balloon clearly. And its outcome may indicate an appreciate method to the manipulator.

C. Performance on phantom test

The developed manipulator was possible to support fetus model stability in first and third experiment. The supporting method may be useful to stabilize the fetus. The manipulator has an ability to support fetus of various size about 25-30 weeks gestation. However, the width between the tip and root frame of the hook-like mechanism is large to the fetus in 19-24 weeks gestation. In order to fit the target fetuses, the width should be smaller.

The clip might be unsuitable to fix the balloon, for it broke the covering part on the balloon. New structure of balloon without clip should be developed, such as a balloon folding not only upside of frames but also around frames. It can keep fetus off the side and beneath of frames.

On the second experiment, we supported the fetus model by hand from outside of the uterine wall because it sank down and there was no space under the fetus for the manipulator. It would be hard to do so under ultrasound or fetoscopic image in clinical usage. The density of the fetus is important factor to consider a procedure to hold it. We should arrange more real environment.

D. Ultrasound guidance

The ultrasound could visualize the manipulator and the balloon. Since we could measure the diameter of balloon, ultrasound can be also available to estimate the pressure of the balloon. In order to visualize the sight hidden by artifact under the manipulator, fetoscope is also need. Since the ultrasound image of 2D gave limited information of relation between fetus and manipulator in space, we will use 3D ultrasound guidance.

E. Prospects for clinical application

The diameter of the manipulator is 8 mm now, but it has to be much smaller to reduce the risk of complications. We aim to develop smaller one which can pass trocar for fetal surgery. Therefore we try to develop the holding unit of diameter 4 mm, excluding balloon. We are sure that we can develop it since the mechanisms of the manipulator are not so complex. The user interface on PC is not ease to operate and needs extra hands, so we should equip manipulator with another user interface like handheld type. Furthermore we try to control the pressure of balloon, adding sensor to water injection unit.

V. CONCLUSION

A manipulator to stabilize fetus, with large contact area by balloon and keeping away from the umbilical cord, for intrauterine surgery are reported in this paper.

The manipulator has two bending mechanisms, one driven by wires is for supporting fetus from beneath, and the other driven by linkages is for adjusting holding plane corresponding to insertion angle into uterus and a balloon which enables area for contact with fetus larger than the diameter of incision to support stably and softly. For clinical use, this manipulator can be divided into holding unit, driving power unit and balloon to meet sterilizations or disposal.

The accuracy of bending performances was sufficient to operate under guidance of ultrasound and fetoscope. The inflated balloon generated sufficient force to support the fetus and its softness showed possibility of not injuring fetus. The phantom experiment showed that the manipulator could stabilize fetus beneath without touching the umbilicus. These results indicated that this manipulator has potential to stabilize fetus in uterus softly.

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which are connected components of computer aided surgery system.

2. Methods

We use two devices: the projector-camera device and the optical tracking device. The projector-camera device identifies relative geometry among surgical surfaces in three dimensions, camera-image, and projector-image and then projects a desired image onto the surgical surface. An optical tracking device tracks the position of a probe which serves as Virtual-pen. Two devices are registered accurately and work as a single integrated system. To implement interactive functions of Virtual-pen, projection areas regard as menus are divided into several regions. Each region corresponds to pre-defined actions. The functions activated when Virtual-pen is laid in the regions.

3. Results

The position accuracy of Virtual-pen in three dimensional surfaces was 0.35 mm in maximum error, which is high enough for most surgical scenarios. Real-time geometric and radiometric compensation techniques enabled us to make the projected image undistorted even on dynamic surfaces such as human body. The optical tracking device was robust because it tracked Virtual-pen without interfering with operation illumination. Our experiments using a phantom of head in a laboratory environment demonstrated an acceptable quality and the clinical test will be performed to verify the practical value of the proposed system.

4. Conclusion

The proposed method enhanced the computer aided surgery system by eliminating the need of inadequate tools and by suggesting an interactive user interface. The position of surgical targets was exactly tracked by the optical tracking device and accurately was marked by direct-projected augmented reality technology. Predefined menus offered various functions dynamically and interactively. The implemented prototype would be integrated into the computer aided surgery system under development in Center for Intelligent Surgery System, Seoul, Korea.

Acknowledgment

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Development of wide–angle view 3D endoscope using wedge prisms

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Keywords Medical robot · 3D Endoscope · Wedge prism

1. Introduction

We have developed a wide-angle view laparoscope that enables the surgeon to control the FOV without moving the laparoscope itself. It is free from the risk of hitting internal organs due to laparoscope movement, and can realize safer robotically assisted laparoscopic surgery. Also, it can apply to other site which does not have enough space to move the endoscope. In this paper, we applied this mechanism to 3D endoscope and developed a new wide-angle view 3D endoscope.

2. Methods

We used a thin 3D endoscope (LS-501D, Shinko Optical Co. Ltd, Tokyo, Japan). Its diameter was 5.4 mm. Two 1/10 inch micro CCD cameras (270,000 pixels) were mounted on the tip. We mounted two wedge prisms at the tip. Each prism was attached to a sleeve and these rotate independently about the axis of the endoscope by motors. In this mechanism, only two sleeves rotate within the endoscope, so the mechanism can be simple and small and yet can observe a wide angle of view.

We used wedge prisms whose diameters are 12 and 8.5 mm. Total diameter of the wide-angle view 3D laparoscope was 14 mm. For the light source, we made a special tube with a fiber. The outer diameter of the tube was 18 mm and inner diameter was 14 mm, so that it could inset into the commercialized trocar (ENDO-PATH Large-Port Trocar, Ethicon). It illuminated the entire moving view range of the endoscope. The material of the prism was LAL18 whose refractive index was 1.7 and wedge angle was decided 10°.

3. Results

The system could bend the light axis in a cone with a vertex angle of approximately 14.5° under the conditions that view angle of the 3D endoscope was 76°.

We evaluated the depth perception of the wide-angle view 3D endoscope qualitatively. We put the two wedge prisms on the tip of the 3D endoscope, and rotate these prisms. Volunteers observed the 3D endoscopic image and tried to grasp objects by forceps. As a result, the volunteers could get the depth perception without sense of discomfort and grasp the object easily. Also, although a little distortion in the image was observed, there was no degradation by prisms.

4. Conclusion

We have developed the 3D wide angle view endoscope using wedge prisms. Bending view angle was 14.5°. In the qualitative evaluation of depth perception, volunteers could get the depth perception without sense of discomfort.

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FOV—changeable endoscope using a beam splitter

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Keywords Endoscopic surgery · Minimally invasive surgery · Beam splitter · Field of view · Polarization plate

1. Introduction

Minimally invasive surgery is becoming more common nowadays. One of the important fields of minimally invasive surgery is endoscopic surgery. In the endoscopic surgery, it is very important to manipulate the endoscope smoothly so that the surgeon can observe where he or she wants to see. In addition, during the operation the surgeon has to manipulate the endoscope safely not to damage body tissues or internal organs.

In the surgery of twin to twin transfusion syndrome, the front view needs to be observed to insert the endoscope safely, and after the proper insertion we need to observe the diseased area which can be the front side or lateral side. How to observe lateral view safely? To solve this problem, we have suggested the endoscope system that can be used to observe the front side and the lateral side without moving or bending the whole endoscope system.

2. Methods

In this endoscope system, the field of view can be changed using a beam splitter and two polarization plates. The endoscope system consists of a CCD camera with the inner sleeve and the outer sleeve.

A beam splitter is attached at the distal tip of a CCD camera which is mounted inside of the inner sleeve. The inner sleeve has a polarization plate at the distal tip and observation window at the lateral side. The outer sleeve has a polarization plate at the distal tip and observation window at the lateral side, also.

Inserting the inner sleeve into the outer sleeve, we can observe the front view through the polarization plates with the observation window closed. And also we can observer the lateral view through the observation window by rotating the outer sleeve. At this time the front view can not be observed by the polarization plates.

We made a prototype of the FOV-changeable endoscope. The experiment on changing field of view was conducted using the prototype.

3. Results and conclusion

The endoscope prototype has 10 mm in diameter including illumination. Two polarization plates seem to degrade the brightness of the front view. In the lateral view, the observation is made through the observation window, so there is no degradation of the brightness. So we used the beam splitter which has 70 percent transmission and 30 percent reflection.

In the experiments using the prototype, the field of view was changed by rotating the outer sleeve without moving the endoscope itself, so the operation can be conducted safely. Also, there are some kinds of operation which need to use the rigid endoscope and lateral view endoscope also. In these kinds of operation, the surgeon has to switch two or three types of endoscope. But using our method the surgeon does not have to switch the endoscope thus the operation time can be reduced and the sterilization can be conducted more easily.

Influence of oscillation of an electronic OR-microscope on neurosurgical preparation quality

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Keywords Neurosurgery · Oscillation · Microscope · Camera · HMD

1. Introduction

Oscillation is a major problem for operating microscopes. An oscillating picture of the operating field puts stress onto the surgeon and is therefore likely to lead to a higher probability of inaccuracy and faults. During the development of a novel visual support-system for endoscopically-assisted neurosurgical interventions the influence of camera-oscillation on the quality of preparation has been of high importance. In this framework the electronic microscope ("exoscope") is handled by a telemanipulation-platform and the acquired images are presented to the surgeon by a Head-Mounted-Display (HMD) without any physical contact between surgeon and camera (http://www.minop.de).

2. Methods

In a first test conventional OR-microscopes were analyzed to determine clinically accepted state-of-the-art values for intraoperative oscillation.

In a second test neurosurgeons had to rate pattern-visibility and to fulfill preparation tasks in a virtual test environment. Special line- and point-preparation tasks had to be performed using a tracked pointer, images were acquired by a virtual oscillating camera and displayed via HMD. Additionally the test-persons (7 neurosurgeons) had to repeatedly state their actual subjective discomfort on a standardized rating scale to identify the influence of the preparation conditions on the strain level.

3. Results

The field tests concerning the oscillation of commercial OR-microscopes showed deceleration times of 2–3 s at oscillation frequencies of about 1 to 1.5 Hz.

Rating the visual differentiability of the virtual test-patterns under various oscillation-conditions the surgeons determined an allowable frequency limit of 4 Hz and allowable amplitudes of up to four times the width of the viewed structure.

Concerning preparation quality a significant reduction of preparation deviation with increased zoom factor, a significant increase of preparation deviation with increased frequency and a highly significant increase of preparation deviation with increased amplitude were identified.

Throughout the test-cycle the discomfort statements on the rating scale increased with a saturation characteristic.

4. Conclusion

The virtual tests showed a clear negative influence of camera-oscillation on the preparation quality and helped to define demands for the concept and realization of the developed exoscope-telemanipulation-platform. However, it has to be taken into account that these results have been achieved using a specific experimental setup (HMD, graphics hardware, simplified tasks, etc.) and will therefore have to be further evaluated with the realized demonstrator-system and under real OR-conditions.

Calculation and visualization of trocar positions for abdominal minimally invasive surgery

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Keywords Augmented reality · Computer-assisted surgery · Minimally invasive surgery · Port planning

1. Introduction

For minimally invasive surgery the placement of the trocars is a decisive factor for the success and the straightforwardness of an intervention. Poor choices for trocar positions often result in prolonged operation times or the need to introduce additional ports. Preoperatively planning of the trocar positions will help solving this problem. For abdominal minimally invasive surgery the insufflation of the patient prevents the direct use of the computed positions because the planning is generally performed with a regular patient model (i.e. without insufflation). We present a system for the visualization of the optimal port positions onto the patient's abdomen for minimally invasive surgery that deals with this issue.

2. Methods

The preoperative input for our system is a reference surface model of the patient (e.g. obtainable through a segmented ct-scan) and the trocar positions and orientations that have been planned with respect to this model. The visualization of the trocar positions is done by direct projection onto the abdomen using projection based augmented reality techniques. The projector system has two attached cameras and the complete setup is photogrammetrically calibrated. For the registration a surface scan based on a projected coded light pattern is acquired from the abdomen of the patient at the beginning of the treatment. This scan is used to register the patient to the preoperatively obtained model. After the patient has been insufflated a second scan of the abdomen is performed. The acquired surface model is then used to modify the preoperatively planned port positions. In the simplest case—each port is used to access only a single target area—the correct trocar locations are calculated as intersection between the insufflated surface and the lines defined by the planned trocar position and the respective target location.

3. Results

The system was evaluated with a torso phantom that supports the simulation of an insufflated abdomen with a maximal insufflation height of 5 cm. A target and several port positions were planned on a reference surface model. The trocar positions were projected on the phantom and recorded with a high precision measurement arm for the regular and the insufflated case. The overall position error was below 3 mm which led to an orientation error of less than 2°.

4. Conclusion

A system for the visualization of trocar positions for abdominal minimally invasive interventions was presented and the evaluation with a phantom showed acceptable accuracy. Intraoperative trials, which are planned for the immediate future, will show if this accuracy can be achieved in the operation theatre.

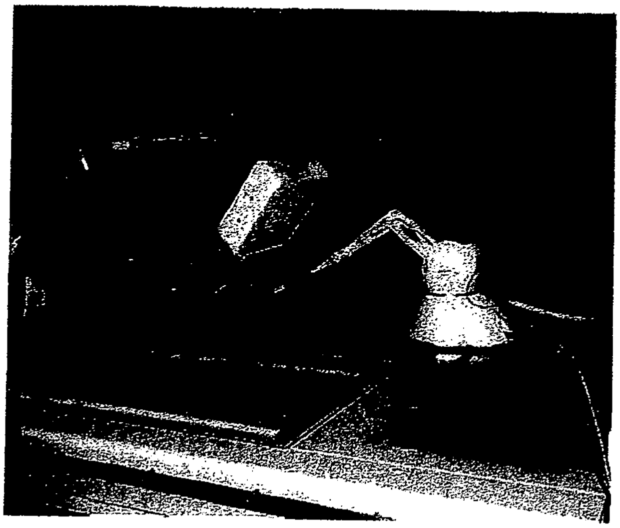

Fig. 1 The lab setup of the system

artificial data set. Uniform noise (0.5 mm) was added to the grid points to ensure that the grid was non-regular. The non-linear deformation of the mesh in the z-dimension was governed by the following equation ($A = 10$, $B = 0.7$):

$$f(z) = f(z-1) - A \times (\exp(B \times (z/z\_\max) - 1) \\ /(\exp(B) - 1)|f(0) = 0,$$

where z denotes the index in the z-dimension and z_max denotes the maximum index in the z-direction. This set of deformed points constituted the points in the Aurora-frame. A rigid transformation $R(100, -70, 50, \pi/4, 0, 0)$ determined the positions of the grid points of the basic mesh in the Phantom frame. A global transformation *T1* was computed by SVD using the corresponding data points from the Aurora- and Phantom-frames. The volume embedded by the deformed mesh was uniformly sampled at 600 positions and the sampled positions were corrected by the dewarping algorithm as well as by *T1*. Table 1 summarizes the results of comparing the computed positions with the real positions. Two datasets were used to assess the accuracy of the system
3.2 Dataset 2

Table 1 Summary of the accuracy tests performed with the artificial data set (dataset 1) and the dataset acquired in the operating room (dataset 2)

Test	Points	RMS (mm)	Mean (mm)	Standard deviation (mm)
Dataset 1 corrected by dewarping	600	1.10	0.96	0.53
Dataset 1 corrected by *T1*	600	7.06	6.54	2.67
Dataset 1 corrected by *R*	600	3.98	2.95	2.67
Dataset 2 corrected by dewarping	600	1.32	1.29	0.29
Dataset 2 corrected by *T2*	600	20.77	18.43	9.56

T1 and *T2* denotes the global transforms computed for dataset 1 and dataset 2, respectively. *R* denotes the real rigid transform which models the relation between the Aurora and Phantom frame

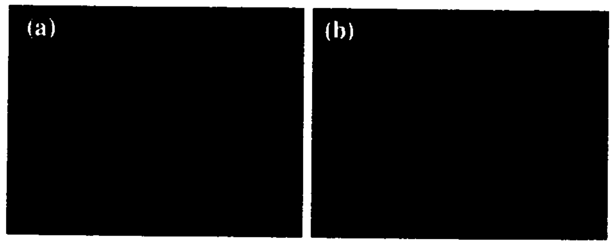

Fig. 2 **a** Visualization of dataset 2. **b** Dataset 2 after using the dewarping algorithm

A second dataset (11× 11× 7 with a resolution of 10 mm) was collected on top of an operating table in an operating room (OR) using the dewarping algorithm (see Fig. 1). To evaluate the accuracy of the algorithm using this dataset, the same physical volume embedded by dataset 2 was uniformly sampled at 600 points with the Phantom. A global rigid transformation *T2* was computed by SVD using all the 600 point sets. Table 1 summarizes the results of comparing the positions computed by the dewarping algorithm, as well as when using *T2*, with the real position of the Phantom. Figure 2 shows the grid sampled in the Aurora-frame on the left, and the corrected grid in the Phantom frame on the right.

3. Conclusion

Electromagnetic tracking is for many clinical applications the only suitable choice of tracking system. However, in the presence of certain materials the accuracy of the system can degrade considerably. We have presented a general system which can detect and improve on these inaccuracies by using a portable and inexpensive haptic device. The main advantages being that the system is highly portable, inexpensive and can correct tracking signals in real-time. However, the system is not able to correct for dynamic inaccuracies, for instance correcting for magnetic distortions due to introduction of surgical instruments. Another restriction arises when using local rigid transformations to construct a global deformation field. This results in a non-regularized deformation field which might lead to non-continuous tracking at the hexahedron boundaries.

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Development of placenta mapping system for treatment of twin-to-twin transfusion syndrome (TTTS)

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Abstract Connecting vessels occurred in twin-to-twin transfusion syndrome (TTTS) cause an imbalanced blood flow between twins. Laser photocoagulation treatment as one of useful method has

been giving a good survival and a low complication rate to the twins. However, the narrow viewing area of endoscope used in the treatment, makes difficult the identification of connecting vessels. We have been developing placenta mapping system to improve the effectivity of the treatment. In this system, first we captured images of placenta surface and make the model of placenta, then performed 3D image mapping and displayed the placenta three-dimensionally. Experimental results show that the system could provide the overall image of placenta and help the surgeon in performing identification of connecting vessels.

Keywords Laser photocoagulation treatment · Image distortion · Active contour · Image mapping

1. Introduction

Twin-to-twin transfusion syndrome (TTTS) is a disease of the placenta that affects identical twins who share a single placenta (monochorionic pregnancy). The disease occurs when the shared placenta contains abnormal blood vessels which connect the twins, resulting in an imbalanced flow of one twin to another. The implication of this condition, one fetus (the recipient) may get too much blood, thereby overloading his or her cardiovascular system, while the other fetus (the donor) may experience inadequate supply of blood. If not treated, TTTS may bring a life threatening condition to both of the twins, and those who survive may suffer from many serious health problems.

Several types of technique have been developed for the syndrome's treatment. Laser photocoagulation is one of useful method, which gives a good survival and a low complication rate to the twins. In this method, a laser fiber and an endoscope are inserted into the uterus. Under ultrasound and direct video guidance, specific vessels that cause the blood-sharing problem are coagulated using the laser fiber to stop the imbalanced flow of blood between the twins. In current laser photocoagulation treatment, the connecting vessels are identified by visual measurement based on endoscope image. However, the narrow viewing area of endoscope makes the surgeon difficult to grasp the whole picture of placenta and decide whether the blood vessels that being observed is one of the connecting vessels or not. As a result, the surgical success relies on the surgeon's ability in memorizing the blood vasculatory system on the placenta surface.

To improve the safety and accuracy of laser photocoagulation treatment for TTTS, we proposed an image mapping system for mapping the endoscope image to the placenta model. This system will provide the overall image of placenta and enable the surgeon to perform identification of the connecting vessels. In the next section, first we introduce the system, then describe the methods for implementing the system. We then describe the experimental results in the following sections.

2. System introduction

Our image mapping system consists of an endoscope, an ultrasonograph device, a 3D position tracking system and a computer (Fig. 1). We use the endoscope to capture images of placenta surface, and the ultrasonograph to obtain the intra-operative placenta. Then 3D position tracking system is used to obtain the position and orientation of the endoscope and the probe of ultrasonograph. These position and orientation of the probe will be used in estimating the position and orientation of placenta model. All of the obtained data are transferred to the computer. Then we correct the image distortion to make the endoscope images ready to be mapped. The image correction is performed only to the image area of a circle shape. We extract this image area with the use of active contour method. To map the images onto the placenta, first we calculate the corresponding positions of points on image data and placenta model. After obtaining the corresponding positions, we map the images onto the placenta model, and display the result in three-dimensional image. However, because we require the position of focal point of endoscope in performing the image mapping, we calibrate the endoscope using point correspondences.

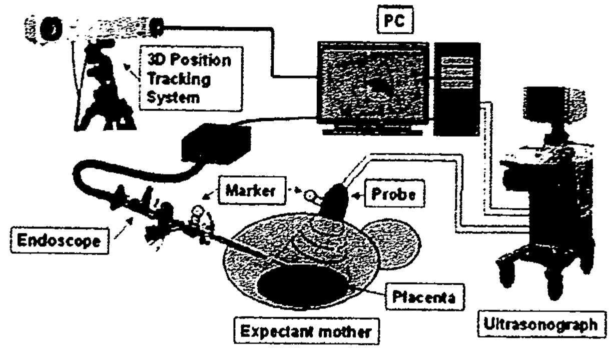


Fig. 1 Conceptual model of placenta mapping system

3. Methods

3.1 Endoscope calibration

In calibrating the endoscope, we use pinhole camera model as the endoscope model. Coordinate of point (X, Y, Z) on test pattern and its image (u, v) are related by :

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \cong \begin{bmatrix} f & 0 & u_0 & 0 \\ 0 & f & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \times \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad (1)$$

where f and (u_0, v_0) are coordinate of focal point and optical point of the lens.

To perform the calculation, we use a plane of test pattern which is set to be perpendicular to the endoscope. Normal vector of the test pattern then is set to be Z-axis, therefore the focal point can be defined as $Z_0 + f_0$, where Z_0 is the distance from the test pattern to endoscope lens, and f_0 is the distance from the lens to the focal point. To eliminate the effect of optical point, we substract the coordinates of two observed points, so that we can define the following equation. By using the least square method, we can calculate the focal point (f) and the distance from lens to focal point (f_0). However, because there is a distortion (Fig. 2b) in the endoscope image, we should correct this distortion first, which will be describe in the next section, before starting the calculation.

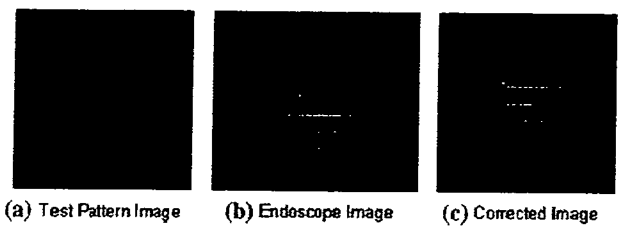
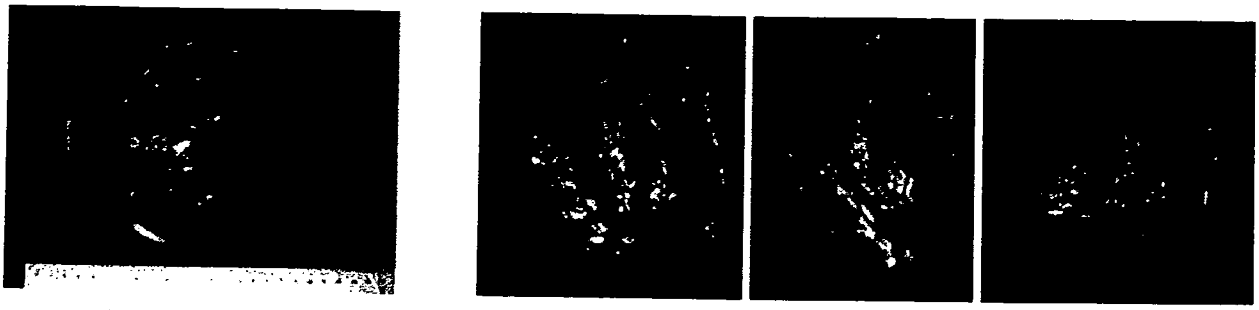


Fig. 2 Illustration of the effect of image distortion and result of image correction. **a** Test pattern image that is used as the object, **b** distorted image that is seen on the endoscope view, **c** corrected image resulting from the implementation of image correction method



(a) Placenta model (b) Image result

Fig. 3 Image of placenta model (a) and result of image mapping (b)

$$\begin{bmatrix} u_{i+1} - u_i \\ v_{i+1} - v_i \end{bmatrix} = \frac{f}{Z_0 + f_0} \begin{bmatrix} X_{i+1} - X_i \\ Y_{i+1} - Y_i \end{bmatrix} \quad (2)$$

3.2 Image area extraction and image correction

Correction of endoscope image is performed only to the figure in the image area of a circle shape (Fig. 2b). To obtain the image area, we use the active contour method [1]. However, active contour is greatly affected by the existence of image noise. To reduce the noise influence, first we pass the image through a low pass filter of Fast Fourier Transformation (FFT). Then, we apply the Gaussian filter onto the image to make blur the image, and reduce the noise more.

After obtaining the image area, we need to correct the endoscope image. This is because the using of fish-eye lens in the endoscope's camera make a barrel type spatial distortion due to wide-angle configuration of the lens (Fig. 2b). Therefore, compensation for this distortion is required in performing the image mapping to enable accurate measurement and registration of features in images. To correct the image distortion, first we compare the position of intersection point of lines on the captured image with those on the test pattern image, and then find the equation that describes the relationship between them. Position of each point on the captured image is measured from the optical center, which is found with the use of a low power laser beam [2]. The equation that describe the relationship, then will be used in correcting the position of every point on the captured image.

3.3 Texture mapping

In performing texture mapping, first we make the surface model of the placenta as a structure composed of triangle patches. In this study, we use MRI to substitute ultrasonograph, in modelling placenta surface. Then by assuming the endoscope as a pinhole camera model, we map every pixel on the images data onto the triangle patches through the focal point of the endoscope.

The position of the focal point and the triangle patches is tracked using a 3D position tracking system. The image position can be calculated using the position of focal point. Then, to map every image pixel, first we find the vector between the focal point and pixel position. Using this vector, we calculate the position of every image pixel on the plane of triangle patch and check whether the position is inside the triangle patch or not. Then, if the position is inside the triangle patch, we check whether the vector comes to the front or back of the triangle patch. The image pixel's corresponding position on the placenta model will be found when the vector comes to the front of triangle patch.

4. Result

We plotted on a graph the distance and rotation degree of intersection points on the captured image against those on the test pattern image. From the result, we knew that only the distance of points were distorted, and the polynomial equation that describes the distortion was $r_2 = -(3 \times 10^{-7})\, r_1^3 + (6 \times 10^{-4})\, r_1^2 - 9.98\, r_1 - 1.04$, where r_1 is the distance on the captured image and r_2 is the distance on the test pattern image. By performing active contour method, we could get the image area and successfully corrected the image area automatically by using the above equation (Fig. 2c). Furthermore, from the endoscope calibration we got the distance from lens to focal point (f_0) is 7.73 [mm] and focal distance (f) is 434.02 [pixel].

We used a placenta model, where we colored its surface with red and blue colours to illustrate vein and artery, as the object in performing experiment to test our placenta mapping system (Fig. 3a). Then the placenta model was inserted into a container which illustrated the uterus. We modelled the placenta surface using *3D-Slicer*, and converted the surface configuration to triangle patches using *VTK*. Furthermore, we mapped the corrected endoscope images to the surface model. The result of mapped 28 images in three-dimensional image was generated using *OpenGL* (Fig. 3b). From these results, we found that this mapping system will be effective enough in providing a large-scale image of the placenta and enabling a surgeon to get the information in convenient way.

5. Conclusion

We developed a placenta mapping system for treatment of TTTS. The feasibility evaluation shows that the system operation is possible for intra-uterine TTTS treatment. The image mapping system can provide three-dimensional large-scale image of placenta surface, which enables surgeon to observe the blood vasculatory system. This can reduce the risk of missing the important vessels in the treatment. In future works, we are going to improve the accuracy of the image mapping and the quality of mapped image by doing image enhancement to get a clearer endoscope image. Furthermore, we are going to test the system in an in vivo experiment.

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Conclusions

The learning process indicates an improvement in the endoscopic skills of the subjects and confirms former studies [7]. Even after a break of 1 week between run 10 and run 11, the test subjects started on a significant better level than in the beginning.

The performance was not significantly better using haptic force feedback additional to visual control in this simulation, neither for time nor for collisions or economy of hand movement. This might be due to the aim of the training which was "avoiding collisions". It might also be due to the large magnitude of friction in trocars, as it was described by Lamata et al. [3] and Picod et al. [5].

The lack of additional benefit of haptic force feedback on learning curves may additionally be due to the limited steps of tissue preparation in endoscopic third ventriculostomy. Furthermore a collision with brain tissue produces a faint force which is often not recognized by the test subject.

From our experiment we draw the conclusion, that for surgical simulators with little tissue interaction or just small occurring forces, haptic force feedback is not necessary.

Acknowledgments

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Miniature bending forceps manipulator for intrauterine fetal surgery: mechanical performance evaluations

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Abstract This paper proposes a miniature forceps bending manipulator of 3.5 mm diameter for intrauterine fetal surgery. We developed 2-DOFs horizontal and vertical bending mechanism driven by an original wire-guided driving method with tip's part wire-driven forceps mechanism. The manipuolator performed high bending positioning accuracy of minimum 0.1 mm and large bending force of maximum 2.57 N, however at tip-side horizontal bending mechanism, further improvement will be needed in linkage driving efficiency. While grasping force of forceps mechanism was 3.48 N, enabling sufficinet graps of tissues. In conclusion our new manipulator has high mechanical performance, and reduction of bending characteristic variations between bending DOFs can realize more secure and stable maneuverability for fine surgical procedures.

Keywords Forceps manipulator · Intrauterine fetal surgery · Wire-guided linkage driving method

1. Introduction

Fetal surgery is operated on fetus in around 19–25 weeks of pregnancy to treat fetal and placental morphologic defects, which are diagnosable early before birth, by means of relatively simple surgical procedures, and to stop their progressions into severe states [1]. For minimal invasive surgery, intrauterine fetoscopic surgery is very effective like laparoscopic surgery, however, instruments' insertion into uterus is limited by placental location, especially in case of anteriorly located placenta. Furthermore in therapy of fetal disease including myelomeningocele, because fetus is floating in amniotic fluid, fetoscopic surgical procedure is severely difficult. Therefore, conventionally ex utero intrapartum treatment procedures (EXIT) are operated popularly, however possibilities of infection, complication, premature birth and membrane rupture are high and their outcomes are poor. For the solution of these difficulties, it is useful to add multi degrees-of-freedom (DOFs) to the conventional straight-shape instruments in order to enable flexible maneuverability in the uterus.

The purpose of this study is to develop a miniature manipulator with 2-DOFs bending mechanism driven by wire-guided linkage driving method. For an end-effector, a wire-driven forceps mechanism is mounted on the tip part of bending mechanism for highly successful intrauterine typical surgical procedure. The results of mechanical performance evaluations are also presented.

2. Materials and methods

2.1 Bending mechanism

Bending mechanism is based on previously reported basic concept [2, 3], which consists of a finger-like multi-joint structure consisted of three frames and two joints (Fig. 1). Tip-side Frame1 and base-side Frame3 are in contact with each other at both arc parts and jointed by intermediate Frame2, which is driven by a linkage's pushing/pulling linear motion. Frame1 and Frame3 are also connected by a pair of stainless-steel wire-ropes (Wire-rope A and B), which is crossing at the contact point for slip-less bending motion between Frame1 and Frame3 from –90° to 90°. Unlike recently reported wire-driven mechanisms, a pair of wire-ropes in this mechanism has low risk of its wear and tear caused by re-

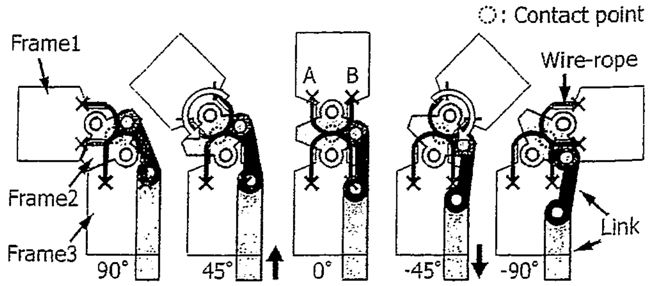

Fig. 1 Bending mechanism driven by wire-guided linkage driving method

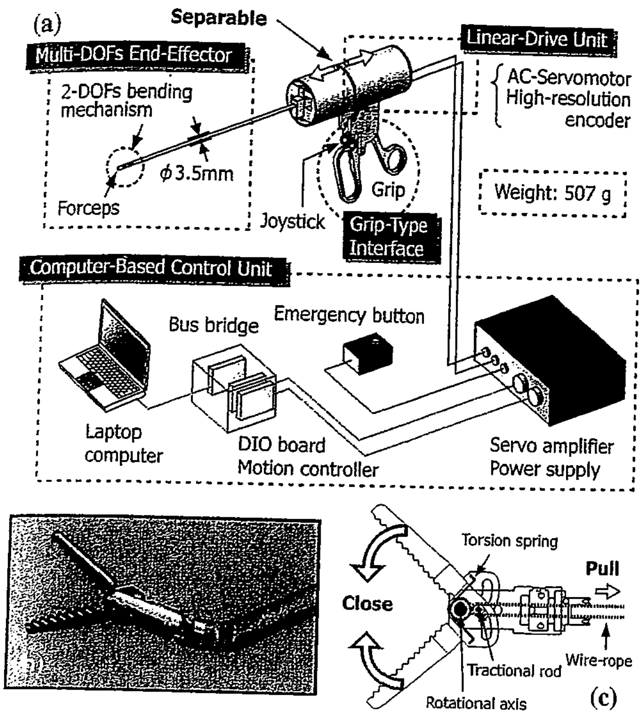

Fig. 2 a System configuration of the miniature bending manipulator. b Tip's part of the multi-DOFs end-effector and c detail of the wire-driven forceps mechanism

peated or powerful strain. The manipulator consists of connection of two bending mechanisms in a line. Base-side mechanism is assigned to vertical bending motion and tip-side mechanism is assigned to horizontal bending motion.

2.2 System configuration

System configuration of the manipulator consists of four parts (Fig. 2a). The first part is the multi-DOFs end-effector with two-directional bending mechanism and forceps mechanism (Fig. 2b). Diameter of this part is 3.5 mm. The second part is the linear-drive unit including two AC-servo linear actuators with high-resolution encoders which enable accurate PD-feedback control of linkage-driven bending mechanism. The third part is the grip-type interface with a joystick to control 2-DOFs bending angles and a grip to open/close forceps in one hand. The last part is the computer-based control unit. This part calculates required displacements of linkages for 2-DOFs bending motion inputted from the joystick and outputs signals to control the linear-drive unit.

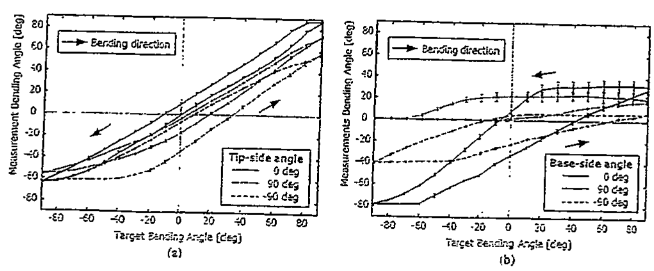

Fig. 3 Results of bending characteristics measurements ($N = 5$). a Hysteresis curves of base-side bending motion in case tip-side bending angle is set to 0°, 90° and –90°. b Hysteresis curves of tip-side bending motion in case base-side bending angle is set to 0°, 90° and –90°

The multi-DOFs end-effector and the linear-drive unit are easily separable for cleaning and sterilization for clinical application. Total weight of the manipulator without any electric cables was 507 g, which realizes easy and flexible maneuverability for fine intrauterine fetal surgery.

About an end-effector as shown in Fig. 2c, the forceps mechanism is driven by a stainless-steel wire-rope. Pulling a tractional rod to slide along circular slits on the forceps blades by wire-ropes' straining rotates a pair of forceps blades to close, and torsion spring's restoring force reverses a pair of forceps blades to open. Wire-ropes pass through a central channel of cylindrical frames. This forceps part is detachable from tip's frame and its function is exchangeable into such as shears and exfoliation forceps by change of blades' shape.

3. **Results**

In mechanical performance evaluations, at first we examined bending characteristics including bending range, bending repeatability error and tip's part positioning accuracy of the manipulator. Parameter in these measurements was the other DOF bending angle, which was fixed to 0°, 90° and –90°. We changed target bending angle in 10° step starting from 90° to 0°, –90°, 0°, and finally returned to 90° with five times repeatedly (Fig. 3). Bending angles were measured by an optical measurement instrument (FUJIFILM Corporation, FinePix F11), which had no distortion and high resolution of 0.07 mm. In base-side vertical bending motion, bending ranges were large despite tip-side horizontal bending angle, which were maximum 150.9°. Bending repeatability errors were small, which were minimum 0.4 ± 0.3 mm, corresponding to high positioning accuracy of minimum 0.2 ± 0.1 mm error. In tip-side horizontal bending motion, bending ranges were maximum 111.9°, which was smaller than one in base-side bending mechanism, and especially in case base-side vertical bending angle was ±90° bending ranges were smaller considerably. However, bending repeatability errors were minimum 0.5 ± 0.2°, corresponding to higher positioning accuracy of minimum 0.1 ± 0.1 mm for intrauterine fine surgical procedures.

Next we examined bending force and torque of each bending DOF by a digital force gauge (NIDEC-SHINPO Corporation, FGP-2), of which resolution was 0.01 N, with ten times repeatedly. Bending directions were 0°–90° and 0° to –90°. In base-side vertical bending motion, bending force was maximum 2.57 ± 0.17 N, corresponding to bending torque of 68.72 ± 4.54 Nmm. And in tip-side horizontal bending motion, bending force was maximum 0.78 ± 0.01 N, corresponding to bending torque of 12.74 ± 0.17 Nmm. Performance in base-side vertical bending mechanism was high for its miniature diameter, however on the other hand, performance of tip-side horizontal bending mechanism was low because of low efficiency of power transmission from the link to rotational frames.

Finally we examined grasping force and torque of forceps mechanism driven by interface's handling with ten times repeatedly. This measurement was carried out by the same digital force gauge. Grasping force was 3.48 ± 0.18 N, corresponding to grasping torque of 17.40 ± 0.88 Nmm, enabling stable grasp of normal interperitoneal tissues [4]. However in practical fetal surgery, tissues are generally very fragile therefore it's necessary to do future sufficient validation with in vivo experiments.

4. **Conclusion**

Diameter of the manipulator is small enough for intrauterine surgery, which includes a sufficient central channel space to pass through wire-ropes to drive forceps blades' motion. From mechanical performance evaluations, repeatability of 2-DOFs bending motion is very high with enough positioning accuracy for fine surgical procedures. On the other hand bending ranges are largely different in bending mechanism. Particularly bending range of tip-side horizontal bending mechanism is small, so this mechanism needs improvement especially in power transmission. In practical fetoscopic surgery, operability of tip-side bending mechanism is significant because it is close to the affected part, therefore reduction of performance variation in bending mechanisms can realize more secure and stable maneuverability for fine intrauterine fetal surgery.

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A planning system for robot based abdominal minimally invasive surgery

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Abstract Selecting proper port positions for laparoscopic procedures is crucial to the success of the intervention. When performing minimally invasive procedures with a telemanipulator system, the positions and configurations of the robot arms are equally important. Preoperatively planning the setup can help solving these issues. For abdominal interventions the insufflation of the patient's abdomen prevents the direct use of the planned data. In this paper we present a system to plan and transfer the setup for abdominal minimally invasive procedures. Our system is composed of a preoperative planning module and an intraoperative registration and transfer module. A first version of the preoperative planning module was developed, which enables the surgeon to position the trocars and—in case of a robot based procedure—to arrange the robot system to get a configuration without possible collisions that offers good reachability and flexibility. The planned trocar positions are transferred into the operating room using projector based augmented reality techniques. The intraoperative module is used to register the patient to the preoperative data, to record the changes of the abdomen due to the insufflation and finally to project the adjusted planned trocar positions directly onto the patient's abdomen. An evaluation with a torso phantom showed acceptable accuracy.

Keywords Augmented reality · Computer-assisted surgery · Minimally invasive robotic surgery · Surgical planning.

1. Introduction

Choosing good trocar positions for laparoscopic procedures is very important for a fast and straightforward operation. For minimally invasive interventions performed with a telemanipulator system like the da Vinci™ surgical system (Intuitive Surgical Inc.) the placement of the robot base and the configuration of the arms are equally important and even more difficult. Poor choices for trocar positions or the manipulator configuration often result in prolonged operation times and additional ports may be necessary to complete the operation. Especially time-consuming is the introduction of an extra port when using a master slave telemanipulator system as the surgeon has to switch between the unsterile master console and the sterile operating table.

Using preoperative planning for the setup can help solving these problems. Several approaches have been proposed to plan port positions and robot configurations for a given intervention and a specific patient model. These methods include automatic optimizations [1–4] and planning using virtual environments and simulation methods [5, 6].

Transferring the planned positions to the operating room can be achieved with navigated instruments [1, 2] or augmented reality techniques [3, 5]. However, for abdominal procedures the insufflation of the patient's abdomen has to be taken into consideration. For these interventions an additional step to adapt the planned data to the changed environment has to be performed intraoperatively.

We propose a system that enables the surgeon to quickly plan operations preoperatively by using templates for specific interventions and patient classes and that has an intraoperative component which adapts the planned data to changed conditions in the operating room (e.g. an insufflated patient).

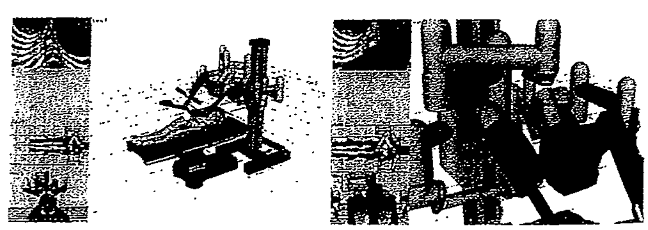
2. Methods

Our system is composed of a preoperative planning module and a mechanism to transfer the planned positions into the operating room.

2.1 Preoperative planning

Prerequisite for the planning system is a patient specific model which has to be obtained e.g. by segmenting preoperative CT, MRI or 3d-ultrasound scans. At a minimum we require a geometric model of the surface that will contain the trocars. However, including additional models (e.g. of obstacles like bones) is recommended.

A first version of the preoperative planning module (Fig. 1a) was developed enabling the surgeon to position the trocars and—in case of a robot based procedure—to arrange the robot system to get a configuration without possible collisions that offers good reachability and dexterity. For this virtual environment the slave part of the da Vinci surgical system was modeled geometrically. A kinematical model was determined and the inverse kinematics was derived allowing the surgeon to easily position and configure the manipulator within the virtual operating room. Fast collision detection and distance computation between geometric models was implemented (Fig. 1b). For this purpose we are using bounding volume hierarchies composed of oriented bounding boxes [7]. This allows real time collision tests and distance computations between the models in the virtual environment.



(a) (b)

Fig. 1 a Planning port positions and manipulator configuration. b Detecting collisions between arm segments

第16回日本コンピュータ外科学会大会
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合同論文集

Computer Aided Diagnosis of Medical Images

会期：2007年11月2日(金)～4日(日)

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07(I)-3

子宮内胎児保持のための多関節バルーンマニピュレータの細径化

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Miniaturization of Balloon-Based Manipulator with Multiple Joints for Stabilizing Intrauterine Fetus

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Abstract: This paper describes a miniaturized manipulator 4 mm in diameter with multiple joints for stabilizing a fetus for intrauterine surgery. In order to limit the translation and rotation of the floating fetus in amniotic fluid, the manipulator with a balloon holds fetal chest and abdomen ventrally from beneath. The manipulator has 3 bending mechanisms. A hook-like mechanism bends manipulator with the balloon into an appropriate shape to support a fetus from beneath. A linkage mechanism is for tilting the supporting plane of hook-like mechanism corresponding to incision point. A finger-like mechanism is for pinching the fetal waist to limit its lateral movement. Performance evaluation showed that the standard deviations of the bending angle of the hook-like mechanism and the linkage mechanism were 3 degrees and 2 degrees respectively. Therefore, the repeatability is considered sufficiently small for keeping configuration of the manipulator.

Key words: Intrauterine fetal surgery, Stabilizer, Balloon, Myelomeningocele

1. はじめに

胎児疾患のうち脊髄髄膜瘤は約 2000 人に 1 人と頻度が高く近年増加傾向にある. 脊髄髄膜瘤は先天性の脊椎管の閉鎖不全により脊髄が腰仙部に露出する疾患で, 子宮壁との物理的な接触や羊水による化学的刺激によって, 妊娠早期には正常な脊髄組織の損傷が分娩時まで子宮内で進行する. その結果, 出生後の歩行障害や排泄障害の原因となる. また, 脳脊髄液の漏出や循環障害により水頭症の原因ともなる. 従来の手術は出生後の治療による残された神経機能の保護と感染の防止を目的とし, 根本的な治療とはならない. そこで胎児期手術によって障害を未然に防ぐ試みがなされ, 妊娠 19~25 週の胎児に対し露出した脊髄の修復やパッチによる被覆が行われる [1]. 当初, 低侵襲な胎児内視鏡下手術が試みられたが, 技術的な困難のため子宮切開の直視下手術に移行した. その困難な点の一つとして胎児が羊水中を浮遊性に移動することが挙げられる. この問題を解決するために子宮内で胎児の動きを制限するマニピュレータを ϕ 4mm で試作したので報告する.

2. マニピュレータ屈曲機構

胎児体幹部を, 腹側から支持しつつ側腹部を左右から挟み込む形状にて, その保持を行う(**Fig.1**). この保持方法を実現するためにマニピュレータは 3 つの屈曲機構をもつ(**Fig.2**).

A. フック状屈曲機構

4 関節で構成され, 直線形状から最大 180° の屈曲が可能であり, 臍帯を回り込むように体幹部を支持する(**Fig.3-a**). 駆動には 2 本のワイヤロープを用い, 関節に配置した超弾性合金線を先端から順に硬くすることにより, 先端側の関節から順に屈曲させることが可能となる. これにより, 屈曲する際のマニピュレータ先端の通過領域が小さくなり, 子宮内へ挿入しつつ先端側から屈曲させることも可能となるため, 胎盤組織に接触する危険性が小さくなると考えられる.

B. リンク屈曲機構 [2)]

2 関節で構成され, 胎盤位置によって制限される子宮内への挿入点・挿入角度に対応するため, フック状屈曲機構によって作られる支持面を最大 90° 傾ける(**Fig.3-b**).

C. 先端指屈曲機構

ワイヤ駆動により 45° 屈曲してリンク屈曲機構部との間に胎児を把持し, 胎児の横方向への移動を制限する(**Fig.3-c**). また, その先端部に取り付けられたシリコーン製の円柱によって, マニピュレータ挿入時にマニピュレータ先端が胎児や羊膜などに接触した場合の損傷の危険性を小さくする.

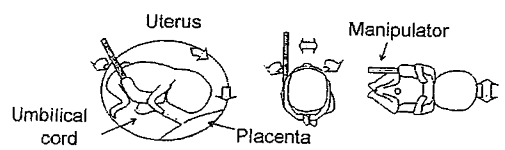

Fig.1 Method of holding fetus.

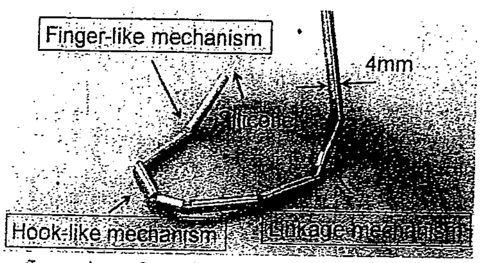

Fig.2 Configuration of manipulator in fetus supporting.

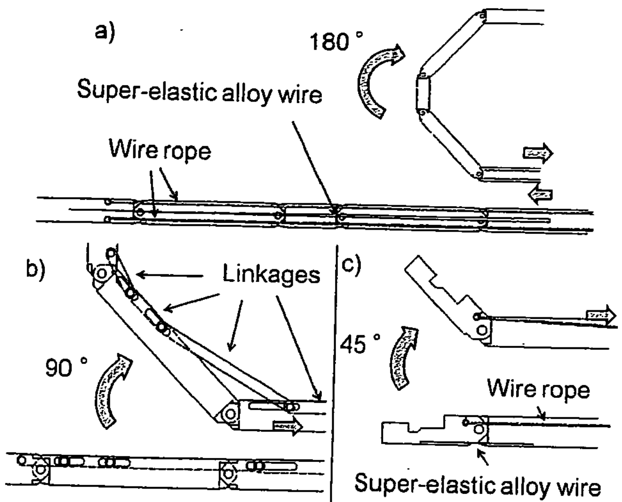

Fig.3 Bending mechanisms. a) hook-like mechanism. b) linkage mechanism. c) finger-like mechanism.

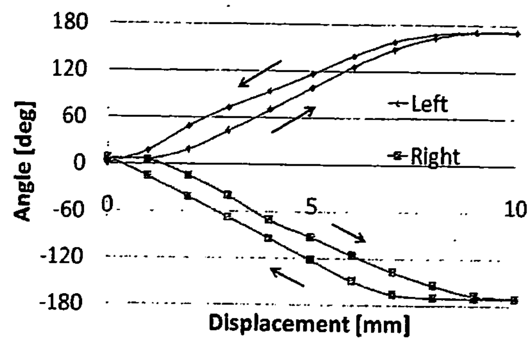

Fig.4 Result of bending performance of hook-like mechanism. (N=3)

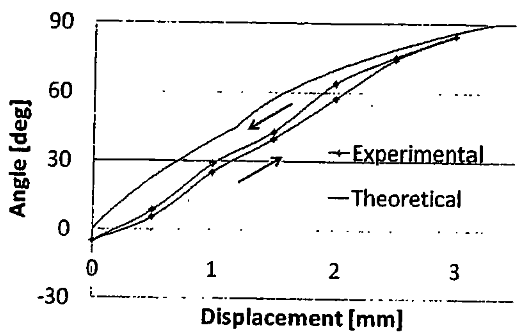

Fig.5 Result of bending performance of linkage mechanism. (N=3)

3. 屈曲動作実験

フック状屈曲機構の動作評価のために，xy ステージを用いてワイヤロープを 1mm ずつ送り屈曲させた．その際のスライド変位量と先端フレームの屈曲角度，ワイヤ張力，先端フレームの軌跡を記録した．その結果，10mm の変位量に対し左右それぞれ 171°，170° の屈曲領域をもち，屈曲角度の標準偏差は約 3° であった(**Fig.4**)．ワイヤ張力は，屈曲角度の増加に伴って大きくなり最大で約 30N であった．先端フレームの軌跡における往復のヒステリシス誤差は約 3mm であった．

また，リンク機構の動作評価のために，リンクを 0.5mm ずつスライドさせ，スライド変位量に対する屈曲角度を計測した．結果は，初期角度のずれがあるが理論値に対してよい追従性を示し，角度の標準偏差は約 2° であった(**Fig.5**)．

4. 考察

フック状屈曲機構は，先端側から屈曲させるために使用している超弾性合金線により，屈曲角度の増加に伴って屈曲に必要なワイヤロープの張力が大きくなる．特に 160° 以上ではワイヤロープの伸び量が屈曲角度の変化量に対して大きくなり，180° の屈曲には至らなかった．しかし，170° 程度の屈曲においてもマニピュレータが胎児の両脇腹に沿う形状となるため保持は可能である．ワイヤロープの伸び量を抑えて 180° の屈曲領域を得るには，太めのワイヤロープを使用すればよいと考えられる．また，張力の変化に応じてワイヤの伸び量が変化する点は，制御する際に考慮する必要がある．屈曲角度の標準偏差は 3° であったが，保持形状となる屈曲角が大きい状態ではリンク屈曲機構部との間に作られるスペース幅の精度は約 2mm となり，胎児保持形状として十分な再現性を有すると考えられる．

リンク屈曲機構の理論値からのずれは，屈曲角度の追従性を考慮すると初期角度のずれが主な要因であると考えられる．屈曲角の標準偏差は 2° であるが，支持面の傾きの精度としては十分である．

両屈曲機構は多関節で構成され，スライド変位量と屈曲角度が一意に定まらない領域があるため，今後は外力を加えての評価，バルーン搭載時の評価も必要である．

5. まとめ

φ4mm の胎児保持用のマニピュレータを試作した．胎児を下から支持するフック状屈曲機構，子宮への挿入点に対応し支持面の角度を変化させるリンク屈曲機構，胎児の両脇腹を挟み込むための先端指屈曲機構の 3 つの機構を備えた．フック状屈曲機構は左右 170°，リンク屈曲機構は 90° の屈曲領域を持ち，標準偏差はそれぞれ 3°，2° と十分な再現性を得られた．

謝辞

本研究の一部は，厚生労働科学研究費補助金 身体機能解析・補助・代替機器開発研究「ハイリスク胎児の子宮内手術におけるナノインテリジェント技術デバイスの開発研究」(H17－フィジー指定－006)による．

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07(I)-4

双胎間輸血症候群治療のためのレーザ鉗子操作マニピュレータ -設計と位置決め精度評価-

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A Manipulator of a Laser Forceps for Twin-twin Transfusion Syndrome Therapy -Design and Evaluation on Positioning Accuracy-

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Abstract: This paper reports a manipulator to locate a laser forceps, which has 2-DOFs bending mechanism at the tip, in 4-DOFs (translation, rotation and pivot motion around a trocar) for fetoscopic laser photocoagulation therapy of twin-twin transfusion syndrome. For safety, the manipulator using 5-bar linkage mechanism is designed for small occupancy of surgical space, and easier sterilization with parts separation mechanism. To evaluate its performance, we measured positioning accuracy of the 4-DOFs mechanisms separately. The results shows that the positioning error was 1.2±0.5mm in 5-bar linkage mechanism, 0.05±0.01mm in forceps translation, and 0.2±0.3° in forceps rotation. It is suggested that the positioning accuracy is enough for photocoagulation therapy with proper value compensation for motion command.

Key words: Fetal surgery, Twin-twin transfusion syndrome, Manipulator

1. 背景

双胎間輸血症候群は胎盤表面の血管吻合により両児の血流量に不均衡が生じる疾患で，吻合血管をレーザにより焼灼・遮断する治療法が行なわれている．この手技は胎児内視鏡下で行なわれるが，レーザファイバの動作が子宮壁挿入孔により拘束され，また胎盤の位置によりアプローチ可能部位が制限されるなど，術具操作は困難で高い技術を要する．これを解決する方法として，先行研究では先端に2自由度屈曲機能を持つレーザ鉗子[1)]が開発された．このレーザ鉗子は現在，術者が持ち操作することを想定しているが，これを術者の代わりに鉗子操作マニピュレータにより把持・操作することで手術の安全性向上と術者の負担の軽減が得られると考えられる．

本研究では上述したレーザ鉗子を把持し，挿入孔まわりのピボット運動，挿入軸方向の並進，回転の4自由度操作を行なう鉗子操作マニピュレータを製作し，その駆動位置決め精度の評価実験を行った．

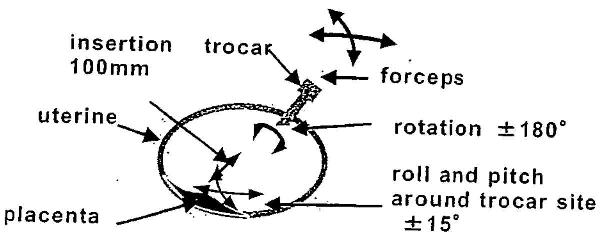

Fig. 1 Degree of freedom of forceps manipulation

2. 方法

吻合血管レーザ焼灼術における，レーザ術具の子宮内挿入深度，患部のサイズを考慮して術具操作範囲を **Fig.1** のように決定した．また，レーザ照射の際にレーザ鉗子先端は吻合血管径が太くても1mm程度であることを考慮してレーザ鉗子先端の位置決め精度は1mm以内とした．

手術中の安全性については，マニピュレータ本体と動作範囲が小さく術者の作業を妨げないこと，マニピュレータが滅菌部と非滅菌部に分離可能であることを要求仕様として設計を行なった．

マニピュレータ全体図を **Fig.2** に示す．子宮壁挿入孔まわりのピボット運動は5節リンク機構[2)]とジンバルジョイントにより実現した．5節リンク機構を採用することによりピボット動作を必要な範囲内に限定した．また5節リンク機構部を患部から離し，先端に取り付けられたフレキシブルアームで鉗子把持部を支持することで患部付近のスペースを確保した(**Fig.3**)．5節リンク機構部は術者の作業を妨害しないよう,手術台脇のレールに設置することを想定している．5節リンク機構と5節リンク機構駆動部とは脱着可能でそれぞれ別々に滅菌処理を行なうことができる(**Fig.4**)．

挿入軸方向の並進，回転は鉗子把持部内のモータですべりネジ，スプラインによる伝達を介して行なう．レーザ鉗子の鉗子把持部への取り付けは，アタッチメントを挟んで行なう(**Fig.5**)．アタッチメントと鉗子把持部の取り付け

フランジが組み合うことで鉗子の回転を伝える. この機構により, レーザ鉗子先端が鉗子把持部に直接接することなく, 清潔性を保ったまま取り付けを行なうことができる.

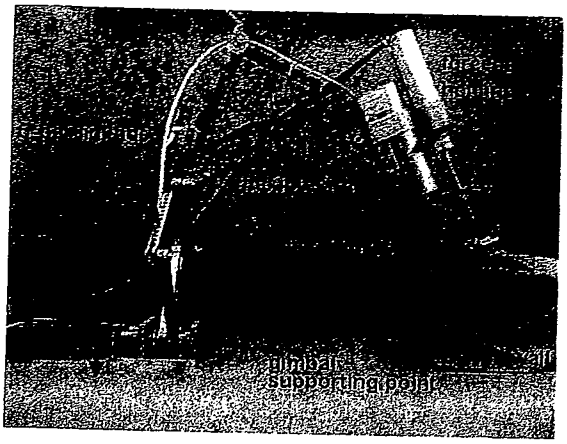

Fig.2 Overall view of manipulator

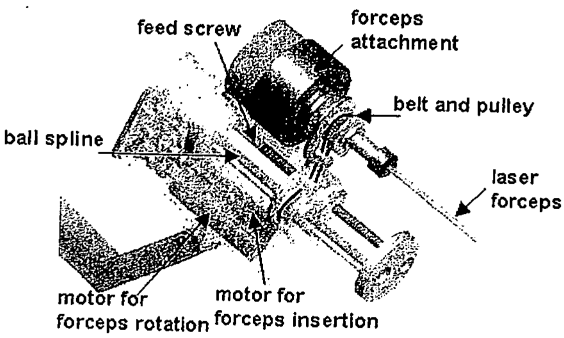

Fig.3 Mechanism of forceps holding unit

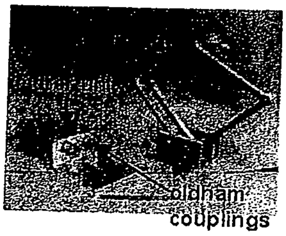

Fig.4 Separation mechanism of 5-bar linkage unit

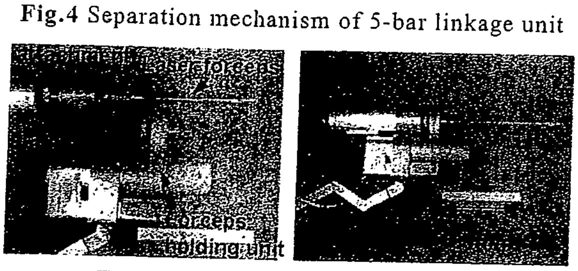

Fig.5 Attachment of Laser forceps

3. 評価実験

術具操作マニピュレータの位置決め精度を 4 自由度それぞれについて調べた. 5 節リンク機構については, 動作範囲内 13 点での位置決め誤差は全点で 1.2±0.5mm 以下であった (n=5). また, 術具の挿入は±15mm の前後移動で 3mm 刻みで, 回転は±90° の往復回転において 30° 刻みで位置決め誤差を測定した (n=5). 挿入駆動の誤差は 0.05±0.01mm だった. 回転駆動では位置決めのばらつきは±0.3° 以内であったが, 3.8° のバックラッシが存在した.

4. 考察

レーザ鉗子の鉗子把持部での支持点と挿入孔との距離を 200mm と想定した場合, 5 節リンク機構の駆動, 術具挿入の位置決め精度は要求仕様であるレーザ鉗子先端での 1mm 以内の精度を実現するのに十分である. 回転駆動ではバックラッシによる誤差が 1mm 程度 (レーザ鉗子屈曲半径 20mm の場合) となるが, 回転駆動の指令値をバックラッシ分補正することにより精確な操作が可能であると考えられる.

術中の安全性に関しては, 滅菌部, 非滅菌部の分離は可能であるが, 例えばキャッチロックのように単純な操作で脱着が可能である方法を検討する必要がある.

5. まとめ

本研究では, 双胎間輸血症候群の治療支援のためにレーザ鉗子を把持, 操作するマニピュレータを製作した. 術中の安全性を考慮し, 手術室スペースを占有しないよう小型化し, また滅菌部, 非滅菌部の分離機構を実現した. 評価実験により, マニピュレータの駆動精度はレーザ鉗子先端で 1mm 以内の精度を実現するのに十分であることを確認した.

本研究の一部は, 厚生労働科学研究費補助金 (H17ーフィジー指定ー006) による.

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07(V)-22

MMC胎児期治療用パッチのピン形状と固定力に関する検討

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Examination of pin's design and fixed force of a patch for fetal myelomeningocele repair

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Abstract: Myelomeningocele (MMC) is a birth defect that the spinal cord and cord tip nerve are exposed before birth due to insufficient closure of the spine. MMC causes secondary disabilities at the fetal period. The chemical stimulation of the amniotic fluid and the physical irritation of friction with the uterine wall lead various neurological disorders. To prevent these disorders, spina bifida defect is closed by surgical operation in the fetal period. However, because of the weakness of the fetal skin, it is difficult to sew up a opening. For this background, a method to apply a patch to cover the spinal cord has been proposed. In the fetoscopic surgery, simple treatement method is required, considering that the interior of the uterus is narrow, therefore, we propose a patch with planted pins. Pins were planted to the patch beforehand, and the patch can be easily fixed to the skin by pushing the pins into the skin.

This study includes designing and manufacturing a prototype patch as a proof of concept, and fixed force evaluation was performed.

Keywords: myelomeningocele, spina bifida aperta, fetal repair, patch

1. 緒言

脊髄髄膜瘤（myelomeningocele:MMC，以下MMC）は開放性二分脊椎（spina bifida aperta）の一種で、神経管閉鎖不全により、脊髄及び脊髄末梢神経などが脊椎管から脱出、露出するものである。胎児期に脊髄組織が羊水の化学的刺激や子宮壁との接触による刺激により、出生後に水頭症や下半身麻痺、排泄排尿障害など一生涯続く後遺症が残る。こうした障害を防ぐためには、胎児期に背中の開口部を閉鎖する手術を行うことが有効と考えられている。この閉鎖手術の方法としては、胎児を子宮から出し、胎児の開いた皮膚同士を縫合する方法がある。しかし本方法では胎児の皮膚がもろい為縫合が難しいことや、胎児を子宮から出すことによる、胎児と母体への負担が懸念される。そこで、内視鏡手術により開口部に防水性のあるシート状のものをパッチとして貼って塞ぐことで、脊髄が外部刺激を受けないようにする方法が考案されている[1]。一方で内視鏡を用いる手術では、子宮内は手術空間が非常に狭いため、術具の可動範囲が小さいことを考慮すると、治療が簡便かつ短時間でできることが重要になってくる。

そこで我々は、簡便に貼り付けるための新しい手法を考案した[2]。本報では新しいパッチのピン形状の検討を行なったので報告する。

2. 方法

パッチ製作における条件として、皮膚への貼付が容易であること、子宮との摩擦によって剥がれにくい形状であること、さらに手術時にパッチを子宮内に挿入するために開ける、母体の腹部と子宮の穴の径をなるべく小さくするため、コンパクトであることが挙げられる。本研究では、皮膚へのパッチの貼付を簡易化する方法として、予めパッチ表面の患部に当たる部分の周囲にピンを植付けておき、そのピン側の面を皮膚側にして患部におき、そのパッチの上から圧力をかけてピンを患部周辺の皮膚に押し込んで固定する方法を検討している。Fig.1 に本方法によるパッチの貼り付け想定図を示した。

またピンの形状等について、これまでの研究で、

パッチに対してピンに角度をつけ、ピンの角度が互い違いになるよう配置して植え付けることで剥がれにくい設計を検討した。しかし、貼り付けが容易ではなかったことから、貼り付けが容易で、かつ剥がれにくくするため、本研究ではピンの形状、向きを単純化して設計した。具体的にはパッチの面に対してピンを垂直に多数植付け、ピン先端に返しをつけることで摩擦による剥がれを防ぐ形状を製作した。パッチの素材は生体適合性のある、シリコーンを採用し、皮膚に固定するためのピンの素材もパッチ部分と同様のシリコーン素材で一体型の成形を行った。Fig.2 に本研究で設計したピンのデザインを示す。Fig.3 は同心円上にピンを 144 本配置したパッチである。胎児期の MMC の患部の大きさが一般的に 10mm 四方程度であることから、パッチの大きさは患部にあたる中心部分を φ 18mm とし、全体を 30mm 四方の大きさ、ピンは 1mm の長さに先端 0.4mm の返しをつけた設計で製作した。

3. 固定力評価実験及び結果

本研究で製作したパッチ形状での固定力を評価するためにファントムに貼り付ける実験を行なった。胎児の皮膚のファントムには胎児の皮膚に近い性質である、ゼラチンを使用し、これにピンの返し付きパッチとピンの返しのないパッチを貼り付け、子宮壁との摩擦を模してパッチを横方向に引張り、固定力がどのぐらいの力まで耐えられるか調べた。その結果、返し付きパッチが平均 0.30N 、返しなしのパッチが平均 0.25N となった。

4. 考察・まとめ

本実験では、返し付きの設計のパッチの方が返しのない設計のものよりも固定力を上げられることがわかった。また単純な形状でありながら固定強度を高められることが示され、MMC パッチ治療において、縫合やクリップによる固定ではなく、ピン一体型のパッチによるパッチの固定の可能性が示唆された。

謝辞

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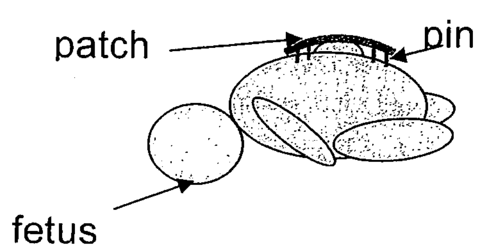

Fig.1 myelomeningocele repair with a new patch

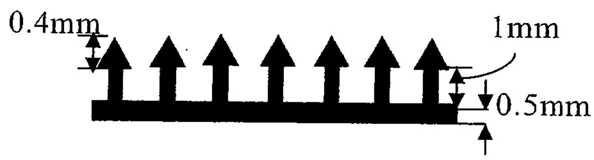

Fig.2　Design of pins for a new patch

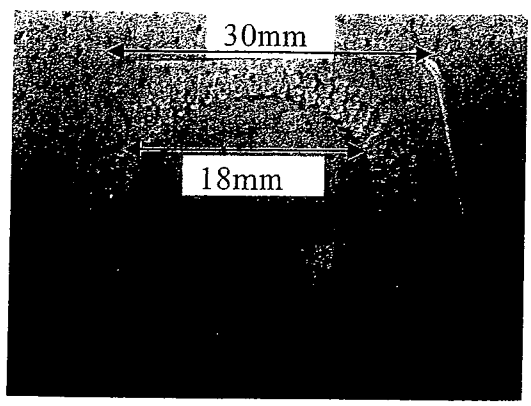

Fig.3　patch with planted pins

07(XIV)-67 **ビームスプリッタを用いた視野可変内視鏡試作機の開発**

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Prototype development of FOV – changeable endoscope using a beam splitter

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Abstract: A novel method to change field of view is proposed. In the endoscopic surgery, it is very important to manipulate the endoscope smoothly so that the surgeon can observe where he or she wants to see safely. In our method, by the use of a beam splitter and polarization plates attached to the distal tip of the endoscope, the front side and the lateral side can be observed without moving or bending the endoscope itself. Therefore, the surgeon is able to observe wide field of view safely.
We developed a prototype which has 10mm in diameter, and it can illuminate the front side and the lateral side at the same time. According to the result of the experiment with this prototype, the field of view was easily changed from the front side to the lateral side and vice versa. The endoscope system has high image quality by the use of CCD camera, and the illumination is bright enough to observe the image clearly in the dark box.

Key words: Endoscopy, Field of view, Beam splitter, Polarization plate, Minimally invasive surgery

1. はじめに

内視鏡下手術において，安全に広視野を得るための内視鏡の円滑な操作は非常に重要である[1][2]．我々は，内視鏡本体の移動を伴わずに直視と側視が観察可能なシンプルな内視鏡システムを開発してきた[3]．本内視鏡システムでは，細径CCDカメラの先端にビームスプリッタと偏光板を搭載し，外側スリーブの回転のみで視野変更を行うため，安全な視野移動が可能となる．

これまでに，外径 ϕ 25mm の先端部モデルを制作し，外側スリーブの回転によって直視と側視の視野変更が可能であることを確認した．しかし，本内視鏡システムを実際の医療現場で臨床応用するためには，内視鏡の細径化と患部照明のための光源が必要となる．

そこで本研究では，照明系を搭載したビームスプリッタ内視鏡の試作機を開発する．光源を含めての内視鏡の外径は，腹部外科で最も用いられる ϕ 10mm とする．また，試作機を用いて暗室内で評価実験を行い，その有用性を検証する．

2. 方法

2.1 試作機

本視野可変内視鏡は細径CCDカメラとそれを収める内側スリーブおよび外側スリーブからなる(Fig.1)．

内側スリーブには，先端部にビームスプリッタと偏光板を搭載する．正面観察の際には，偏光板を通しての観察であるため，明るさがやや落ちる問題があり，それを解決するために透過率70percent，反射率 30percent のビームスプリッタを用いることにした．

外側スリーブには，偏光板と照明用光ファイバを搭載する．

それぞれのスリーブには側面観察のための観察窓を用意する．CCD カメラが収められた内側スリーブを外側スリーブに挿入し，回転させることで直視と側視の視野変更が可能となる．

照明系を含めた外径は ϕ 10mm である．

2.2 照明系

広視野内視鏡や視野可変内視鏡において，一般の照明系では，視野の全領域の照明が困難であるため，画面の一部が暗くなり，観察ができない問題点がある．

本内視鏡システムでは，一本の内視鏡で直視と側視の観察が可能であるため，両方向の照明が可能な特殊照明を用いることにした．光ファイバの一部は直視用照明とし，一部は斜めにカットすることで，側視を照明することが可能となる(Fig.2)．

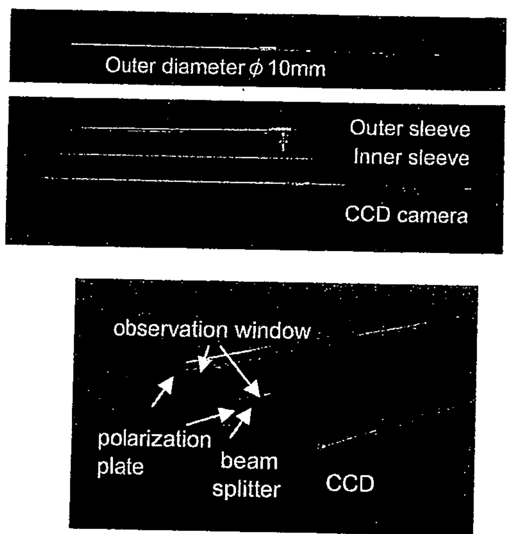


Fig.1 Prototype of FOV- changeable endoscope

Fig.2 Illumination method

3. 評価実験

試作したビームスプリッタ内視鏡を用いて評価実験を行った.

ボックスの中に胎児のモデルを設置し，ビームスプリッタ内視鏡でボックスの中を観察する(Fig.3). 内視鏡の正面には胎児の口と鼻，側面には胎児の手が位置するように設置した. また，照明系の有用性を検証するために，ボックスの中を暗くした状態で実験を行う. 内視鏡の先端部から観察領域までの距離は 30mm~50mm である.

内視鏡を固定した状態で，外側スリーブを回転しながら撮像を行った.

4. 結果

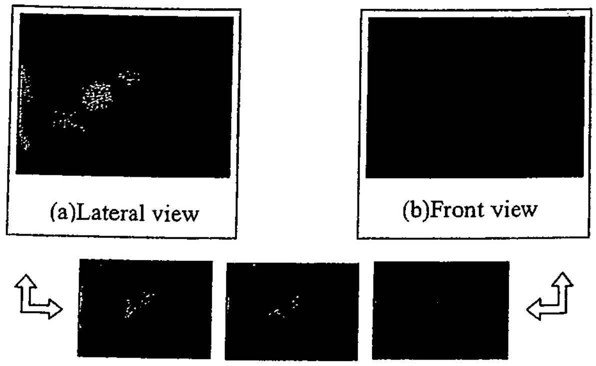
Fig.4 に評価実験の結果を示す.

まず，Fig.4 (a)の状態で，偏光板の働きにより正面は見えなくなり，観察窓を通して側面を観察することが可能である. この状態で外側スリーブを回転させると，Fig.4 (c)のように徐々に直視に切り替えられ，外側スリーブを 90deg 回転させると，観察窓は閉じ，偏光板は同一向きになるため，Fig.4 (b)のように正面の観察が可能となる. 以上のように，外側スリーブの回転のみで視野の変更が可能であることが分かる.

直視では胎児の口と鼻が，側視では胎児の手が明確に観察できる. 直視，側視の両方とも高画質で，鮮明に観察することが可能である.

さらに，照明に関しても，直視と側視の両方とも十分に明るい画像が得られた.

Fig.3 A fetal model in the dark box



(a)Lateral view

(b)Front view

(c) Rotating outer sleeve

Fig.4 Fetal model images

5. 考察とまとめ

本研究では，内視鏡本体の移動を伴わずに直視と側視の視野変更が可能なシンプルな内視鏡システムを提案した. これは，狭い体内空間で内視鏡先端部を屈曲させることなく，視野の変更が可能であるため，体内臓器や周辺組織に傷をつける危険性がなく，安全性に優れている.

また，直視鏡と側視鏡の両方を必要とする手術の場合，内視鏡を入れ替える手間がかからないため，手術時間の短縮になり，医師の負担を軽減する. さらに，内視鏡を空気に露出する時間が減るため，感染の心配が低下し，衛生性や滅菌性にも優れている.

今回は，腹部外科で最も用いられる外径 ϕ 10mm の試作機を制作した.

試作機を用いての評価実験では，外側スリーブの回転のみで簡単に直視と側視の視野変更が可能であることを確認した. また，CCD カメラを用いることで，非常に高画質の鮮明な画像を獲得し，直視と側視の両方の照明が可能である特殊照明系を用いることで，十分な明るさでの観察が可能であることを確認した.

今後は本ビームスプリッタ視野可変内視鏡を胎児外科，脳外科，整形外科など極細径内視鏡を必要とする分野に臨床応用するために，内視鏡の細径化を行う. さらに，3D 内視鏡を搭載することで，正面と側面の観察が可能な 3D 視野可変内視鏡を開発する.

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07(XV)-80

双胎間輸血症候群の治療における胎盤血管情報提示システムの開発　-内視鏡画像を用いた生体情報の計測-

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Development of Placenta Vasculature Visualization System for Treatment of Twin-To-Twin Transfusion Syndrome (TTTS) - Measurement of Biomedical Signal with Endoscope Image -

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Abstract: Twin-to-Twin Transfusion Syndrome (TTTS) is a disease of the placenta that affects identical twins who share a single placenta. This condition occurs when the shared placenta contains abnormal blood vessels which connect the twins, resulting in an imbalanced flow of one twin to another. For the treatment of TTTS, endoscopic laser photocoagulation is one of useful method, which gives a good survival and a low complication rate to the twins. But narrow view of conventional endoscope made it difficult for surgeons to understanding the entire structure of vasculature on the surface of placenta. For higher rate of procedural success, surgeons need the information of biomedical signals of blood vessels like blood flow or oxygen saturation during the operation. In this paper, we have considered measuring biological signals only from the endoscope's images. First, we tested capturing the pulse from vessel with endoscope's camera. We can detect the pulse from a finger of human with infrared LED and infra-red camera, but it's difficult to detect the pulse from mesentery of rat. Next, we tested discriminating artery and vein with color information of vessel. As a result of discriminant analysis, we can distinguish arteries and veins with around 70% of success ratio.

Key words: Twin-To-Twin Transfusion Syndrome (TTTS), Placenta, camera, blood vessel.

1. 緒言

双胎間輸血症候群(TTTS)は、一卵性双胎で、胎盤を共有した双胎児の血管が吻合し、双子の間で血流の不均衡が生じる疾患である。TTTS の低侵襲な治療法の一つとしてレーザ焼灼療法が注目されている。この方法は、医師が内視鏡で胎盤表面を辿り、目視で吻合血管の同定を行い、レーザで焼灼して不均衡な血流を遮断する。ここで、医師が吻合血管の同定を行うには胎盤上の全体的な血管系を把握する必要があるが、内視鏡の視野は非常に狭いため、把握は困難である。そこで我々は、医師が胎盤血管の全体像を把握するのを支援するために、胎盤表面マッピングシステムを開発してきた[1,2]。このシステムは、3次元超音波画像から構成した3次元形状モデルに内視鏡で撮影した画像をマッピングするもので、これにより、医師の吻合血管同定が容易になる。

(a) Placenta model　(b) Result of image mapping

Fig.1 Result of image mapping system we have developed.

一方で、循環系障害であるTTTSの治療のためには、血流や酸素飽和度などをはじめとする胎盤血管情報も必要とされる。そのため、これらの情報がマッピングシステムと統合されれば、より優れたナビゲーションを行うことができる。現在、血管に関する情報を計測する装置としては血流計やパルスオキシメータなどがあるが、低侵襲な治療を実現するためには新たにセンサを導入するのは望ましくない。本稿では、内視鏡画像のみから胎盤血管の特徴を判断する方法について検討した。特に血管の拍動に由来する脈波、及び、血管の色情報について取り上げる。

2. 血管の拍動に由来する脈波検出に関する基礎的検討

吻合血管の同定に必要な情報の一つに、血管の動静脈の区別が挙げられる。そこで、内視鏡画像中の血管の動静脈の別を脈波の有無から判断するため、近赤外線カメラや 3CCD カメラで撮影した映像を用いて基礎的な検討を行った。

2-1 ヒトの指を用いた予備実験

ヒトの指の血管の脈波をカメラ画像から確認できるか実験した。赤外線LEDを用い、指を透過させた赤外光を赤外線カメラで撮影し、時間方向の輝度値の変化を見

た。これと同時に、心電図(ECG)を計測し、ECG の波形と比較した。Fig.2 に結果の一部を示す。

輝度値が最低値に達する時、つまり血管径が最大値になる時は心電図の QRS 波より平均 0.37s 遅れているが、この遅れは常に一定であった。血液は、心臓から出て末梢の組織まで到達するまで多少時間が掛かり、脈波と ECG の QRS 波との時間差は常にほぼ一定になるはずである。以上から、赤外線カメラで撮った画像から輝度値変化を見ることで、心拍による脈波の情報を得ることができたと言える。

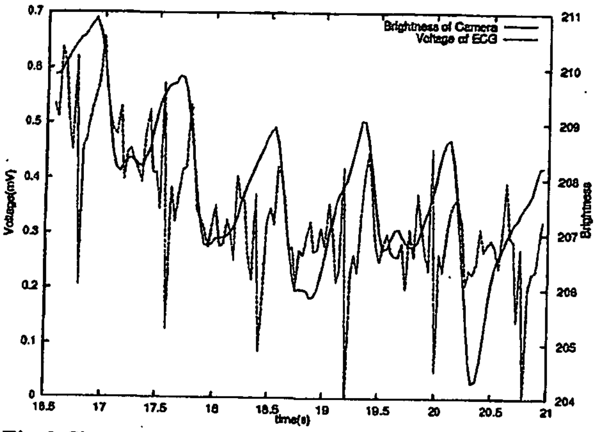

Fig.2 Change in brightness of camera image and ECG.

2-2 動物実験による脈波検出法の評価実験

続いて、ラットの腸間膜血管を用いて脈波の取得を検討した。呼吸による影響を受けないように腸間膜を体外で固定し、また表面での光の反射を防ぐため水中に沈めた。内視鏡用の光源のみを当て、赤外線カメラや 3CCD カラーカメラで血管を撮影し、生存時の血管、及び過剰麻酔で循環を停止させた後の血管の、輝度値の変化を見た。このとき、血流停止時は規則的な輝度値の変化は認められなかったが、生存時の輝度値は周期的な変化が見られ、1 秒当たり約 1.63 パルスであった。ここで、ラットの心拍数は 5 日齢頃までは 300~400 回/分程度で、この変化(98 回/分)と比べて大きな差がある。ラットの呼吸数は 70~115 回/分程度であるから、当該輝度値変化は、呼吸による血管の振動の可能性が大きいと考えられる。

以上から、本手法は呼吸などの影響を大きく受けるため、術中にカメラの輝度値変化で脈波を検知するためには、計測方法等の更なる検討の余地がある。

3. 内視鏡画像の色情報を利用した動静脈の判別に関する基礎的検討

更に、内視鏡画像中の血管の色に注目し、色情報から動静脈を判別する手法を検討した。実際の手術での内視鏡画像を録画した映像から、50 枚の画像を切り出し、写っている血管の、医師による動静脈の判断を記録した。動脈 78 箇所、静脈 43 箇所、総 121 箇所から RGB 情報のサンプルを取った。そして判別分析によって動静脈の判断可否を検討したところ、78%程度の弁別率を得た。

この映像から得られた判別関数による動静脈の特徴が、他の映像でも共通して観察されるかを確認するため、別の症例内視鏡映像から 33 枚の画像を切り出し、動脈 41 箇所、静脈 26 箇所から RGB 情報のサンプルを取り、前者の判別関数で後者のデータを解析した。その結果、他の症例の画像での正判別率は約 70%となった。(Fig.3)

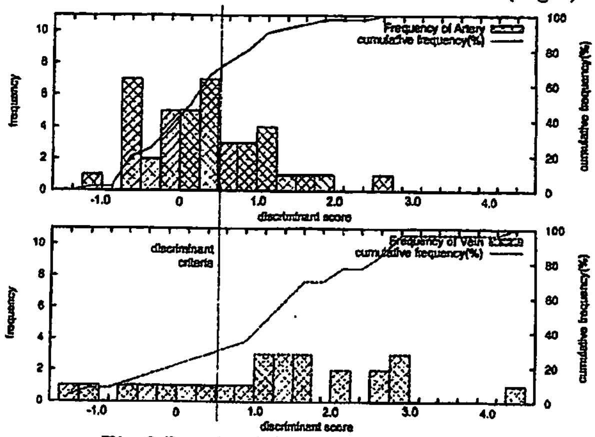

Fig.3 Result of discriminant analysis

以上から、映像の色情報を利用した動静脈の判別はある程度は可能であると思われる。

4. まとめ

内視鏡画像からの動静脈の判別法として、拍動による血管画像の輝度値の変動を計測する方法と、血管の色画像を解析する方法を検討した。ヒト指を対象とする予備実験では拍動を検出できたが、ラット腸間膜を対象として実験では呼吸動その他の影響が大きく拍動を検出することができなかった。また色画像解析による判別法では 70%程度の正答率での判別が可能であった。よって、これらの手法を用いた動静脈の判別はある程度可能ではあると思われるものの、手術支援に利用するためには、計測方法の検討や判別率の向上など、更なる手法の改善が望まれる。

謝辞

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