sensation of pain. The pain due to tooth decay is the same. The sensation of pain is felt when cold and hot substances are consumed, where tissue fluids in the tubules move and stimulate nerve ends due to temperature related expansion and contraction of fluids in the tubules. That is, pain is felt when the dentine is drilled and the level of pain increases for prolonged drilling due to heat generated by friction. Further, acute pain is felt if drilling is continued into the pulp.
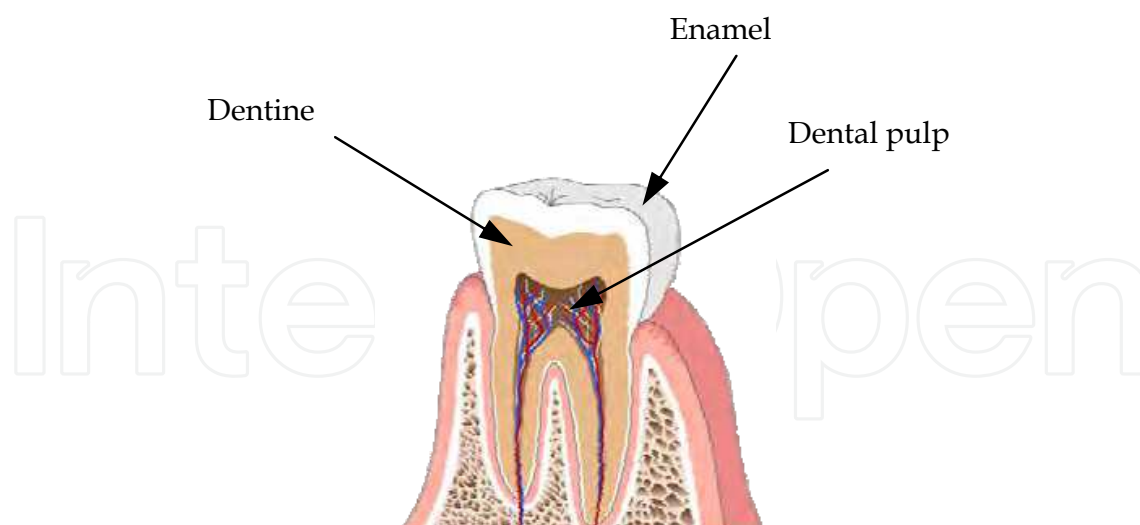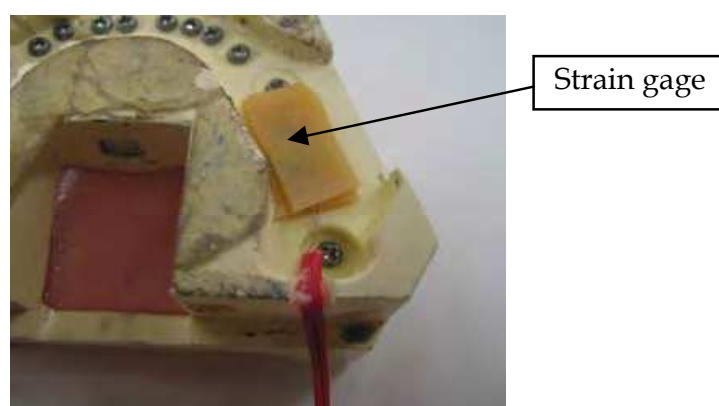
Figure 8. Tooth model [6]

Figure 9. Installation of tooth sensor (bottom view)

4.3 Force sensor for drilling and grinding of teeth

Force sensing is achieved by monitoring the load of drilling during surgery by a sensor embedded in one of the 2nd molar teeth on the left side. The sensor consists of a strain gauge sandwiched in gum, which is attached to the teeth arrangement model (Fig. 9). In this way, when the spring is compressed under the action of a load, a screw is pushed and the strain gauge sandwiched in the gum is bent (Fig. 10). During this procedure, the voltage of the strain gauge is recorded which is a measure of the load acting on the tooth.

4.4 Effusion of bleeding

For dental students and trainees, the effusion of blood is one of several unexpected situations. Thus, in order to train students to react calmly to unexpected bleeding during surgery, the patient robot is designed to reproduce the effusion of blood. The main locations for bleeding in the oral cavity are regions inside of both cheeks and areas ranging from the surface to below the tongue.
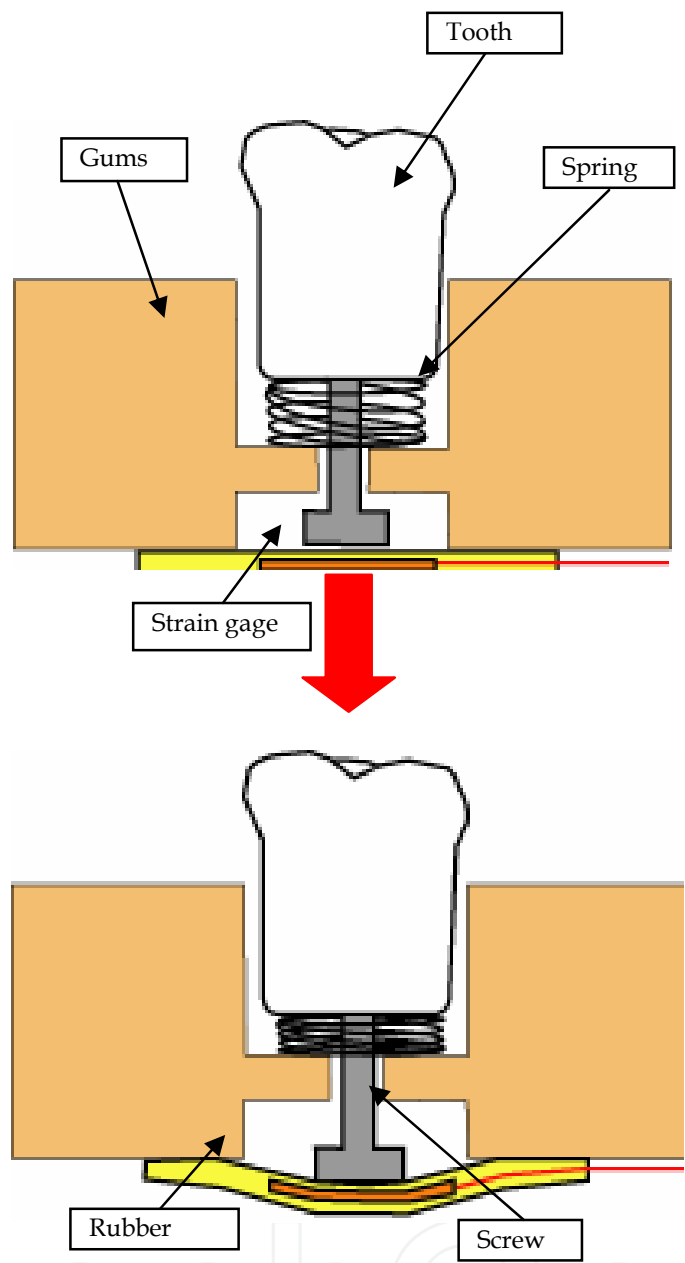
Figure 10. Mechanism of tooth sensor

Figure 10. Bleeding results

The main reason for bleeding in these regions is due to accidental contact of the air turbine with the cheeks or tongue during surgery of the 2nd molar, when patients are prone to move their tongue. For these reasons, the patient robot is also designed so that bleeding results under the above conditions from both cheeks and the tongue regions as described. This is implemented as a three layered structure, consisting of red pigmentation sandwiched between two silicone resin plates. This structure is only a mere 0.4[mm] thick, and suitable for fitting into the oral cavity.

4.5 Saliva

The ease of performing dental surgery is affected by the amount of saliva. In particular, it is desirable that the surface of teeth be dry when inserting fillings. If the volume of saliva is large then the moist surface hinders adhesion of the fillings. Thus we have fitted a saliva mechanism to the patient robot. Since 2/3 of saliva secretion is exuded from the parotid gland, the saliva is produced from the parotid gland of the patient robot. The tube from an externally connected air pump is placed into a water tank, an air pump is used to push into the tube which flows out at the location of the parotid gland inside the oral cavity. The saliva flow volume for a patient at rest is 0.3 [ml/min]. External stimulation results in this volume increasing to between 1.0~1.7[ml/min]. The patient robot is able to produce 7.7 [ml/min], which reproduces the saliva flow patients undergoing surgical procedures.

4.6 Uvula

This robot have a uvula sensor that simulates human vomiting reflex. As in Fig. 11, a touch sensor was installed in the oral cavity. The robot vomits when something touches it. In the training situation, supervisor clicks the vomiting button to evaluate the trainee's reaction for the robot's vomiting.
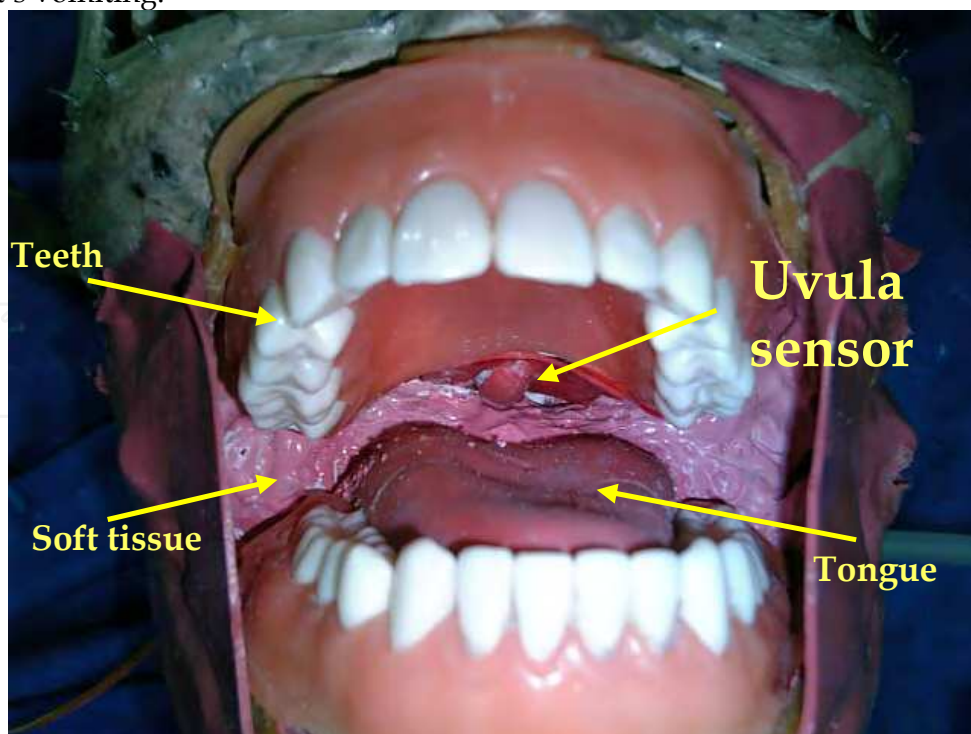

Figure 11. Uvula sensor

5. Experiment

5.1 Method

The performance of the patient robot was evaluated by 32 members of Showa University (two clinical interns, 29 students in the 5th year who had completed basic clinical training using phantom heads; and one veteran doctor). The experiments were conducted using the functions available at the present time and involved cavity preparation and drilling of the 2nd molar on the left side of the jaw, that is, drilling of back molars. The experiments were conducted in groups consisting of a trainee and two assistants. The supervisor evaluated the performance of the students by giving instructions to the patient robot via the interface of the PC (Fig. 12). The view from the camera embedded in the patient robot is shown in Fig. 13.

Figure 12. Practice scenery that uses Patient Robot

Figure 13 View from camera of Patient Robot

5.2 Experimental results

Fig. 14 shows a selection of the results of a questionnaire following the training.

Which components of the robot were well reproduced?
- Movement of the eyes, mouth and head and hardness of the lips.
- Unexpected movements (neck, vomiting, sudden closure of the jaw)
- Respiration, the act of swallowing, raising of hand
- The slow closure of the mouth during treatment
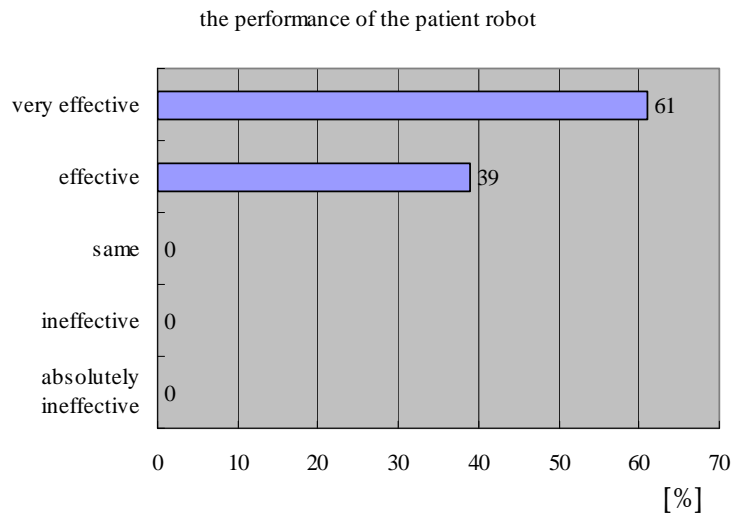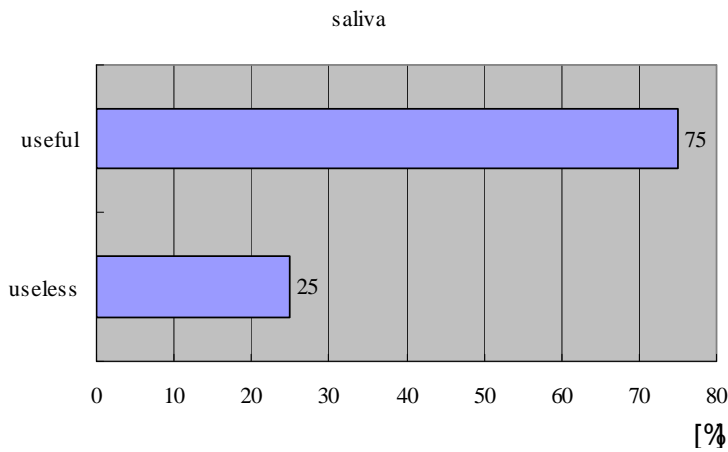
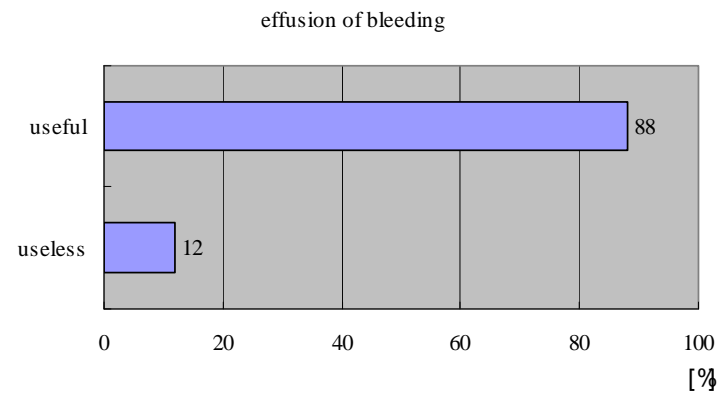What components of the robot were not well reproduced?
- The opening of the mouth was too small and the tongue movement insufficient.
- The lips and buccal mucous membrane were too tight. The angle of the mouth too rigid.
- The pharynx was too deep inside the oral cavity
- Respiration movement was too large

What are the effective features of the patient robot?
- Reproduction of the movement as found in actual patients during surgery was instructive for learning about the difficulties of treatment.
- Treatment was difficult due to hard lips. Unexpected movements were realistic.
- Different to conventional machines thus enabling interactive learning.
- Voice recognition enabled students to respond individually.
- The importance of talking became apparent.
- A certain degree of tension was generated during training.

What aspects were ineffective?
- Cavity formation would become difficult to understand if the robot were to be used from the beginning.
- The lips and jaw angle were rigid.
- I do not think that patients move in the same way as the robot.
- The timing of the mouth closing was a little different from reality.
- There were occasions when there was not a response to the actions of the trainee.
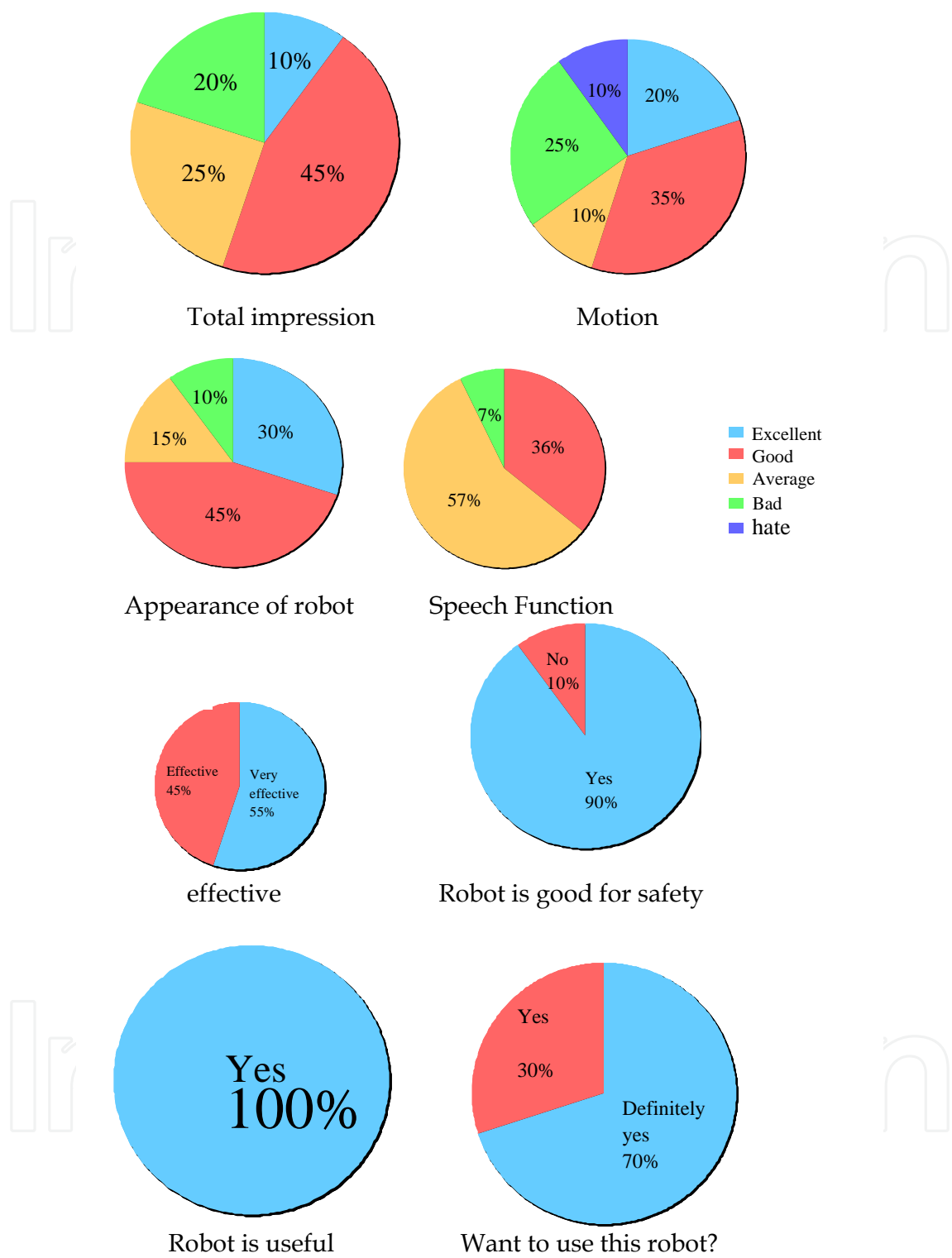- I did not understand the reasons for certain reactions during treatments.

effusion of bleeding

useful	88
useless	12

0 20 40 60 80 100
[%]

saliva

useful	75
useless	25

0 10 20 30 40 50 60 70 80
[%]

the performance of the patient robot

very effective	61
effective	39
same	0
ineffective	0
absolutely ineffective	0

0 10 20 30 40 50 60 70
[%]

Figure 13. Result of questionnaire

Regarding comments about the ineffectiveness of reactions during treatment, I think that improving the performance of the sensors will resolve these problems. Also, I have consulted with dentists and been told that the rigidity of the mouth is acceptable as designed and hence this issue is not a problem. The major differences of opinion between

the clinical residents and students were the volume of the mouth opening and stiffness of the lips. Clinical residents have actual experience of treating patients and are familiar with the rigidity of the lips and volume of the mouth opening and used the robot as in usual procedures. However, in the case of students who have not operated on actual patients yet, there were many instances of comments about the rigidity of the lips, volume of the mouth opening and signs of forcibly opening the mouth.

This is because the phantom usually used by dental students for training, has a larger sized mouth opening than actual patients and thus they find it difficult to carry out procedures using actual sized models. Also, since students performed surgery by looking only into the oral cavity, they did not notice the patient robot raising its hand in response to pain. This cannot be reproduced using a training phantom and is another useful feature of the patient robot.

6. Conclusions and future works

A patient robot with an oral cavity mimicking unexpected movement due to vomiting and pain and functions to induce bleeding and saliva flow was developed and used for clinical training. Trainee students and clinical residents were asked to complete a questionnaire about the patient robot. The results showed the patient robot to be effective as a means of training students to respond to unexpected movements during surgical procedures.

In the future, the author intend to incorporate additional sensors such as those used in the oral cavity, to enhance reactions to due pain so that clinical students could train by themselves without supervision.

7. Aknowlegement

8. References

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Medical Robotics

Edited by Vanja Bozovic

The first generation of surgical robots are already being installed in a number of operating rooms around the world. Robotics is being introduced to medicine because it allows for unprecedented control and precision of surgical instruments in minimally invasive procedures. So far, robots have been used to position an endoscope, perform gallbladder surgery and correct gastroesophogeal reflux and heartburn. The ultimate goal of the robotic surgery field is to design a robot that can be used to perform closed-chest, beating-heart surgery. The use of robotics in surgery will expand over the next decades without any doubt. Minimally Invasive Surgery (MIS) is a revolutionary approach in surgery. In MIS, the operation is performed with instruments and viewing equipment inserted into the body through small incisions created by the surgeon, in contrast to open surgery with large incisions. This minimizes surgical trauma and damage to healthy tissue, resulting in shorter patient recovery time. The aim of this book is to provide an overview of the state-of-art, to present new ideas, original results and practical experiences in this expanding area. Nevertheless, many chapters in the book concern advanced research on this growing area. The book provides critical analysis of clinical trials, assessment of the benefits and risks of the application of these technologies. This book is certainly a small sample of the research activity on Medical Robotics going on around the globe as you read it, but it surely covers a good deal of what has been done in the field recently, and as such it works as a valuable source for researchers interested in the involved subjects, whether they are currently "medical roboticists" or not.

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