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Biomechanical behavior study of dog's small intestines*

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Abstract：The biomechanical behavior of dog's duodenum and jejunum were studied and a formulation of the stress-strain relation is presented in this paper. The results obtained indicated that the exponential coefficient α and the incremental duodenum of the elastic modulus are both larger than those of the jejunum. It means that the duodenum is more deformable than the jejunum. The experimental results of this work provide basal data for kinematics study of a robotic endoscope.

Keywords：Biomechanics，Intestines，Biomechanical model
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INTRODUCTION

An international hot topic now for study are the noninvasive medical microrobots. And many devices had been designed as robotic endoscope to enter the human body (Hayashi et al.，1998). These devices have two disadvantages. One is that the devices are introduced into the body by forces applied at their proximal ends and located outside the patient's body. The other is that in the process of moving into the endocoeles，the direct contact between the robotic endoscopes and endocoeles damages the lumen wall and causes much pain (Zhou et al.，2000). So it is necessary to look for a new noninvasive method to drive the robotic endoscope. Zhou et al. (2001) designed a new medical microrobot for minimally invasive surgery. It was found that the robots' kinematic characteristics were relative to the biomechanical behavior of the intestines. The running of the medical microrobot will cause distortion and shrinking of the intestine. Then the resistance of the intestinal juice will be changed. In order to research the kinematic characteristics of the robot，it is very necessary to study the biomechanical behavior of the intestine. But the researchers cannot study the human intestines directly. So all that can be done is to analyze data on the biomechanical behavior of other mammal's intestines，and by analogy，to infer whether the results are applicable to human intestines.

Some researches indicated that the intestines are made up of smooth muscles like those of the walls of other internal organs of various life forms. These muscle tissues contract without conscious control. The structures，functions and biomechanical behaviors of the smooth muscles are very different in different organs. That is to say we cannot infer that data on the intestines wall by analyzing the data on wall of other organs. And to study the smooth muscles of different organs，we have to research them individually. What is more，formerly there was no easy method for doing experiments on the smooth muscles.

For these reasons，only few people conducted research on the smooth muscles in the past years. Price et al. (Fung，1983) studied the mechanical behavior of the smooth muscle of the urethra and taenia colon of the guinea pig. Storkholm et al. (1998) and Gregersen et al. (1997) studied the passive elastic wall properties in isolated guinea pig and the mechanical behavior of guinea pig small intestine. Hoeg et al. (2000) researched the biomechanical modeling of the small intestine for the robotic endoscope which braces

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parts of its body against the intestinal walls. They found that compared to dead tissue, live tissue responded differently to applied stresses. They used live and dead tissue studies to provide a reasonably useful way to infer live human tissue response from studies of cadaver tissue, but did not give the formulation of the stress-strain relation. And because our device has no adjoining contact with the intestinal walls, their model is not suitable for our system.

Because the intestines of some mammals such as dogs and pigs closely resembles those of humans in the length, inner diameter, structure and biomechanical behavior, we carried out our research with the dog's intestine. The results of this experimental study on dog and pig intestines will provide basal data for study of biomechanical behavior of the human intestine and then extend to kinematics study of medical microrobot. In addition, this research will hopefully provide a common and efficient method for study of the smooth muscles of mammals.

MATERIAL AND METHOD

The schematic of a tester is shown in Fig. 1. The dissected dog, a mongrel from Sichuan Province of China, weighed 13 ± 3 kg. As soon as the dog was dissected, the duodenum and the near end of jejunum were cut to 100 mm long, and cleaned with physiological saline. Then the same experiment was carried out on both of them. The jejunum was immersed in physiological saline when the duodenum was being dealt with.

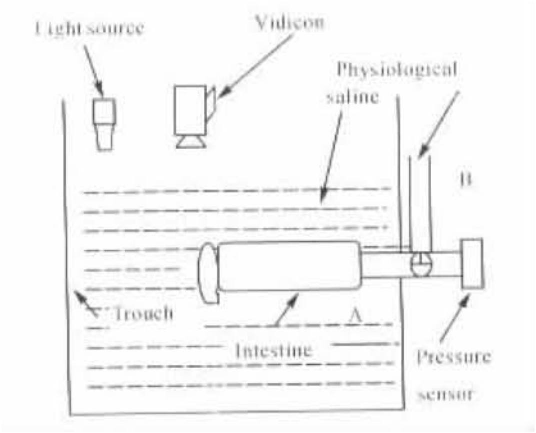

Fig. 1 The schematic of a tester

First, both ends of the duodenum were cut away perpendicularly to the duodenum axis and then the duodenum horizontal section and the two rings were laid parallel to bottom of a flat bottom through filled with the physiological saline. After the two rings were marked, the section of them was shot with a vidicon (image shown in Fig. 2). Second, after one end of the remnant intestine was sutured up, the other end was put into port A shown in Fig. 1, and then tied them up with the suture. Thirdly, after the other end of the intestine was also sutured up, and then the intestine was immersed entirely in the physiological saline. The physiological saline was injected into port B gradually (see Fig. 1). When the reading of the pressure sensor reached 0, 5, 15, 20, 30, 40, 50, 60 mm water column pressure, the vidicon was used to record the status of the intestine distortion. After dealing with the duodenum, the same experimental procedure was done on the jejunum. The two experimental procedures should be finished in two hours.

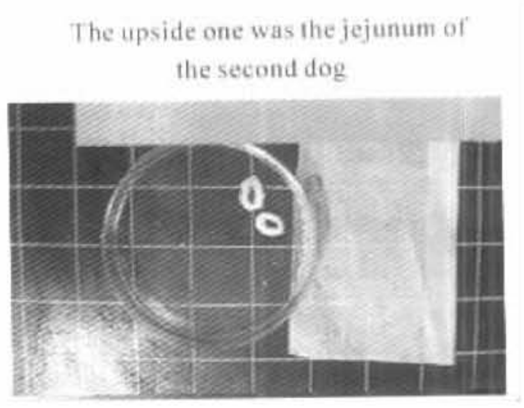

Fig. 2 The image of ring section

In order to enhance the accuracy of the study, six dogs were sampled in the study. All the experiment were completed in the biological engineering laboratory of Chongqing University.

RESULTS AND ANALYSIS

The recorded digital picture of the video camera was processed with the software image tool to yield data on the diameter of the intestines

D_i and the axial length L_i under different pressures P_i. All the parameters are shown in Fig. 3.

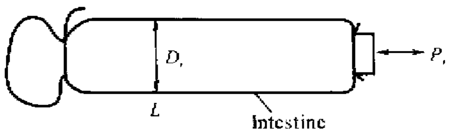

Fig. 3 Intestine parameters

When the pressure reached to 0 mm water column pressure, the axial length of the intestines was denoted as L_0 and the diameter of the intestines as D_0. The above parameters were regarded as those of the original state. The ratio of axial and radial elongation are denoted as λ_i^L and λ_i^C. Then the ratio of the radial elongation can be written as

$$\lambda_i^C = \frac{D_i}{D_0}. \tag{1}$$

And the ratio of axial elongation can be written as

$$\lambda_i^L = \frac{L_i}{L_0}. \tag{2}$$

The Green strain E is defined as

$$E = \frac{1}{2}((\lambda_i^C)^2 - 1) \tag{3}$$

Denote the unpressurized and pressurized cross-sectional area of the section as A_0 and A_i. On assumption that the material of the intestines is incompressible material, the equation for the length and cross-sectional area of the intestine is

$$A_0 L_0 = A_i L_i \tag{4}$$

There upon, A_i can be obtained from Eq. (5).

$$A_i = \frac{L_0}{L_i} A_0 = \frac{A_0}{\lambda_i^L} \tag{5}$$

If the inner diameter at different pressures is d_i, then A_i can be expressed by Eq. (6).

$$A_i = \frac{\pi}{4}(D_i^2 - d_i^2) \tag{6}$$

And the inner diameter can be defined as

$$d_i = \sqrt{\left(D_i^2 - \frac{4A_0}{\pi\lambda_i^L}\right)} \tag{7}$$

Denote the thickness of intestines as h_i, then h_i can be written as

$$h_i = \frac{1}{2}(D_i - d_i) \tag{8}$$

Cauchy stress (denoted as S_i) can be defined as

$$S_i = \frac{P_i d_i}{2h_i} \tag{9}$$

$$S = \alpha E C \exp[\alpha(E^2 - E^{''2})] \tag{10}$$

According to the Eq. (10) on the stress-strain relation that was assumed by Fung (1983), the experimental result can be made to fit a curve (Fig. 4) with the method of least squares of Newton-Gauss. The obtained exponential coefficient α and the biomechanics coefficient C of the duodenum and the jejunum are given in Table 1.

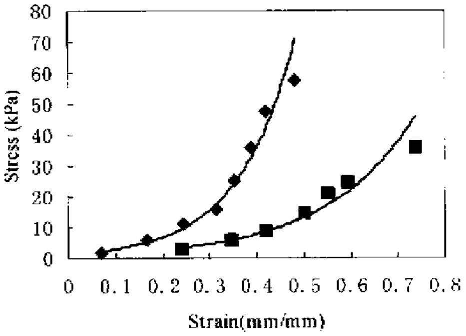

Fig. 4 Schematic of the stress-strain relation

◆duodenum ■jejunum

Table 1 The material constants of the intestines

	Sample number	C (Pa)	α
Duodenum	6	8006	5
Jejunum	6	10321	2

In Fig. 4, the sign ◆ means the testing data point of the duodenum and the sign ■ means the testing data point of the jejunum. And the real line is the curve fitting the Eq. (10). The experimental results were found to fit the equation very well.

The results obtained indicated that the exponential coefficient α and the incremental elastic modulus of the duodenum are larger than those of the jejunum. It means that the duodenum is more deformable than the jejunum. The variation trend of the mongrel dog's curve accorded with that of the guinea pig's. It was found that the span of the stress of the intestines of the guinea-pig (which was about 0 – 25 kPa) was congruous to that of the mongrel dog (which was about 0 – 60 kPa). The magnitude of the maximal stress of the dog and pig's intestines were the same.

CONCLUSIONS

1. The formulation of the stress-strain relation accorded well with Eq. (10)

2. The exponential coefficient α of the duodenum was larger than that of the jejunum. At the same time the biomechanics coefficient C of the duodenum was smaller than that of the jejunum.

3. Under a certain stress, the incremental elastic modulus of the duodenum was larger than that of the jejunum. It means that the duodenum is more deformable than the jejunum.

4. Compared to reported results (Storkholm et al., 1998), the incremental elastic modulus of the duodenum of the guinea pig was larger than that of the jejunum under a certain pressure . The conclusion was similar to those of the dog. And the span of the stress of the intestines of the guinea-pig (which was about 0 – 25kPa) was congruous to that of the mongrel dog (which was about 0—60kPa). The magnitude of the maximal stress of the dog and pig intestines was the same.

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