Measurement of palpation motion using prostate examination simulator and motion capture system

Takeshi OKUYAMA*, Shota YOKOYAMA**, Yoshikatsu TANAHASHI*** and Mami TANAKA**

*Department of Bioengineering and Robotics, Tohoku University
6-6-04 Aramaki-Aoba, Aoba-ku, Sendai, Miyagi 980-8579, Japan
E-mail: okuyama@rose.mech.tohoku.ac.jp
**Department of Biomedical Engineering, Tohoku University
***Office Urology Tanahashi

Abstract
In this paper, palpation motions for prostate gland were measured using a prostate examination simulator and motion capture system in order to clarify effective motions for accurate diagnosis. It is difficult for students to learn how to make a palpation motion and what information to obtain during palpation. Quantitative evaluation of palpation motion is demanded. Firstly, the prostate examination simulator was developed and six kinds of prostate models, including a healthy model, a cancer model, and a hypertrophy model, were prepared as palpation samples. Next, by using these measurement system, prostate palpation motions by an expert and five students were measured. While participants diagnose the presence of lumps in prostate models and the size of prostate, fingertip position and force applying on prostate models were measured. From the results, it was confirmed that the expert diagnosed the state of prostate glands more accurately. Then motion analyses for trajectory of fingertip, contact force, and finger posture were carried out and motion characteristics between the expert and students were compared. From these results about both of trajectory and contact force, and it was found that the expert commonly explored over the whole of models by relative larger contact force than students do, it was suggested that the expert simultaneously explores presence of lumps and the shape of prostate. And from the results of analysis on finger posture, it was found that palpating the entire prostate with the fingertip is effective. As a results, the motion characteristics of the expert were extracted by using the developed system.

Key words: Palpation, Prostate gland, Motion analysis, Measurement, Finger posture, Simulator

1. Introduction

Palpation is one of simple diagnosis methods that physicians examine the body or organs by feeling with their hand and fingers (Najarian et al., 2009). Physicians estimate the physical properties of the palpated object, such as existence of lumps in objects, location of lumps, size of lumps and objects, stiffness of lumps and objects, and movability of lumps. By using palpation, physicians diagnose conditions of various diseases, such as breast cancer, prostate cancer, and cirrhosis of the liver (Aubin et al., 2014, Tanabe 2006). However, the diagnosis by palpation is essentially subjective, and physicians need long-time training and practice to make an accurate diagnosis using palpation. Moreover, it is difficult for beginners to learn how to make a palpation motion and what information to obtain during palpation (Aubin et al., 2014). Therefore, studies on the palpation are demanded. Two major attempts have been conducted. One is to improve the current procedure and training (Aubin et al., 2014, Burdea et al., 1999, Ullrich and Kuhlen, 2012). The other is to develop the effective palpation device for measuring tactile information during palpation (Najarian et al., 2009, Okuyama et al., 2010, Tanaka et al., 2014). For both attempts, it is necessary to measure the palpation motion of experts and beginners quantitatively and objectively, and to reveal the effective motion for accurate diagnosis.

Therefore, we aim to develop a measurement system of palpation motion and to reveal the characteristics of the
effective palpation motions to obtain the accurate diagnosis. In this paper, we focus on palpation of prostate gland (Martini and Bartholomew 1997). In Japan, as population aging advances, the number of patients with prostatic disease is increasing. The prostatic disease is taken seriously. The prostatic disease is diagnosed by prostate specific antigen(PSA) measurement, transrectal ultrasonography(TRUS), digital rectal examination(DRE), and biopsy (Ito 2005, Mettlin et al., 1996). Imai et al. reported that PSA had the highest sensitivity and positive predictive value in the diagnosis of prostate cancer. However, Some prostate cancer not to be detected by PSA were detected by DRE and/or TRUS (Imai et al., 1995). Therefore, in general, combination of PSA measurement, DRE and TRUS are recommended. If an abnormal finding is found in any of these three methods, biopsy is recommended (Ito 2005).

DRE is the simplest and most cost-effective method and widely used for diagnosis and a follow-up of treatment. DRE is to palpate the prostate gland with inserting a finger through the anus. Because the finger motion cannot be observed, it is difficult to master the technique of DRE. Burdea et al. (1999) have developed the virtual reality-based training system using PHANToM system. The training system is available to excise the palpation. However, it is difficult to archive the natural palpation motion by experts, due to the restriction of mechanical feedback, such as tactile sensation. In this paper, to overcome the problem, a prostate palpation simulator for measuring actual palpation motions is developed. Using the simulator, 3-axis load cell and motion capture system, palpation motions of an expert and five beginners are measured and compared. The effective palpation motion for prostate gland is clarified.

2. Palpation simulator and motion capture system

In the palpation of prostate gland, physicians insert a finger into the rectum through the anus and they palpate the prostate through the rectum (Ito 2005). In order to analyze the palpation motion, a prostate palpation simulator was designed as shown in Fig. 1. The palpation simulator essentially consists of an anus part that is a thick polyurethane sheet with a hole (15 mm in diameter), a rectal part that is a thin polyurethane sheet (5 mm in thickness) placed behind the anus part, and prostate models imitating several prostate states. In this work, we prepared six prostate models including prostatic hyperplasia models, prostatic cancer models, and a healthy prostate model as shown in Fig.2 and Table 1. The prostate models are made of polyurethane resin (EXSEAL Corporation, HITOHADA gel, H0) and lumps are made of silicone resin(Shin-Etsu Silicone, KE-1300T). Shape of Model 1 and Model 4 imitate that of normal prostate. The right lobe of Model 2 and Model 5 are enlarged. Model 3 and Model 6 are enlarged in whole. And some lumps (ball with 12 mm in diameter) are implanted in the cancer models (Model 4, Model 5, and Model 6). As shown in Fig.1(b), the prostate model is fixed above the rectal part. In usage of the simulator, a participant inserts an index finger into the hole in anus part, and examines the prostate model through the rectal part.

Figure 3 shows a schematic drawing of measurement system with the developed simulator. In the measurement system, a 3-axis load cell and motion capture system are integrated to measure the applying force to the prostate model and the finger position during palpation. The load cell (Tech Gilhan, USL06-H5-200N) is attached to the prostate model as shown in Fig.3. Motion capture system(Inter Reha Co.,VICON) consists of four infrared cameras(Inter Reha Co., MX-T160). Three markers (6 mm in diameter) are attached to participant's nail of the index finger, distal...
Fig. 2 The prostate models. Model 1 and Model 4 simulate size of normal prostate. Model 2 and Model 5 simulate size of hypertrophy prostate with enlarging the right lobe. Model 3 and Model 6 simulate size of hypertrophy prostate with enlarging both lobes. Silicone balls (12 mm in diameter) are implanted in Model 4, 5, and 6 as lumps. Dash circles indicate positions of implanted silicon balls.

Fig. 3 Measurement system. The system is composed of the prostate examination simulator, the prostate model, 3-axis load cell, and motion capture system with four infrared cameras. Markers for motion capture system are attached on nail, DIP joint, and PIP joint of the index finger.

Table 1 Properties of Prostate models

<table>
<thead>
<tr>
<th>Index</th>
<th>State</th>
<th>Number of lumps</th>
<th>Size (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal</td>
<td>Non</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Hypertrophy (right lobe)</td>
<td>Non</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>Hypertrophy (both lobe)</td>
<td>Non</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>Cancer</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>Cancer</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>Cancer</td>
<td>3</td>
<td>65</td>
</tr>
</tbody>
</table>

These markers’ three-dimensional positions are analyzed. The markers’ positions and load cell outputs are measured simultaneously. The load cell outputs are measured by 1 kHz and markers’ positions are recorded by 100 Hz. Coordinate system is defined as shown in Fig. 1. X axis is horizontal direction, Y axis is longitudinal direction, and Z axis is vertical direction.

3. Experiments

Figure 4 shows the experimental setups for measurement of the prostate palpation motion. In the experiments, the palpation simulator and measurement system mentioned above are used. Participants were six volunteers. One of them is an expert urological physician, and the others are students. In this paper, the expert indicates index "MD" and students indicate indices "A", "B", "C", "D", and "E".

In experiments, participants sat in front of the developed palpation simulator, and wore a latex glove on dominant hand. Participants insert their index finger into the hole in anus part and they examine the prostate model. At first, the normal prostate model was introduced as a standard of healthy prostate to participants. Then participants explored the six models like conducting palpation, and answered two questions about the presence of lumps and the shape of the prostate model.
prostate. When participants found lumps or abnormal shapes, they also answered the locations in addition. They answered all the questions orally. The answers and response time to each question were recorded by a reporter.

Each participant palpated every prostate model once, and presentation order of the models for every participant was the same. Palpation time and answer order were not restricted.

4. Results and discussion

4.1 Diagnosis

The accuracy of diagnosis was summarized in Tables 2 and 3. Table 2 shows the diagnosis about size. Table 3 shows the diagnosis about lumps. In the tables, “○”, “△”, and “×” indicate that diagnosis is completely correct, partially correct, and completely wrong, respectively. For instance, answer for Model 1 of the participant “E” is “×”, because he answered abnormal shape for Model 1(normal prostate model). And answer for Model 2 of the participant “E” is “△”, because he answered abnormal shape for Model 2 but enlarging location was wrong.

From a comparison between Table 2 and Table 3, diagnosis about size is more difficult than that about lumps. From
a comparison of answers of each participant, it was confirmed that the expert diagnosed more correctly than all the students did. This shows that the expert has better palpation skills than the students.

4.2 Palpation motion data

Figure 5 shows an example of palpation motion data. Figure 5(a) is a trajectory of fingertip marker in XY plane, and Fig.5(b) is time evolution of contact force measured by the load cell attached to the prostate model. In Fig.5(a), blue line indicates the trajectory and red line indicates the outline of the model. As shown in Fig.5(a), participant B palpated the whole of model. This applies to other participants as well. In Fig.5(b), contact force applying to the prostate model is frequently changed during measurement. However, the data included both palpation motions for diagnosing the size and the lumps. In analysis of the data, we focused on the data for 10 seconds just before answering each question. We assumed that palpation motion effective on diagnosis was observed just before answering the diagnosis. Therefore, the data for 10 seconds just before answer each question were extracted and analyzed below.

4.3 Trajectory

Figure 6 shows the representative results of the extracted trajectories for 10 seconds during palpation of Model 5. Model 5 has abnormal shape and lumps. Figures 6(a) and (b) indicate the trajectories of participate C and E just before answering about size, and Figs.6(c) and (d) indicate the trajectories just before answer about lump. As well as Fig.5(a), blue line indicates the trajectory and red line indicate the outline of the model.

As shown in Fig.6, trajectories when they answered about lumps commonly concentrated above lump position, while trajectories when they answered about the shape of the prostate were spread over the whole prostate model. Therefore, in order to evaluate these characteristics, palpation area was defined as shown in Fig.7. The smallest rectangular in which the trajectory for 10 seconds is enclosed was defined as palpation area. The sides of the rectangular are parallel to X axis or Y axis.

The obtained palpation areas of all participates for Model 5 are shown in Fig.8. As shown in Fig.8(b), palpation area of students (participate A to E) when they answered about lumps commonly concentrated above lump position, while the expert's palpation area(participate MD) did not concentrate and spread over the whole prostate model. On the
other hand, from the results of Fig. 8(a), it was found that all palpation area when they answered about the shape of the prostate were spread over the whole prostate model. The difference between students and the expert was observed in results for other models as well. As the results, it was found that the expert has the common palpation motion regardless of questions.

4.4 Contact force

Contact forces for 10 seconds just before answering were extracted as well as the trajectories. Then the average contact forces for each axis were calculated. The average contact forces during palping Model 5 are shown in Fig.9. Figures 9(a), (b), and (c) show the average contact forces in X direction, Y direction, and Z direction, respectively. The definition of coordinates is shown in Fig.1. The contact force in Z direction is regarded as pressing force against prostate models.

The characteristics of the expert are different from those of students. Figure 9(a) and (b) indicate that participant MD applied larger contact forces in X and Y direction than the others did. Moreover, concerning pressing force, in the case of students, pressing force when they answered about the shape of prostate is less than that when they answered about lumps. On the other hand, in the case of the expert, pressing force does not depend on the components of questions.

From these results about both of trajectory and contact force, characteristics in the students' palpation motion depends on the question item, but the difference in the motion characteristics due to question items is not observed in the expert's palpation motion. The expert commonly explored over the whole of models by relative large contact force. The average contact forces of the expert in X and Y direction are around 1N and that in Z direction is around 2N. From the comparison between the expert and students, it was suggested that the expert simultaneously explores presence of lumps and the shape of prostate. The expert's simultaneous exploring is considered to be an important skill to realize the shorter palpation and to reduce the burden on patients.

4.5 Posture of finger

To examine finger postures during palpation, two kinds of angles shown in Fig.10 were calculated by using the formula of scalar product. $\theta$ is angle of XY plane shown in Fig.1 and the fingertip, and the angle was calculated from
Fig. 11 Calculated angles related to finger posture when participant B palpated Model 1

Fig. 13 Fingertip trajectory separated by finger posture when participants palpated Model 2

the positions of marker on nail, hereinafter referred to as Marker 1, marker on DIP joint, hereinafter referred to as Marker 2, and hypothetical marker, hereinafter referred to as Marker 0, which is defined by X coordinate value of Marker 2, Y coordinate value of Marker2, and Z coordinate value of Marker 1. \( \theta_2 \) is a joint angle of DIP, and the angle was calculated from the positions of Marker 1, Marker 2, and marker on PIP joint, hereinafter referred to as Marker 3.

The typical time evolution of the calculated angles are shown in Fig. 11. In this figure, the data when participant B palpated Model 1 are shown. As shown in Fig.11, \( \theta_1 \) varies around 30 degrees and \( \theta_2 \) varies around 180 degrees. \( \theta_1 \) has a tendency to decrease with increase of \( \theta_2 \). The correlation coefficient between \( \theta_1 \) and \( \theta_2 \) was -0.799, and it was found that \( \theta_1 \) has a negative correlation with \( \theta_2 \).

Hence, Finger posture during palpation are classified into two types as shown in Fig.12. One is to palpate with the fingertip as shown in Fig.12(a), hereinafter referred to as "fingertip pose". In this case, the DIP joint is bended, \( \theta_1 \) became larger, and \( \theta_2 \) became smaller than 180 degrees. The other is to palpate with the finger pad as shown in Fig.12(b), hereinafter referred to as "finger pad pose". In this case, the DIP joint is extended, \( \theta_1 \) became larger, and \( \theta_2 \) became larger than 180 degrees.

A threshold of angle \( \theta_1 \) is set for classification of the finger posture. In this paper, the threshold was experimentally determined to be 30 degrees so as to easily find the differences between the participants. Finger postures when \( \theta_1 \) is larger than 30 degrees are assumed to be close to "fingertip pose", and finger postures when \( \theta_1 \) is smaller than 30 degrees are assumed to be close to "finger pad pose".

To investigate the distribution of finger posture on the prostate model, Fig.13 shows the trajectories to use different color for each finger posture. Red lines indicate the trajectories with "fingertip pose", blue lines indicate the trajectories with "finger pad pose", and green lines indicate the outline of the prostate model. Figs.13(a), (b), and (c) show the trajectories when Model 5 was palpated by participant MD, C, and D, respectively.

As shown in the result of participant MD (Fig.13(a)), most of the trajectories are red, and the prostate model is covered with the red trajectories. In trajectories of participant C (Fig.13(b)), blue and red lines are observed comparable, and red trajectories are concentrated in the upper part of the prostate model. Concerning participant D, as shown in Fig.13(c), most of the trajectories are blue. The difference in the finger posture between the expert and students is clarified. From these results, it was found that the expert palpated the whole of prostate model with "fingertip pose", while almost of students palpated the upper part of the prostate model with "fingertip pose" and the bottom part of the prostate model with "finger pad pose". The tendency was also found in the results of other palpation models. As a results, it was suggested that palpating the entire prostate with the fingertip is effective. To increase the credibility of these findings, the calibration of initial posture and the objective determination of the threshold are needed in further investigation.
5. Conclusion

In this paper, the prostate examination simulator was developed in order to evaluate the palpation motion. By using the simulator, 3-axis load cell, and motion capture system, palpation motion of an expert and students were measured. From the comparison between diagnoses of the expert and students, it was confirmed that the expert diagnosed the state of prostate glands more accurately. And motion analyses for trajectory of fingertip, contact force, and finger posture were carried out and motion characteristics between the expert and students were compared. From these results about both of trajectory and contact force, it was suggested that the expert simultaneously explores presence of lumps and the shape of prostate. It is believed that the characteristics is important to reduce the burden on patients. Moreover, from the results of analysis on finger posture, it was found that palpating the entire prostate with the fingertip is effective. As a results, the motion characteristics of the expert were extracted by using the developed system. It was found that the developed palpation simulator and the measurement system are available to measure the palpation motions for prostate gland.

In future, we will measure the motions of more participants of expert and trainee doctors by using the developed systems, clarify important features of experts' palpation motion, and construct the method to indicate the features.

References