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Design and Finite Element Analysis of Anastomosis System for Digestive Tract Surgery*

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***Abstract* – Aiming at the problem of small space in digestive tract surgery, the design scheme of digestive tract operation anastomosis system is put forward, which is composed of four modules: the continuous body mechanism, the terminal actuator, the two-arm grab clamp and the endoscope anchor, which can realize the crawl, shear and suture action of lesion tissue. Using the universal drive bending mechanism as the driving and compensation scheme of the continuous body mechanism, the continuous body mechanism has 38 degrees of freedom, and the actuator movement is carried out by the line driven control end, so that it can complete the difficult operation in a narrow space. In order to eliminate the surgical tremor, based on ANSYS Workbench software, the finite element model of the continuous body mechanism is established, the natural frequency and maximum deformation number of the first ten-order modes are obtained, and the natural frequency range of the whole machine is obtained, thus avoiding the resonance occurrence, which provides a reliable guarantee for the safe implementation of the operation and the subsequent animal experiments.**

Index Terms – digestive tract; anastomosis system; continuous body mechanism; structural stability; drive compensation; the finite element

I. INTRODUCTION

In the study of the program of digestive tract surgery matching system, there have been many studies at home and abroad. Japan's Olympus early launch of the Eagle Claw endoscopic suture system, is a typical needle suture system, it was first used in endoscopic peptic ulcer suture hemostatic treatment, later improved by the Apollo research team and applied to the CLOSED treatment of NOTES fistula. Eagle Claw endoscopic suture systems are bound to the mirror body and are delivered to the digestive tract with the endoscope (protection by the jacket tube) and can be performed under the direct look of the endoscope for full-layer stitching of the walls of the digestive tract, as shown in Figure 1. Animal experiments show that Eagle Claw has a good effect on the closure of the digestive tract fistula[1].

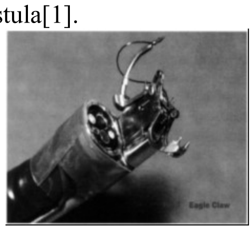

Figure.1 Eagle Claw Stitch System

In 2008, Germany introduced an endoscope metal clip (over-the-scope clip, OTSC) system, as shown in Figure 2. The OTSC is installed in the release casing at the front of the endoscope, first by special grasping pliers or negative pressure to attract the lesions and surrounding tissue pulled into/ inhalation sleeve, and then use the supporting rotary trigger system by wire pull to release OTSC, OTSC out of the cap quickly restore the original fit, the tissue bite together, It acts as a hemorrhage stop and closes the perforation. Compared to ordinary metal clips, OTSC has a 12mm wingspan, which is designed to allow it to bite more tissue, effectively close perforations within 3cm in diameter, and close the entire layer of the digestive tract wall. The new device has been proven to be effective, safe and easy-to-operate in cavity organs by animal experiments and numerous clinical trials[2].

Figure.2 OTSC System

Apollo Endosurgery of the United States developed a suture device called OverStitch^{TM} in 2012, as shown in Figure 3 (a) and (b). The device completes the stitching steps as follows, pre-mounting the OverStitch^{TM} control handle on the double clamp endoscope, feeding the needle cap system and the fixed switching arm into the patient's digestive tract until near the defect site, and holding the needle cap on the bent needle holder near the far edge of the tissue and passing through, while clamping the needle cap with a fixed exchange arm. Separate the needle cap from the holder, bend the needle holder to the fixed exchange arm, re-fit the needle cap, repeat the above step at the edge of the tissue near the side, press the blue button on the control handle, release the needle cap in the fixed exchange arm, replace the fixed device through the double clamp endoscope close to the face, close the tension seam, so that the edge is attached, Release the retainer to complete a stitch. Repeat the above steps as appropriate until the face is completely closed. A large number of tests have shown that it is safe and effective to use OverStitch^{TM} suture equipment to close large gastric incisions[3].

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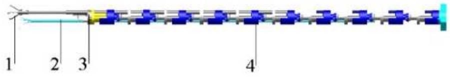
Figure (a) Apollo hinged stitching arm Figure (b) operator handle and movable needle

Figure.3 Overstitch^{TM}

Compared with the traditional surgery, the development of endoscopic digestive tract surgery has improved the treatment of various diseases such as perforation and anastomotic fistula in the esophagus, stomach and intestine, and the closure ESD surgical wound, and reduced the recurrence rate of the disease. However, these complex operations make surgery particularly difficult. In addition, due to the small space of digestive tract surgery and the accurate removal of the lesion is extremely difficult and other factors, the safety and precision of the operation will have a greater impact, so the digestive tract surgical anastomosis system research, has important academic significance and medical application value[4-6]. This paper focuses on the design of the fit system of gastrointestinal surgery and the stability of its continuum mechanism.

II. Design Of Anastomosis System For Digestive Tract Surgery

In order to solve the instability factors in digestive tract surgery because of the small space and difficult equipment operation[7-10], this paper proposes to divide the anastomosis system into four basic modules, namely, the continuous body mechanism, the end actuator, the two-arm gripper clamp and the endoscopic anchor four basic modules. The continuous body has 38 degrees of freedom, and its maximum working dimeter and working length are 10mm and 250mm, respectively. The main body of the continuous body mechanism consists of nine groups of the universal drive bending mechanism, each of which is connected by a spherical pair and has a total length of 240mm, which is capable of exercising 34 degrees of freedom in complex spaces. It can realize the function of perceiving the contact pressure of the inner wall of the digestive tract in different directions. The end actuator consists of a main manipulator and a suture needle, which has a working length of 10mm, and a number of basic operating functions such as resection, peeling, cutting and stitching can be completed with two-arm gripper and endoscopic anchors. The three-dimensional structure model of digestive tract surgical anastomosis system is shown in figure 4.

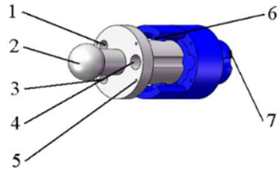


1-the two-arm grab clamp; 2-endoscopic anchor; 3-end actuator 4- the continuous body mechanism

Fig.4 Three-dimensional structure model of digestive tract surgical anastomosis system.

A. *The continuous body mechanism design*

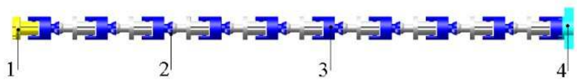
Because the internal space of the human digestive tract is small, in order not to damage other organ walls during the operation, the universal drive bending mechanism is used as the driving compensation scheme of the continuous body mechanism. The universal drive bending mechanism of the continuous mechanism adopts the principle of universal joint, which can realize 4 degrees of freedom to bend an pitch in complex space. The three-dimensional structure of the universal drive bending mechanism is shown in figure 5.



1-lighting channel; 2,7-spherical pair; 3-camera system channel; 4-surgical instrument channel; 5-nickel titanium alloy wire channel; 6-rotating axis

Fig.5 Continuous body mechanism 3D model diagram.

The cross section of the nine-group universal drive bending mechanism is mainly composed of pressure sensor and ball face joint. The ball face joint has 2 degrees of freedom of pitch and rotation, and the use of wire drive limits its freedom to rotate around the X-axis. The nine-group universal drive bending mechanism is composed of 18 joints, which constitute nine ball faces of the continuous body mechanism, and its bending part has 36 degrees of freedom. The 18 joints are connected in turn and fixed on the support base, forming the main body of the continuous body mechanism, and the three-dimensional structure model of the continuum mechanism is shown in figure 6.

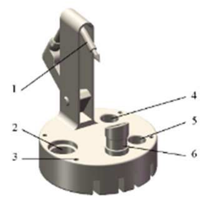


1-end actuator support disk; 2-universal drive connection; 3-universal drive bending mechanism; 4-continuous body mechanism support base

Fig.6 Three-dimensional structure model of continuous body mechanism.

B. *End actuator design*

After the completion of the traditional digestive tract surgery, it is necessary to remove the endoscope to reinstall the surgical instruments and then enter the digestive tract to stitch the wound, which requires the doctor's ability to operate extremely high, and easy to cause harm to the patient again. Therefore, the design of the end actuator should be simple, lightweight and precise, the advantage of which is to complete cutting, stitching, clamping, injection and other actions.The three-dimensional structure model of the end actuator is shown in figure 7.



1-suture needle; 2-surgical instrument channel; 3-nikel titanium alloy filament; 4-camera system channel; 5-lighting channel; 6-anastomosis channel

Fig.7 Three-dimensional structure model of end actuator.

C. *Design of two-arm grab clamp*

Surgical auxiliary equipment two-arm grab clamp is used for the crawl of tissue in soft endoscopic surgery, which requires the minimum of 3.2mm in endoscopic working cavity. The two-arm grip clamp consists of two separate active arms, a fixed central rod, a soft shaft, two separate sliding handles and a handle of a total of five parts. The two-arm clamp is introduced into the working cavity tube through the surgical instrument channel of the continuous body mechanism. Its innovative function is: placed on the tissue to undergo surgery, respectively, push the handle on both sides, the tissue can be firmly clamped by the control arm, at this time using the end actuator's suture needle from the matching channel to extract nylon thread can be completely stitched the lesion syllorify tissue, so as to achieve surgical results. The three-dimensional structure model of the two-grab clamp is shown in Figure 8.

1-two active arms that can be separated; 2-fixed central rod; 3-soft shaft;4-two separate sliding handle; 5-handle
Fig.8 Three-dimensional structure model of two-arm grab clamp

D. *Design of endoscopic anchor*

The endoscope anchor of the suture system used to organize auxiliary applications has a soft endoscope working cavity with a minimum diameter of 2.8mm. The endoscope anchor consists of a total of five parts: anchor, spiral groove tube, 165cm long soft rod, locking button with separate trigger and locking equipment, and safety handle. Its innovative function is: endoscope anchor through the digestive tract surgical fit system of the continuum of the surgical instrument channel introduced to the work channel placed at the grasping tissue, press the lock button and push upward, the endoscope anchor into the tissue, while the fit channel release nylon line with the end of the continuous mechanism of the suture needle to match the lesions tissue, In order to achieve the effect of surgical stitching. The three-dimensional structure model of the endoscope anchor is shown in figure 9.

1-anchor; 2-spiral groove tube; 3-soft rod; 4-lock button; 5-safety handle
Fig.9 Three-dimensional structure model of endoscopic anchor.

III. FINITE ELEMENT ANALYSIS OF CONTINUOUS BODY MECHANISM OF DIGESTIVE TRACT SURGERY ANASTOMOSIS SYSTEM

Modal analysis is a modern analytical method to study the dynamic characteristics of structure, and it is the application of system identification method in the field of engineering vibration. Modality is the inherent vibration characteristic of mechanical structure, and the modal parameters include natural frequency, damping and vibration type, which are used to reflect the modal characteristics. Modal analysis is the most basic and critical part of all dynamic selius analysis, and vibration properties play a decisive role in the response of structural dynamic loads, so the first thing to do before studying other dynamic seliusis is to analyze them.

In order to ensure that the digestive tract matching system can work safely, the finite element analysis of the continuous mechanism in the digestive tract matching system is carried out. The three-dimensional model of the continuum mechanism established in Solidworks was imported into the ANSYS Workbench software, and the default material was selected, with a material property density of 7850kg/m^3, an elastic module of 2x10^{5}MPa and a Poisson ratio of 0.3. The use of automatic meshing, that is, the use of tetrahedron units, the total number of nodes 85384, the total number of cells 46417, control its global grid size of 2mm, the continuous mechanism finite element grid division model is shown in Figure 7. The fixed point is fixed on the base disc with the displacement of the two cross-intersectionshafts, according to the set boundary conditions, the binding modal analysis of the omnidirectional drive bending mechanism of the continuous body is applied by the ANSYS Workbench software, and the fixed point is fixed on the base disc with the displacement of the two cross-intersections, according to the set boundary conditions The application of ANSYS Workbench software to the continuous mechanism of the omnidirectional drive bending mechanism for the binding modal analysis, in the modal analysis, generally will not calculate the entire natural frequency and vibration type, but consider the system work the greatest impact, will cause the system resonance probability of a relatively large frequency. In this paper, in the calculation of the natural frequency of the first ten-order modal mode, the results of the first ten-order modal normal frequency calculation and the corresponding vibration type are extracted, as shown in Figure 11.

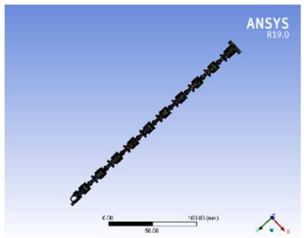


Fig.10 Finite element mesh model of continuous body mechanism.

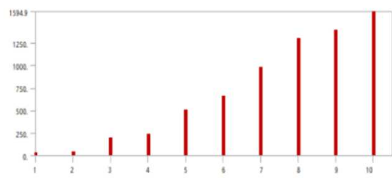


Fig.11 The first ten-order modal frequency graph of the continuous body mechanism.

The natural frequency and maximum deformation of the first 10 order of the continuous mechanism of digestive tract surgery are consistent with the system as shown in table 1.

Table I
THE NATURAL FREQUENCY AND MAXIMUM DEFORMATION OF THE FIRST 10 ORDER

Order number	Frequency /Hz	Maximum deformation
1	35.92	239.42
2	42.17	247.94

3	190.55	259.15
4	240.32	266.08
5	506.62	274.56
6	662.95	280.92
7	976.17	291.57
8	1296.4	298.2
9	1391.6	265.81
10	1594.6	303.58

The first ten order modes of the continuous mechanism constraint mode of the digestive tract surgery anastomosis system are shown in figure 12 to figure 21.

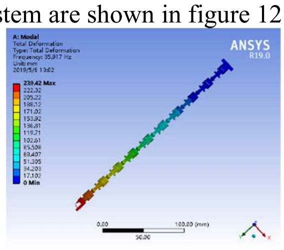


Fig.12 First mode shape.

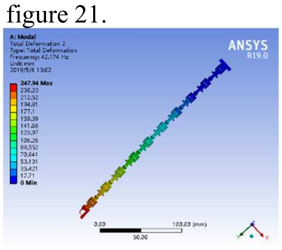


Fig.13 Second-order vibration mode.

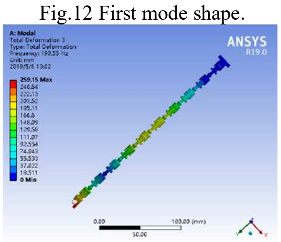


Fig.14 Three-order vibration mode.

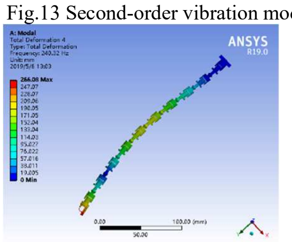


Fig.15 Fourth-order formation.

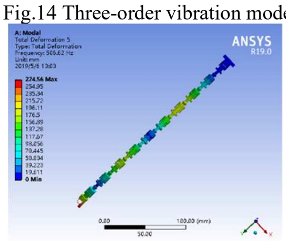


Fig.16 Fifth-order formation.

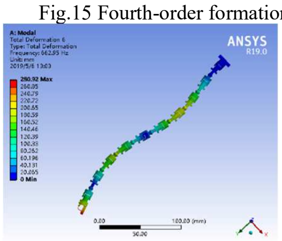


Fig.17 Six-order formation.

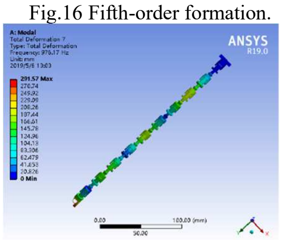


Fig.18 Seven-order formation.

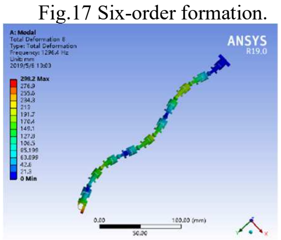


Fig.19 Eight-order formation.

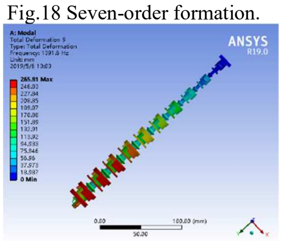


Fig.20 Nine-order formation.

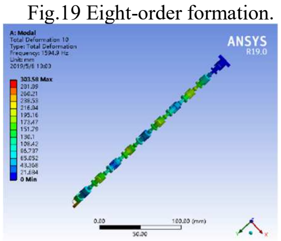


Fig.21 Ten-order formation.

In summary, according to figure 11 to figure 20, digestive tract surgery anastomosis system the continuous body mechanism in the first 10-order modal mode, the natural frequency is the lowest 35.93Hz, the highest is 1594.6Hz. According to table I, the maximum deformation of the first order is the smallest, the maximum deformation is 239.42mm, the front end of the continuous body of the digestive tract operation anastomosis system vibrates left and right along the Z-axis direction, the maximum deformation of the tenth order is the largest, the maximum deformation is 303.58mm, and the continuous body mechanism of the digestive tract operation anastomosis system bends and vibrates in the direction of the Z-axis. Through the above analysis, it provides a theoretical basis for the design of the continuum mechanism of the digestive tract surgical system, which can effectively avoid the occurrence of resonance phenomena and tremors in the actual design, and ensure the stability of the working of the digestive tract conformity system and the reliability of subsequent animal experiments.

IV. Conclusion

*1)*Aiming at the problem of fibrillation caused by small space in digestive tract surgery, this paper puts forward a design scheme which divides the digestive tract operation anastomosis system into four modules, including the continuous body mechanism, the end actuator, the two-arm gripper clamp and the endoscope anchor four modules. And the three-dimensional structure model is established by using solidworks software. The continuous body mechanism can enter the digestive tract from the human mouth to accurately reach the lesion position and observe the situation, the end actuator with the two-arms grab clamp and endoscopic anchor can complete the digestive tract surgery cutting, clamping, stitching and injection and other surgical actions, so that the lesion wound is safe and effective treatment.

*2)*Based on ANSYS Workbench software, the finite element model of continuous mechanism of digestive tract surgical anastomosis system is established, and the natural frequency and maximum deformation number of the first ten-order modes of the continuous mechanism of the digestive tract operation anastomosis system are obtained through modal analysis, and the range of the natural frequency of the whole machine is determined to be 35.93Hz~1594.6Hz, the maximum number of deformation is 303.58mm,the minimum is 239.42mm, thus avoiding resonance occurrence, for the development of physical prototypes and animal experiments to provide a safety guarantee.

Acknowledgment

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