A NEW CONCEPT FOR LAPAROSCOPIC INSTRUMENT DESIGN

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Abstract: Laparoscopy brings some disadvantages to the operators. For example laparoscopic surgeons are faced with restricted vision, image distortions, difficulty of hand-eye coordination and poor instrument design resulting to a higher probability of getting musculoskeletal disorders compared to conventional surgical procedures. Many surgeons suffer different amounts of physical pain and stiffness in their upper limbs after performing a laparoscopy. The higher strain may cause exhaustion and possibly damage nerves of the upper extremities. However, longer operating times could be another reason that needs to be considered. These difficulties can affect the surgeon’s quality of life. This paper presents a new concept for laparoscopic instrument design and it was examined by a virtual reality motion capture system. The evidence showed that the new laparoscopic instrument is able to reduce stresses on the surgeon and the performing time.

1. INTRODUCTION

Laparoscopic surgery is a kind of surgery technique, which involves the use of a micro-invasive fibre-optic telescopic technique. This allows the surgeons to navigate around the internal organs and other structures in the body without creating a large opening through skin and muscle. This causes minimal tissue damage to the patient. The technique may also be used to aid diagnosis, where this cannot be made by external examination or through symptom description.

Unfortunately, the laparoscopic procedures require the surgeon to maintain the same posture and repeat similar motions for a long period of time in a small working space above the abdominal cavity. These restrictions cause surgeons to complain of upper back pain, shoulder aches, wrist pain and finger pain after performing laparoscopy (Lee and Chae, 2001). Bicchi et al. (1996) postulated that the heavy instruments also bring aching wrists and sore thumbs to surgeons. Moreover, finger rings on the pistol grip handle of laparoscopic instruments cause various compressions on fingers when the surgeon actuates the tip of the instrument (Lee and Chae, 2001). These points may be the reason for physical pain and stiffness commonly encountered in the surgeons’ upper limbs after the laparoscopic performance (Berguer et al., 2001; Matern, 2001; Nguyen et al., 2001).

There have been a number of laparoscopic instrument designs for suture procedure in the past 10 years. Croce and Olmi (1997) offered a “tube in tube instrument” for laparoscopic suturing. This design allows the
surgeon to use his hands to tie the knot outside the body and replace the thread back into the body again. This method is very complex and the patient has a high risk of being infected since materials are being brought in and out of the body cavity.

Nagai and Araki (1999) presented a semi-automatic suturing device (ManicepsÔ) for laparoscopic surgery. A needle with thread is attached to the tip of the instrument in order to peg the object. It can prevent the needle swivelling and save operating time. However, it may result in damage to the organ, since the needle is attached on the instrument before being inserted into the body.

Dohi (2005) designed a multiple joint instrument for laparoscopic surgery. Two joints installed near to the tip of instrument are used to change the position of the instrument’s tip. This innovation can improve the DOF of the instrument. This instrument was examined with open surgery technique on a porcine model. It cannot be used in reality because the operating area of the instrument is out of the laparoscopic range of vision, which may damage the intra-organs in the patient’s body. As a result, it is necessary to design a better instrument for laparoscopic application.

Ergonomics is an important factor needing to be considered whilst designers create new equipment or techniques (Wilson, 2000). Over the past 50 years, the ideas of ergonomics have made significant changes to the design of instruments, equipment, systems, and environments in many fields including health care, but there are still many challenges (Stone and McCloy, 2004). For laparoscopy ergonomics, the surgeon needs to remain in an uncomfortable posture during laparoscopic performance influence by the un-ergonomic instrument design and the position of the monitor (van Veelen et al., 2004).

For these reasons, a user-friendly interface instrument was designed to improve the quality of life of surgeons. In order to investigate the new laparoscopic instrument, a virtual reality motion capture system has been set up to capture extreme postures and motion easily in real time when surgeon perform laparoscopic tasks. Statistical analysis has been applied in this project to classify the ergonomics of the task for individuals. The purpose is to find if there are any differences between performing conventional laparoscopic instrument and new laparoscopic instrument. The results show the new concept for laparoscopic instrument design, which not only saves operation time, but also reduces strain on the surgeon’s body.

2. THE NEW CONCEPT FOR LAPAROSCOPIC INSTRUMENT DESIGN

The procedures of laparoscopic suturing are primarily the same as the Instrument Tie in the conventional surgical technique. However, it is more difficult for the surgeon to tie a suture knot with the laparoscopic technique. The present designs of laparoscopic instruments requires the surgeon to retain the same posture in a small working space above the abdominal cavity (Figure 1), which causes wrist ache and sore shoulders to the surgeon (Luks et al., 1999). In reality, it is not possible to reduce the length of laparoscopic instruments (40cm) since the technique is used to reach intra-abdominal organs from outside the patient’s body.

Adopted from: http://www.skills.uct.ac.za/photos/laparoscopy%20demonstration.jpg

Figure 1. Posture during Laparoscopic surgery
The goal here is to design a novel laparoscopic needle holder designed to reduce the pain to the surgeon’s fingers and make the suture thread more manageable. The idea behind the proposition for a new instrument is that if we cannot improve the surgeon’s vision then we may need to limit the degree of movement required by the surgeon.

Lee and Chae (2001) indicated that the surgeon suffered pain in their hands and thumbs after performing laparoscopy using pistol handles. Hemal et al. (2001) did a study by questionnaire to examine the extent of surgeons’ discomfort between conventional and laparoscopic techniques. The results showed 17.5% of 131 laparoscopic surgeons felt finger pain after performing laparoscopic surgery, but only 2.8% of 73 conventional surgeons felt finger pain after open surgery. This was a significant effect with p-value = 0.04. The size and shape of finger rings on pistol grip handles (Figure 2), which are used to actuate the jaw, are the main problem. These rings were made of solid plastic and there is no soft material between the handle and hand. Moreover, the contact area between thumb and the ring is very small. As a result, the small contact area cuts deep into the thumb and compresses the surgeon’s fingers (Berguer et al., 1999).

Figure adopted from: http://www.dewan-surgical.com/html/endoscopy_1.htm

Figure 2. Pistol Grip Handle Style Instrument

Lee and Chae (2001) suggested a linear handle design (Figure 3) is the most comfortable design, because it does not have finger rings. However, since a greater angle of abduction is required to hold the linear instrument in place greater stress is placed on the surgeons’ shoulder. Note that in this figure the needle part with the tool extending into the body has been removed for clarity.

Figure adopted from: http://www.dewan-surgical.com/html/endoscopy_2.htm

Figure 3. Linear Handles

By observation of surgeon it was seen that during the suture task, the suture thread is not attached to any objects in the abdomen. Therefore, it does not remain stationary. It is flexible and movable, which makes suturing tasks even more difficult; it is especially noteworthy that the laparoscopic tool stem is smooth. This is the prime reason that robotic surgery systems find it difficult to make suture loops. In some cases they have developed a special threading system to carry out this task. The problem is demonstrated by looking at a 2D image and attempting to do 3D measurements, for example the surgeon can estimate the distance between Point A and Point B (Figure 4) with his/her eyes (3D).
However, it is not easy to guess the distance in front of the loop when the surgeon closes one of his/her eyes (2D). From another angle it seems that there is a complete loop from the front side of the loop (Figure 5), however, if he/she looks laterally then the two ends of the loop could be either quite close or widely separated.

During the investigation, it was found that surgeons move their arms in six DOF with four DOF vision. In this case, the surgeon finds it very difficult to make sure that the knot has been made, which could be the major problem with laparoscopic suturing. 3D imaging is one of the best ways to solve this problem. Otherwise it can only be solved though the surgeon’s experience and increased operating time.

A “Thread Holder” is installed on the instrument stem, which due to manufacturing restrictions is 3cm behind the main jaw as shown in Figure 6. The idea is to use the “Thread Holder” to hold the suture thread during the instrument rolling. That will fix the position of the suture thread and let the surgeon make laparoscopic circular movements more easily and speedily.
In other words, the surgeon can mentally figure out the 3D picture by tactile sensation without vision. The surgeon finds it easier to determine the position of the two ends of the suture knot. The suture thread cannot be moved without turning the instrument, since the two ends have been held by the two instrument jaws. Another benefit of this design is that it did not change the procedure of suturing and it is very simple for surgeons to learn and operate. Therefore, novice surgeons can be more confident in their practice of laparoscopic suturing.

The instrument has to have as simple a construction as possible so that it may be sterilised repeatedly. For example, it can contain no electrical components. The only difference between conventional instrument and this new design is to install an innerspring switch on the top on the holder to control the “Thread Holder”. The user can easily pull the switch with his thumb to open the “Thread Holder” or release to close it.

3. EXAMINATION OF THE NEW CONCEPT OF LAPAROSCOPIC INSTRUMENT

The purpose of this analysis is to find if the new instrument can reduce joint torques and operating time when a surgeon performs laparoscopic suturing. For the reason, the Motion Tracking System (Figure 7) was used to capture surgeons’ arms motion when they are performing laparoscopic surgery. This system contains VR software (Jack®), motion sensing system (MotionStar™), a laparoscopic image-processing unit, laparoscopic instruments, general surgical suture instruments, a high adjustable table, a surgical training kit and a laptop.
Five medical and three engineering students were recruited and taught how to use the new needle holder. These five medical students attended the investigation earlier. Two weeks training was provided to these students. Each participant was asked to perform laparoscopy sutures on a surgical practice kit using the original and the new instruments.

In order to capture position and orientation of the surgeon’s upper limbs movement during performance of a surgical task performance eight sensors were used. In fact, the activities of attention for this investigation are in the upper limbs and so it was not necessary to record every joint or limb of the body. Instead the placement of each sensor was carefully chosen in order to capture the movements which are important for this study. In the end, these eight sensors were attached at the top of head, the back of the neck, the shoulders, arms, and hands of surgeons when they were performing the test tasks.

4. RESULTS

This section describes the results of a comparison between the original and novel laparoscopic instruments.

4.1 Results for Operating Time between two types of laparoscopic instrument

These students spent 185.46 seconds tying a suture knot using the old instrument on average with the minimum 154 seconds and the maximum 223 seconds. However, they spent 153.04 seconds on average completing a laparoscopic suture with the new instrument, with the minimum 97 seconds and the maximum 205 seconds. This indicated that suturing using the updated instrument can reduce performance time by 17.5% compared with the original instrument. These differences between the old and new instrument suturing time were statistically significant (P = 0.020) by using a 5% significance level (P ≤ 0.05) with the Mann-Whitney U-Test.

![Figure 7. The Mean Value of Operating Time between Old and New Instruments](image)

However, the five medical students had previous laparoscopic suturing training. Therefore, they were able to tie a laparoscopic suture more quickly and correctly than engineering students. The operating times of medical students were 195.27 seconds (Peak-to-peak = 177-223) with the old instrument and 138.2 seconds (Peak-to-peak = 97-186) with the new instrument. This showed that the new instrument operating time is 29% lower than the old instrument operating time.

4.2 Results for Torque measure two types of laparoscopic instrument

Motion tracking results shown the higher arm joints torque was measured when students perform laparoscopic suturing by using the old instrument. The Kolmogorov-Smirnov Test showed all joint torques were not normally distributed. For this reason, arm joints were tested by the Mann-Whitney U-Test. The
statistical analysis results present the geometric means and use a 5% significance level ($P \leq 0.05$), for the quantitative outcome measures.

Performing laparoscopic suturing with the conventional instrument has a higher torque value on the two shoulders. Another, higher torque values were also measured at students’ lower arms when they performed laparoscopic suturing with the original instrument (Table 1). For example, the mean values for right and left wrists joint torques are 0.65Nm and 0.54 (SD = 0.15; 0.13) when surgeons perform laparoscopic suturing with the conventional instrument, but the two wrist joints mean value were both 18.5% and 14.8% lower when surgeons used the new instrument. These outcomes indicate that the new instrument is able to reduce arm joints torque stress on the operators.

Table 1 Summary of Shoulder Joints Torque Results

<table>
<thead>
<tr>
<th>Name of Joints</th>
<th>Types of Instrument</th>
<th>Mean (Nm)</th>
<th>Std. Deviation (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Shoulder</td>
<td>Conventional</td>
<td>7.17</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>New Design</td>
<td>6.47</td>
<td>0.84</td>
</tr>
<tr>
<td>Left Shoulder</td>
<td>Conventional</td>
<td>6.71</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>New Design</td>
<td>5.92</td>
<td>0.83</td>
</tr>
<tr>
<td>Right Elbow</td>
<td>Conventional</td>
<td>3.13</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>New Design</td>
<td>2.77</td>
<td>0.42</td>
</tr>
<tr>
<td>Left Elbow</td>
<td>Conventional</td>
<td>3.04</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>New Design</td>
<td>2.47</td>
<td>0.49</td>
</tr>
<tr>
<td>Right Wrist</td>
<td>Conventional</td>
<td>0.65</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>New Design</td>
<td>0.53</td>
<td>0.13</td>
</tr>
<tr>
<td>Left Wrist</td>
<td>Conventional</td>
<td>0.54</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>New Design</td>
<td>0.46</td>
<td>0.12</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

In order to improve the functionality and acceptability of laparoscopy, a new concept of laparoscopic instrument design was presented. The idea was to install the ‘Thread Holder’ on the instrument stem, which can help the surgeon make the suture faster and easier. The most important thing is that the design does not change the procedure of suture operation and it is very simple for surgeons to operate. In addition, the eight students who attended this investigation did not take longer to learn how to use the new instrument. They only practiced using it for two weeks, which means this instrument will be easy for novices to use as well. These achievements are potentially significant for surgeons who perform laparoscopies.

The results showed that operating time and joint torque values were decreased when students tied a suture using the new laparoscopic instrument. This is because they did not need to remember the 3D location of the suture thread as the new instrument helps to manage the movement of the suture thread. These benefits make the suture procedure smooth and can increasing novices’ inclination to learn the laparoscopic technique in order to augment the proportion laparoscopic surgery performed in the future. These achievements increase the range or surgeons who will use laparoscopy. In the future, the idea of the “Thread Holder” could be installed in a robotic surgery system that will also improve the functionality of the robotic system.

6. REFERENCES


