The 2013 World Congress on
Advances in Nano, Biomechanics, Robotics, and Energy Research (ANBRE13)
Seoul, Korea, August 25-28, 2013

Design and Development of Flexible Surgical Instrument for Natural Orifice Transluminal Endoscopic Surgery

Jung-Wook Suh, Ju-Won Jeong, Dong-soo Kwon and Jung-Ju Lee*
*)*Department of Mechanical Engineering, KAIST, Daejeon 305-701, Korea*
2) leejungju@kaist.ac.kr*

ABSTRACT

A new type of surgical robot instrument was developed for NOTES (Natural Orifice Transluminal Endoscopic Surgery). It consists of many short links and tendon-sheath actuated joints, thus it secures stable motion and smooth insertion into bent overtube channel. Each instrument has 4-DOF including translation, rotation and 2-DOF wrist motion, except the end-effector. The wrist joint, composed of 4 serial rolling joints to secure wide driving range, is assumed to have ideal bending motion, and it showed fine performance with wide driving range of ±90°. In the experiment, the proposed system succeeded to cut the sliced beef within a short moment using forceps and cautery.

1. INTRODUCTION

Laparoscopic surgery is a kind of MIS (Minimally invasive surgery), and the purpose of MIS is to minimize the incision. Recent laparoscopic cholecystectomy, different from traditional open surgery which needed a big incision of about 20 cm, makes three or four small incisions of only about 10 mm. Intuitive Surgical, Inc. developed da Vinci® system and reduced the instrument diameter to 5.5 mm. Furthermore, surgeons are trying to minimize the incision for surgery as ever. They invented two kinds of new experimental methods for abdominal surgery in recent years. One is SPA (Single Port Access) surgery, and the other is NOTES (Natural Orifice Transluminal Endoscopic Surgery). The SPA surgery is performed using single entry port, typically the patient's navel. Because the procedure of SPA surgery is very similar to laparoscopic surgery, most of laparoscopic surgical instruments and laparoscope can be utilized as well. On the other hand, NOTES needs no external incision on patient's skin, because it is performed via natural orifices such as mouth, anus, vagina or urethra. And an internal incision on the organ wall is necessary to approach the surgical site. It means that no scar on patient's body remains after surgery. In conclusion, NOTES can be considered as the ideal procedure for abdominal surgery from the viewpoint of MIS.

However there are two huge obstacles to apply this brand-new technique to real surgeries. One is that operating procedures for NOTES are not yet established well.

But simple abdominal surgeries like cholecystectomy are already being performed using NOTES procedures for both of animals and humans, and it will be solved by surgeons after a while. The other is the absence of appropriate instruments for NOTES. Unlike SPA surgery, NOTES cannot utilize traditional laparoscopic instruments, because flexible surgical tools should be inserted via bent human orifices. Therefore a variety of proper surgical instruments for NOTES should be developed so that NOTES can be one of general surgical operations for abdomen. Furthermore, robotic system for NOTES is expected to change the status of NOTES in abdominal surgery as in the case of laparoscopic surgery. There is few commercial NOTES system because of many constraints of the NOTES, but lots of institutes are trying to develop manual and robotic NOTES systems (Thompson et al., 2009; Can et al., 2008; Phee et al., 2008; Suzuki et al., 2010).

2. STRUCTURE

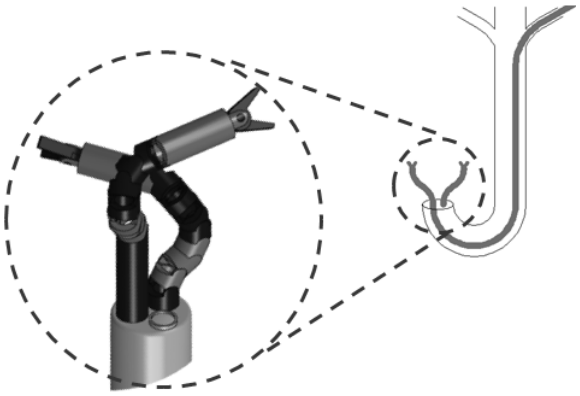

Fig. 1 Two armed NOTES robot for transgastric cholecystectomy.

For NOTES procedure, more than two surgical instruments are needed to be inserted into patient's natural orifice with an endoscope as shown in Fig. 1. Each instrument is desirable not to exceed 5mm in diameter for transgastric surgeries with 4-DOF motion except the end-effector. External operator can serve translation and axial rotation directly. Thus, internal 2 DOF motion should be made using different ways such as remote actuation using wire cables.

Several types of small sized joint mechanism exist for the wrist joint already. Multi-spherical joints design is frequently applied for many researches because of the advantage that it's relatively easy to product small sized joints. The size of a manipulator using multi-spherical joints design developed for interauterine surgery by Waseda Univ. is only 2.4 mm in diameter (Harada et al., 2005). This kind of manipulators has a severe problem that they are so weak to external forces that the assembled joints are easily bent. In order to prevent the S-shaped bending by applied external forces, French CNRS fixed lots of actuating wires on each links and actuated them with different speed using pulleys (Meer et al., 2005). 5 mm sized Endowrist, laparoscopic instrument for da Vinci® system, has similar but advanced mechanism using gear tooth and universal joint at proximal driving part. For miniature joints, rolling

contact has great advantage of wire tension maintenance without any pulley. Fig. 2 shows how the single rolling joint is actuated using remote actuation. To make 2 DOF motion in the wrist joint, it is composed of 4 unit joints changing the axes of rotation alternately for wide driving range. The exact kinematics of the wrist joint is quite complex and difficult to be solved inversely. Assuming circular arc shaped bending, it can be expressed some duplicated Denavit-Hartenberg parameters.

The most important part for NOTES robot is the internal arm inserted into patient's body. The robot arm is composed of short links and the overall diameter is 5.0 mm for the smooth insertion. All the links have internal hole of 3.0 mm, so the arm serves an internal channel that can be used to insert additional actuation cables and electric wires for the end-effector. Two cables are used to stiffen the shortly chopped links. Removing the tension on the stiffening wires, all the links get loosened. It can be inserted into the working channel whose inner diameter is 5.5 mm and radius curvature is 100 mm as shown in Fig. 3.

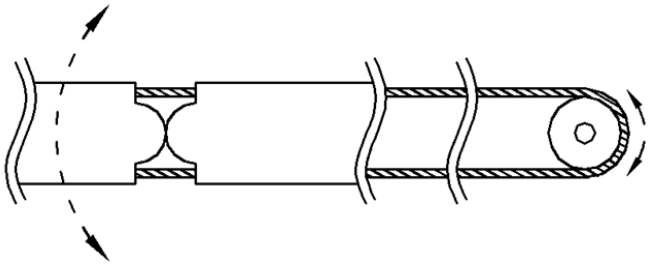

Fig. 2 Remote actuation rolling joint without pulley.

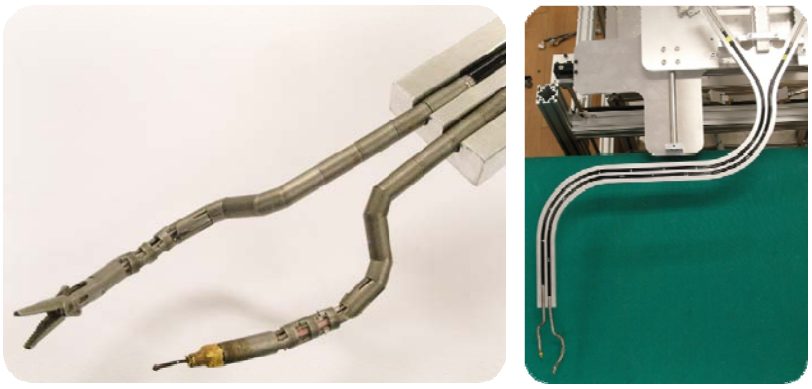

Fig. 3 Assembled prototype.

3. EXPERIMENTS

Fig. 4 shows the bending performance of the wrist joint. It can bend more than ±90° in any direction smoothly because it consists of four rolling joints. It does not make S-shaped curvature in a neutral position when there is no external force on the arm. Because rolling joint is very effective in maintaining length and tension of the driving wires without any pulley. Moreover, it made similar motion in pitch and yaw direction thanks to the appropriate arrangement of the unit rolling joints.

Simple experiment to cut the sliced beef into fingernail sized piece was performed using left forceps arm and right cautery arm with the developed master system (Park et al., 2009) and the endoscope built-in external overtube robot (Shin et al., 2009). The work was completed within one and a half minutes in spite of the absence of the 3 dimensional images. It did not take more than one minute to exchange the instruments in average. Fig. 5 shows the NOTES robot that performs the experiment after being inserted into the slightly bent dummy esophagus and stomach.

Fig. 4 Bending of the the wrist joint: (a) 90°, (b) 0°, and (c) -90°

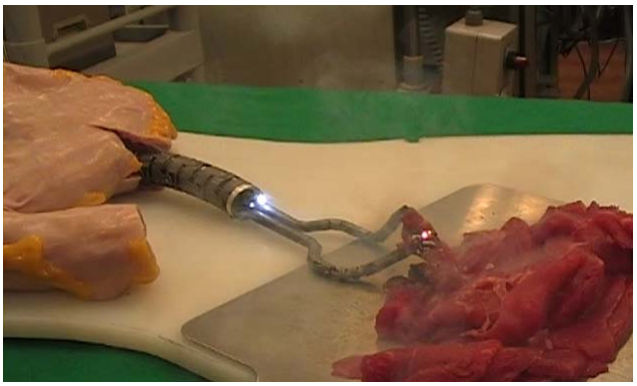

Fig. 5 Beef cutting experiment using forceps and cautery robot.

4. CONCLUSION

NOTES is an experimental operating technique for abdominal surgeries to avoid an external incision or scars. In this paper, we suggested a flexible surgical robot arm that suits NOTES procedures. It has 4 DOF including 2 DOF bending wrist motion, and it secures smooth insertion thanks to the flexible insertion tube and the shortly chopped serial rigid links. Moreover, this system uses small 2 DOF bending joint composed of 4 serial rolling joints and it showed great bending performance of ±90° in any direction. Rolling joint maintains length and tension of the driving wires without any pulley, so this mechanism can be used extensively for the composition of small robot joints.

Nevertheless, this system still has some problems to be improved. First of all, the developed joint is not strong enough to the external force. Next, the fixed elbow limits

the axial rotation and the workspace. Besides, the serial chopped links cannot support well only with the stiffening wires. These problematics would be solved by applying various methods such as multiple actuation cables, parallel mechanism, active elbow-out joint, hybrid NOTES procedure, etc. The research for NOTES is still in its infancy. Deep consideration about NOTES system and surgical method should be kept going constantly.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2012-0001007)

REFERENCES

C. C. Thompson, M. Ryou, N. J. Soper, E. S. Hungess, R. I. Rothstein, and L. L. Swanstrom (2009), “Evaluation of a Manually Driven, Multitasking Platform for Complex Endoluminal and Natural Orifice Transluminal Endoscopic Surgery Applications,” Gastrointest. Endosc., **70**, 121-125.

S. Can, A. Fiolka, H. Mayer, A. Knoll, A. Schneider, D. Wilhelm, A. Meining, and H. Feussner (2008), “The Mechatronic Support System HVSPS and the Way to NOTES,” Minim. Invas. Ther., **17**(6), 341–345.

S. J. Phee, S. C. Low, Z. L. Sun, K. Y. Ho, W. M. Huang, and Z. M. Thant (2008), “Robotic System for No-scar Gastrointestinal Surgery,” Int. J. Med. Robot. Comp., **4**(1),15–22.

N. Suzuki, A. Hattori, K. Tanoue, S. Ieiri, K. Konishi, M. Tomikawa, H. Kenmotsu, and M. Hashizume (2010), “Scorpion Shaped Endoscopic Surgical Robot for NOTES and SPS with Augmented Reality Functions,” Lecture Notes Comput. Sci., **6326**, 541-550.

K. Harada, K. Tsubouchi, M. G. Fujie, and T. Chiba (2005), “Micro Manipulators for Intrauterine Fetal Surgery in an Open MRI,” in: Proc. IEEE Int. Conf. Robot. Autom., 502 - 507.

F. V. Meer, A. Giraud, D. Esteve, and X. Dollat (2005), “A Disposable Plastic Compact Wrist for Smart Minimally Invasive Surgical Tools,” in: Proc. IEEE/RSJ Int. Conf. Intell. Robot. Sys., 919–924.

W. Shin, S. Kim, and D. Kwon (2009), “Development Of A Flexible-Rigid Endoscopic Robot System For NOTES,” in: Proc. Asia Conf. Comput. Aided Surg.. 128.

S. Park, K. Lim, J. Jeong, and Y. Yoon (2009), “Design of Master Console Robot for Natural Orifice Transluminal Endoscopic Surgery,” in: Proc. ICROS-SICE Int. Joint Conf.