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Objective Assessment of Surgeon's Skill using Needle Grasping Virtual Reality Module

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ABSTRACT

Conventional practice for surgical skill assessment relies heavily on expert surgeons using direct observation of outcomes. This is highly subjective and prone to inter and intra-rater's variability. The aim of this study is to develop a computer based assessment module and to identify the measurable parameters that can be used to assess surgical skill objectively. The virtual-reality computer modules namely 'Needle Grasping' were developed using Visual C++, PHANTOM Omni haptic device and sensors emulated a fundamental step in suturing and evaluated the needle grasping angle and grasping position. To validate the modules, experiments was conducted with 4 surgeons and 11 non-surgeons to identify significant parameters that could differentiate between expert and novice subjects. Experimental results showed that surgeons outperformed non-surgeons significantly in needle grasping position, where the comparison values were 2.64 ± 3.48 and 3.99 ± 3.94, respectively

Key words: Assessment parameter, psychomotor skill, surgical skill, virtual reality.

1. INTRODUCTION

Surgery is one of the medical specialities that involves cutting of human body or animals in order to threat pathological condition, to improve body function and also can be used to repair unwanted ruptured areas. Surgery is done by a surgeon who has additional fellowship training and experience in the specialized field. Based on previous studies, the surgical speciality is the most popular choices of speciality among young medical students [1-3]. A survey of career choices conducted by Malaysian researchers found the surgical speciality to rank the highest in career preferences among the medical students in Malaysia [4]. Similar result was found by Scott et al. [5] when conducting a survey among Canadian medical students, where almost 80% of them considered the surgical specialty as their foremost career interest.

Suturing is one of the most important tasks that surgeon need to perform during surgical procedure, such as for closing a wound and joining the tissue [6]. Correctly holding the needle by needle holder is one of the most basic tasks for early step in suturing. The correct technique to grasp the needle is very important because it will affect the smoothness of the trajectory during the suturing task and affect the fineness of the suture [6]. Wrong technique may lead to undesired surface damage of the tissue. Grasping needle near to the swage might cause the needle to break easily and might lead to rotation or tilting of needle when it passes through the tissue. On the other hand, if the needle is grasped too close to the tip, suturing range would be limited and could not provide enough length of the needle to pass through both sides of the wound [7]. The ideal grasping position for the surgeon to grasp the needle was recommended between middle and 2/3 from the needle tip point and the ideal grasping angle should be 90o between the needle holder and the curve needle [7].

Toole et al. developed an interactive VR surgical simulator for the training and assessment of suturing technique. This study compares the performance of vascular surgeons and medical students when performing the virtual reality suturing task. Their performance were evaluated using 8 parameters for early suturing [8]. In other study, Kazemi et al. developed custom made needle insertion module using virtual reality system to assess suturing skill. This study evaluated the performance of subject when handling the interaction between needle and the tissue during insertion task [9]. However, assessment parameters related to the needle grasping technique in early insertion task and early suturing were not studied.

Hence, in this study, an experiment was conducted to assess the needle grasping position and angle using the 'grasp and transfer' task. In previous study using MIST- VR simulator, grasping and transferring task are normally used to developed coordination skill while manipulating the objects. The virtual objects are usually represented as 3-D target balls. The same concept was applied in this module, however the task did not use spherical balls as objects. A 3D virtual needle was designed to investigate how well the subjects are able to coordinate and manoeuver a tool corresponding to the target location and different orientations. In this module, the tool was represented by a pair of forceps and the target was represented by a curve suture needle.

2. RESEARCH METHOD

Twelve subjects without known hand pathology participated in this study involve with two groups: surgeon and non-surgeon. The surgeon group comprised four surgeons with at least 3 years of experience in surgery, while non-surgeon group comprised four medical students and seven engineering students. Informed consent was obtained from the participants.

2.1 Experimental Setup

Development of virtual reality module for grasping task was prepared using PHANTOM Omni haptic device, 3D monitor Acer HS244HQ with a pair of active 3D shutter glasses (built-in IR emitter), Alienware M17× laptop with graphic card nVidia GeForce 54m series, force sensor and NI-USB 6009 data acquisition card. The module was rendered in 3D, allowing depth perception within the visual display when using 3D shutter glasses. In the needle grasping module, only three objects were modelled: needle, forceps and wire sphere (dumping bin) (Figure 1).

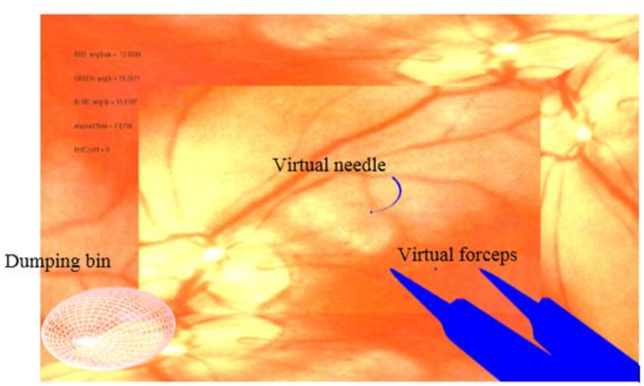

Figure 1: Visual display for needle grasping task

Virtual forceps can move based on the movements of the PHANTOM Omni stylus. The movement of the PHANTOM was magnified 10× on screen to give an effect of magnified motion under microscope. The force sensor was attached to the PHANTOM and it was used to represent the opening and closing of the virtual forceps when the user pressed and released it (Figure 2).

Figure 2: Haptic and force sensor

The movement of the needle only depended on the magnitude and direction of force applied from the forceps. When forceps gripped the needle and moved, the needle moved together with the forceps. The development of virtual needle that appeared in assessment module was built by numerous numbers of spheres that aligned and bounded together in a particular manner (Figure 3). Each sphere was represented by its own specific ID number which was used to record the needle grasping point whenever the forceps grasp the needle.

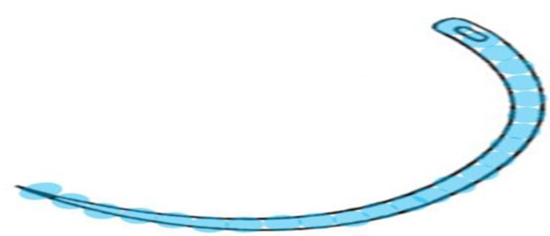

Figure 3: Development of virtual needle

All subjects were shown a short video before start the experiment trials. This video showed them how the needle grasping simulator works and subjects were given chance to familiarize with the procedure. Once the subject understood the procedure they proceeded to start the experiment.

Subjects were required to be seated at the table in a comfortable seating position with the eyes levelled to the middle of the screen and looking at the 3D monitor screen through the shutter glasses (Figure 4). In this experiment, subjects were asked to grasp a needle with the best orientation and position and place it in the dumping bin. Each session would comprise six needles that appeared randomly in difference orientation. Only one needle would appear on the screen at a time. A new needle would immediately appear when subject managed to successfully release the needle in the bin. When the needle was within the bin boundary, the bin's colour changed from red to green indicating to the subject that they can release the grip. The trial was considered incomplete if the needle was released outside the bin. Hence, subject had to grasp the needle and place it properly again within the bin. Each subject was asked to repeat the session three times, making the total needle grasped to be 18 per subject.

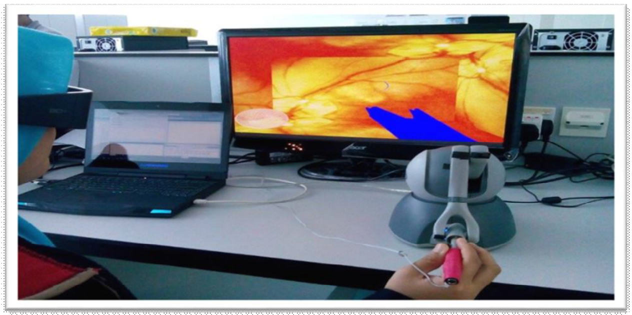

Figure 4: Experimental set-up for Needle Grasping module

2.2 Data Analysis

The main performance assessment parameters in this module were needle grasping angles (yaw, pitch and roll) and needle grasping position. The angle and the position were calculated based on the direction vectors derived from a few points on the virtual needle and forceps.

2.3 Grasping Angle

The appropriate grasping angle for the surgeon to grasp the needle should be 90° between the forceps and the curve needle. In this study, the grasping angle error was identified as the assessment parameter and it measured how much angle error made by the subject from the appropriate grasping angle (90°). Three different grasping angles were used to compare the performance between two groups. They were pitch, yaw and roll angles as shown in Figure 5.

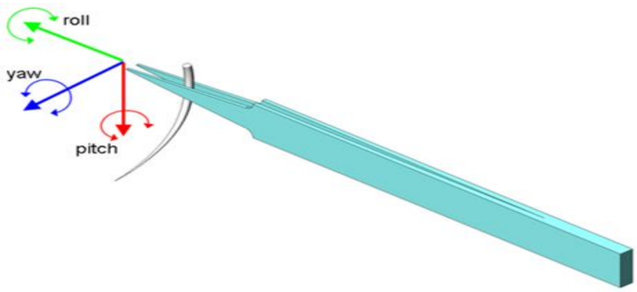

Figure 5: Grasping angle: roll, yaw and pitch

Figure 6 shows the right grasping technique and how the calculation of angles errors was measured. To calculate the grasping angle error, the reference vector from the virtual needle and virtual forceps were compared. Reference vectors were obtained using several points on the needle model. For the forceps vector, it was identified using the transformation matrix from the PHANTOM unit. By using those points, the side, frontal and normal vectors of the needle was obtained. Then, the grasping angle errors for pitch, yaw and roll was calculated using dot product of the matching pairs between reference needle and forceps vectors as shown on Equation 1.

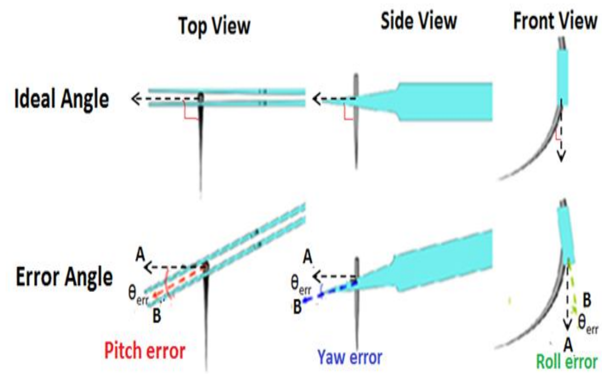

Figure 6: Optimal grasping angle (top) and how individual pitch, yaw and roll angles error are calculated (bottom)

Grasping angle error, $\theta err = \cos^{-1}\left(\frac{A \cdot B}{|A||B|}\right)$ (1)

where:
|A| is the magnitude (length) of reference vector
|B| is the magnitude (length) of forceps vector
θerr is the grasping angle error, angle between reference vector and forceps vector

The performance of each subject based on angle error was gathered and further categorised into two groups: surgeon and non-surgeon. The mean values of angles error for each group were identified for performance comparisons.

2.4 Grasping Position

Grasping position was measured based on deviation error from ideal grasping position (Figure 7). Since the ideal grasping point has been identified, the deviation error grasping from the ideal grasping position was calculated based on Equation 2.

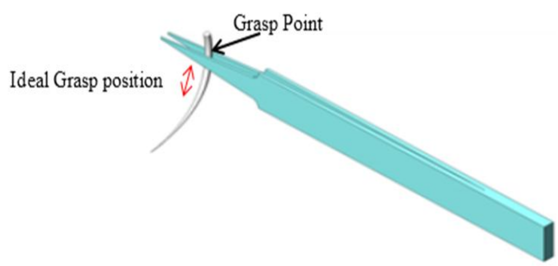

Figure 7: Virtual needle grasping

$$\text{Deviation error} = |\text{Grasp Point} - \text{Ideal Grasp Point}| \quad (2)$$

Where Grasp Point is the position needle grasped by subject while Ideal Grasp Point is the ideal of needle grasping position, which is between the midway and 2/3 from needle end point.

The performance of each subject based on grasping position error was gathered and further categorised into two groups (surgeon and non-surgeon). The mean values of position error for each group were identified for performance comparisons.

3. RESULT

This section presents the result of needle grasping task. Two metrics were extracted from the analysis, which were grasping position errors and grasping angle error and comparisons were made between two groups: surgeon and non-surgeon.

Figure 8 shows that grasping position error for surgeon's group was lower than non-surgeon's group. The deviation error from ideal grasping position for surgeons and non-surgeons were 2.64 ± 3.48 and 3.99 ± 3.94 respectively. A Mann-Whitney U test revealed the difference between two groups was statistically significant ($p < 0.05$).

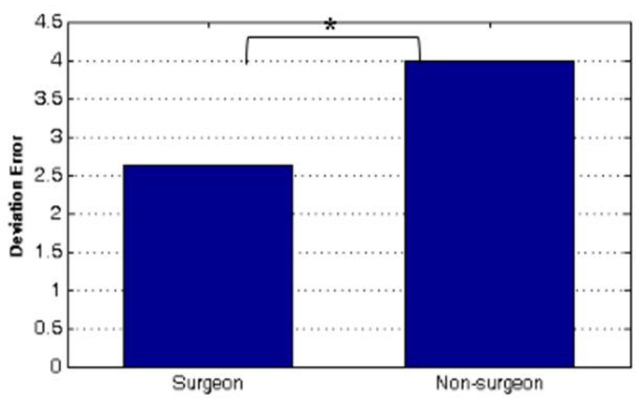

Figure 8: Grasping position error

Figure 9 shows the result of grasping angle error for surgeon and non-surgeon. The error value for surgeons and non-surgeons were 51.58 ± 17.89° and 52.23 ± 18.82° (for pitch angle), 42.982 ± 22.99° and 47.71 ± 22.31° (for roll angle) and 44.44 ± 17.93° and 44.54 ± 21.84° (for yaw angle) respectively. The difference results between these two groups were not statistically significant for all types of angle ($p > 0.05$). Table 5.4 shows the result of Needle Grasping module for all parameters.

4. DISCUSSION

Grasping needle is one of the basic principles of suturing. Needle holder is normally used to grasp the needle during suturing task. Incorrect techniques of grasping needle may result in a bent needle and may cause difficulty in tissue penetration. Two parameters evaluated in this grasping task module were grasping position error and grasping angle error. The average grip position error of the surgeons was significantly lower than non-surgeons. It is likely because surgeons, who have more experience, had automated their movement pattern during the surgery. In addition, surgeons automate for most psychomotor skill and visual spatial perception, which has been considered as essential surgical skill [10].

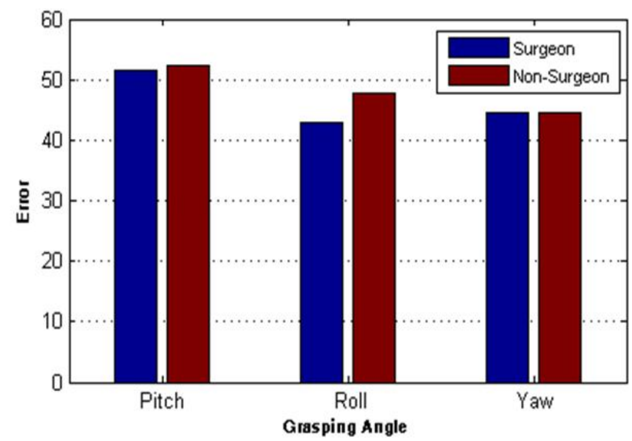

Figure 9: Grasping angle error

The result also did not show any significant difference between two groups for all types of angle error. It probably relates to the limitation of the experimental design. The task module was using virtual reality system, which was different from their normal tools. Surgeons normally deal with real surgical instruments such as forceps, needle holder and needle. However, in this experiment the PHANTOM Omni haptic device and force sensor were integrated together to model the forceps. When performing the experiment, it was hard for the subjects to fully adapt with the instrument used in this study and may lead to discomfort, awkwardness and perception difficulty in angle manipulation. The discomfort and awkwardness may cause the surgeon to perform similarly with the non-surgeon for the needle angle parameters. In addition, surgeons normally perform the real suturing task using two hands. Stabilizing the position angle between the needle holder and needle with correct orientation require both hands. During real surgical task, surgeons will use their left hand to hold the needle while the right hand is used to find the best grasping orientation. However, the setup of this experiment was only using one hand, only one unit of PHANTOM Omni of haptic device was used to represent the needle holder. It was difficult for the subjects including the experts, even though they have good knowledge and skill to orientate the grasping technique. It would be better if the two types of tools were used: needle holder for the right hand and forceps for the left hand. It is thus proposed that two

PHANTOM Omni are used for this experiment. Another suggestion is, instead of using haptic stylus with force sensor as needle holder, it is suggested to integrate real surgical tools with sensors, attached to the haptic devices to increase microsurgical realism. By using real surgical tools in the experiment, the surgeons can easily manipulate the tool as they would during a real procedure.

5. CONCLUSION

In this study, an experiment using needle grasping module has been conducted to evaluate the performance of subjects using two assessment parameters which are the needle grasping position and needle grasping angle. No significant difference in terms of grasping angle between surgeon and non-surgeon was detected. However, surgeon showed better grasping position compared to non-surgeon and this result is significant. The results showed that, this parameter can potentially be used to assess performance related with the needle grasping technique at early stage of training. With the right method and parameters, it is possible to use computer-based assessment to complement conventional methods in the evaluation of surgical skill. In addition, exploring more performance parameters and techniques will enable the assessment system to provide more specific feedback to the trainees.

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