Proceedings of 2013 ICME
International Conference on Complex Medical Engineering
May 25 - 28, Beijing, China

Experimental study of remote angiography using vascular interventional robot

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***Abstract* - Robot technology made rapid development in the medical surgical and remote communication technology promote the development of telemedicine. Vascular interventional robot has become a promising technology. To assess the clinical usefulness, accuracy, and safety of remote angiography, we used vascular interventional robot system. Vascular interventional robot system is designed to complete the remote cerebral angiography surgery. Experts in Japan had controlled the slave part of robot in Beijing through operating the host part of robot, and performed cerebral angiography in dog. The positioning accuracy, usefulness and safety were observed. Animal experiment was successful with no complications. The whole procedure included incubating and angiography of common carotid artery and vertebral artery in both sides, it took 45 minutes. The remote positioning accuracy was 1 mm. The result indicates that remote angiography using vascular interventional robot is reliable and safe. In the future, we think that the remote manipulation will advance collaboration between surgeons, develop sharing of resources, and have good prospect in the field of vascular intervention surgery.**

Index Terms* - *Robotics, Remote angiography, Vascular intervention, Animal experiments

I. INTRODUCTION

Robot technology made rapid development in the medical surgical in recent years, and the advancement of computer technology and remote communication technology promote the development of telemedicine, its advantage lies in the breakthrough of the space limitations of conventional surgery, and enhance the capacity expansion of medical experts. According to the World Health Organization, cardiovascular and cerebrovascular disease is the first "killer" of human disease, more than 3 million patients with these diseases died each year in China. Vascular surgical intervention has become the third pillar of modern medicine, and be on behalf of minimally invasive surgery. Vascular interventional robot has become a promising technology and has produced a prototype (vascular interventional robot, VIR), which had been used in animal experiments [1].

On the basis of the successfully application of the VIR and remote operation of stereotactic surgery in 32 cases with the use of the CAS-R-5 robots [2], and department of Neurosurgery, Navy General Hospital explore the remote cerebral angiography surgery using vascular interventional robot (VIR-2) to verify the feasibility of teleoperation vascular interventional procedures and security, and provide a basis for further clinical applications, and achieved satisfactory results are as follows.

II. MATERIALS AND METHODS

VIR-2 robot system: the robot includes 3 parts, which include master-slave system, three-dimensional navigation system, and the force feedback of the catheter end.

The master-slave part of propulsion system: according to the requirements of the vascular intervention surgery, prototype of the robot was designed and produced; propulsion system was responsible for a straight line forward, backward and rotation of the catheter during the procedure. Vascular interventional robotic structures are composed of two parts, the master part (Figure 1) is far away from the source of radiation and was connected to the network, by the manipulation of the operating surgeon, guiding the movement of the auxiliary part (slave part, Figure 2 the auxiliary part refers to the propulsion system at the bedside which directly advances the catheter. Mechanical arm is a mechanical structure with five degrees of freedom drived by Hydraulic Mechanical arm can adjust the posture of auxiliary part by grasping it to adapt to the direction of target vascular. Two parts can be connected through wired and wireless networks.

The master part of propulsion system is more adapt to manipulating habits of hand. The operator can rotate or moves back and forth the wire of master part by holding it, like holding the end of catheter.

The three-dimensional image navigation system: visual positioning system and 3D vascular reconstruction system based on dual-angle Digital Subtraction Angiography (Digital subtraction angiography, DSA). The Visual positioning system obtaining the location parameters of the c-arm is the premises of the navigation system, reconstruction of 3D vascular image based on the dual-angle DSA image provide a road map for navigation and guide interventional procedures. The reconstruction method is same as VIR-2 robot, but the software have been improved.

Fig. 1 the main part of propulsion system

Fig2 the auxiliary part of propulsion system

The force feedback system of the distal catheter: In this study the fiber optic pressure sensor made by Canadian medical company FISO was fixed on the terminal of universal catheter, to measure the hepatic of front-end. During operation the resistance encountered by the catheter was transmitted through the connection to the actual operator in order to guide the completion of the surgery real-time (Figure 3-4).

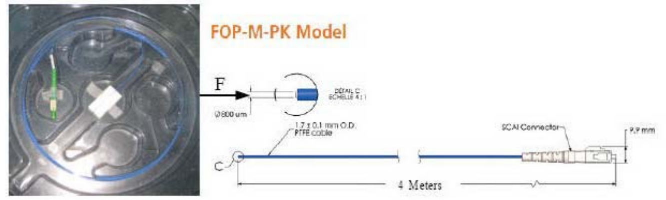

Fig3 the fiber optic pressure sensor made by Canadian medical company FISO

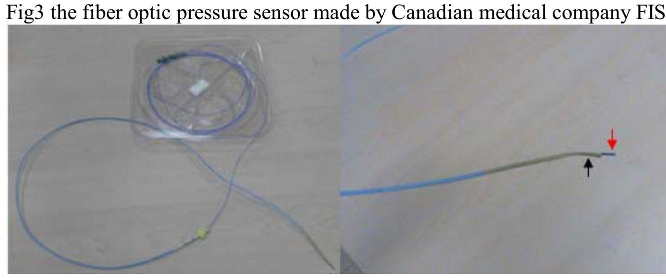

Fig4 the sensor (800μm in diameter, shown in red arrow) was fixed on the terminal of universal catheter (single-bending catheter with 5F diameter, ,shown in black arrow).

Remote surgery system: It consists of network communication, video (from Scene camera) transmission, graphic simulation and human-computer interaction components. It provides information and technical support for medical experts to implement teleoperation surgery, which main features include remote surgical simulation, surgical monitoring and teleoperation. Remote communication between China Beijing and Japan Kagawa was internet, which connects the main server located in Japan and auxiliary server in Beijing and transmits surgical planning, sends control commands of remote robot; execute real-time data exchange (Figure 5). The data transmission speed was 8M/sec, and network time delay was about one second which does not affect the implementation of the surgery.

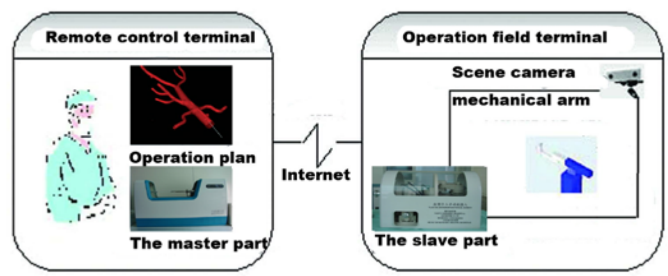

Fig 5 Schematic diagram of remote surgery system (The information exchange through internet includes: 1.remote control terminal send order to the slave part; 2. catheter movement routes in scene and the resistance encountered by the catheter was transmitted to the remote control terminal)

A healthy clean male beagle adult dog, weighing 16.5Kg (purchased from the Experimental Animal Center of Peking University Health Science Center). The conditions for the animals were room temperature 20±3C, natural light, freely - available drinking water and food, and were reviewed and approved by the Institutional Animal Care at the Navy General Hospital, Beijing.

Surgical procedures: The surgery was performed by specialists in Navy General Hospital, in Kagawa University and vascular interventional robot. The remote console of main part was located in Kagawa, and the auxiliary part of robot and the local console was located in Beijing.

The dog was anesthesiad with intramuscular injection as 0.2mL/kg of mixture of Sumianxin and ketamine (1:2); a 5F diameter arterial sheath was artificial inserted into the right femoral artery of anesthetized dog using the Sedinger method. A single-bending catheter with 5F diameter was guided into the arterial sheath. The Sterilized propulsion system of robot was introduced to fixing catheter. Mechanical arm fixed propulsion system, and adjust the position, while three-way valve connect the high-pressure syringe and heparin saline drip system (Figure 6).

Experts controlled the main part of VIR in Kagawa University, Japan, under the guidance of the 3D image navigation through the Internet, operating the main part of the instruction through the network. The order was transmitted through the network to the auxiliary part of robot lied at intravascular interventional operating room in Navy General Hospital, Beijing, which was far away as 2500 km, catheter movement routes in scene was captured by scene camera and transmitted directly to the main part through the network, surgeons perform procedures depending on the actual process information(1.catheter movement routes in scene was captured by scene camera;2. the resistance encountered by the catheter was transmitted through the connection to the actual operator), carry out a road map or selective angiography when it was necessary, and finally complete the whole cerebral angiography surgery (Figure 7).

Fig6 Surgery scene of remote surgery (red arrow show Mechanical arm, black arrow show auxiliary part.)

Fig7 Surgical master - the doctor controlled robot system for remote operation

Intracranial angiography procedures: catheter was move forward, backward and rotation under fluoroscopy drive by the propulsion system of the robot, pass through femoral artery, abdominal aorta, thoracic, the descending aorta and reach the ascending aorta artery, and three-dimensional image of aortic arch was reconstructed based on Left anterior oblique 30° and right anterior oblique 30° image, contribute to confirm the entrance of the bilateral common carotid artery and vertebral artery, and guide catheter into proximal of above artery and begin angiography surgery. The time of surgical procedure and ray exposure time of Staff was measured. The success rate of single manipulate refers to the success rate of catheter selectively inserted into a special branch vessel. Remote positioning accuracy was measured according to the difference between three-dimensional navigation and the actual position of target vessel.

III. RESULTS

Animal experiments were quickly carried out with no complications. The process of teleoperation cerebral angiography was smoothly. It took 45 minutes to complete incubating and angiography of common carotid artery and vertebral artery in both sides. The left carotid angiography was shown in Figure 8; the left vertebral artery angiography was shown in Figure 9. Positioning operation was finished at first time, and the success rate of single manipulate was 100%, and remote positioning accuracy was 1 mm. The ray exposure time of Staff was 0 minutes. Time delay is one second; it does not affect the operation. Other surgical procedure was completed by robot controlled by doctor except the vascular sheath inserting into the femoral artery operation. The entire experimental procedure basically realized mechanization and automation. The dogs were returned to normal activities 1 hour after operation.

Fig8 the right carotid artery angiography

Fig9 the left vertebral artery angiography

IV. DISCUSSION

The rapidly development of surgical robotics, computer navigation system and public high-speed network make telesurgery and telemanipulation operation possible. The application of surgical robots is growing rapidly, robot-assisted surgical techniques begun initial application in minimally invasive cardiac surgery, abdominal surgery and urology[3].On September 7, 2001, doctors in New York finished Laparoscopic cholecystectomy operation by controlling Zeus medical robot through a network between France and the United States[4].Due to the complexity of surgical procedures in the field of neurosurgery, the mature products is the remote monitoring and remote guidance system, primarily provide real-time remote surgical guidance for the medical center's experts[5].

Modern neurosurgery which main goal is minimally invasive is developing in direction of precise, procedures and intelligent. Neurointerventional technology is a branch of neurosurgery, and become an important means to deal with cerebrovascular disease. Conventional interventional procedures are carried out under the guardianship and monitoring and radiation of X-ray. The purpose of vascular interventional robot is to improve the precision of surgery, to reduce the radiation to the doctor, to improve the maneuverability of operation.

Background of vascular interventional applications, this study combined with advanced robotic technology, computer graphics processing and visualizing technology, network communicating technology, computer control technology and minimally invasive surgical techniques, had improved the original vascular interventional robot system 1, and successfully implemented one cases teleoperation cerebral angiography.

Cerebral angiography is selective Intubation and angiography of bilateral carotid and vertebral artery. In this case operation is successfully completed, that means VIR-2 can complete the teleoperation cerebral angiography, and it has the prospect of clinical application, especially the patient was able to get the professional service of medical experts without experts presenting at the scene.

The features and advantages of VIR-2 system lies in: (1) it adapted Master-slave robot structure and ergonomic design, the main part was more consistent with the habits of doctor's operating, more easily manipulated by doctors, more compact flexible[6], so as to adapt to the complex needs of vascular interventional surgery; (2) three-dimensional medical image navigation can guide the surgeon quickly and accurately to advance the catheter to the specified location, which is helpful for successful operation. Fast reconstruction of 3D DSA image which is based on the dual-angle DSA images, combined with the matching techniques of the virtual image and actual image, the ultimately realized the target of navigation from 2D image to 3D image, and thus catheter reaching the target blood vessels is more smooth, Simplifies operation, improve quality of operation; (3) the application of minimum force sensor, micro force sensor is installed at the end of the catheter, real-time access the collision information between the catheter and blood vessels during operation, and thus reduce the risk of surgical intervention, intervention and alarm will be adopted if necessary7;(4) the teleoperation surgery is completed through the public Internet, breaking the space limitations of conventional surgery, which significantly enhanced the ability of medical experts radiation, and help to play the role of the major hospitals and medical experts. Remote surgery has a positive potential to the worldwide transmission of medical resources.

Judging from the entire system, teleoperation animal experiments application using the VIR-2 telemanipulation system is safe and feasible. It can realize telemanipulation of catheter, and the master-slave systems meets the operating characteristics of the traditional intervention, three-dimensional navigation guide operation more smoothly, force feedback provides real-time haptic information of remote catheter and provide security for the surgery, but also shortens Operation time and improve the quality of operation.

The system still needs further improvement, mainly miniaturization of master-slave structure, more high-speed of software functions of 3D image navigation, and real-time performance of force feedback signals. At present the scope of application is vascular interventional surgery in Large-diameter vascular, but its application will take some time in small-diameter vascular, such as three level of cerebral vascular and micro vascular. Because the requirements of teleoperation is very lower on the local medical technology, the physicians familiar with the general procedure is capable of performing his duties, and major surgical procedures is done under remote monitoring by the remote expert. Application scope has been expanded, on the basis of the surgical safety been guaranteed.

There is 2500 km away between Beijing and Japan. The main part of robot located at Kagawa University in Japan controlled the slave part of robot in Beijing, had completed animal cerebral angiography through the Internet. It means remote operation of vascular interventional procedures is successful, which indicates that VIR-2 system is safe, reliable and easy to use. With the continuous improvement of medical robotics and Communication technology, remote operation will conducive to the exchange and training of medical staff, and will have broader applications in medical surgery [7].

ACKNOWLEDGMENT

This work was supported by the National High Technology Project ‘Research on Vascular Interventional Robot’ (Grant No.2007AA04Z246).

ABBREVATIONS

VIR-2, vascular interventional robot; CAS-R, computer-assisted surgery robot; DSA, digital subtraction angiography.

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