pump (N) from 1600rpm to 2000rpm per 100rpm, or clamped the outlet of the pump to measure PV-loops during no assistance with the RBP.

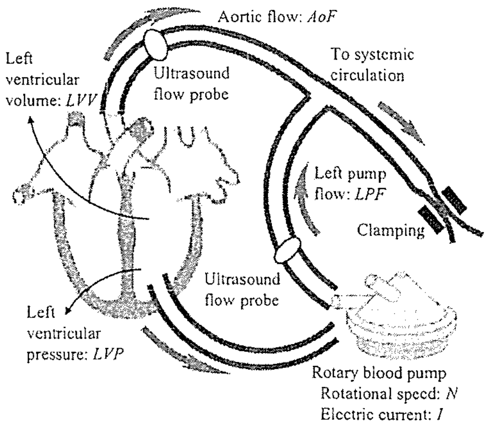
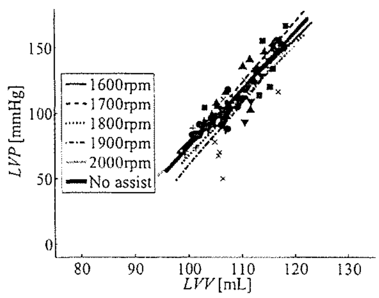


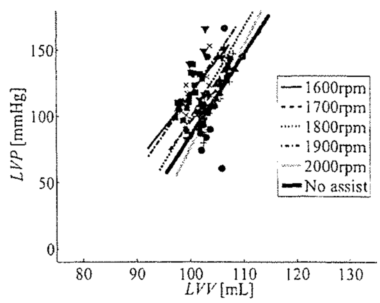
Fig.2. Experimental setup

3. Results

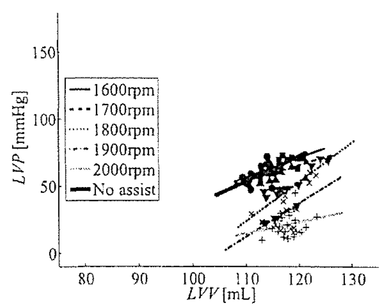
Figs. 4 (a) to (c) show the ES points and ESPVR while cardiac function was normal, augmented and diminished, respectively. Table 1 shows a summary of values of E_{max} in each condition and experiment.



(a) Normal cardiac function



(b) Positive inotropic intervention



(c) Negative inotropic intervention.
Fig.2. ES points and ESPVRs in each cardiac function.

Table 1 Statistical comparison of E_{max}

Exp. No., condition	With assist (mean ± S.D.)	No assist
Exp.1(a) NCF	3.51 ± 0.96	4.24
Exp.1(b) PII	5.40 ± 0.37	4.75
Exp.1(c) NII	2.88 ± 0.51	2.90
Exp.2(a) NCF	4.28 ± 0.40	4.36
Exp.2(b) PII	6.16 ± 1.09	6.14
Exp.2(c) NII	1.79 ± 0.89	1.87
Exp.3(a) NCF	3.65 ± 0.51	3.73
Exp.3(a') NCF*	3.99 ± 0.37	4.56
Exp.3(b') PII*	5.26 ± 0.33	5.85
Exp.3(c') NII*	2.27 ± 0.39	1.19

* In exp. 3, acidosis due to a ventricular fibrillation that occurred after the data acquisition for (a) NCF.

4 Discussion

The experimental results showed that the value of E_{max} increased when the cardiac function was augmented, and vice versa, even if the bypass with the RBP existed, as seen in the cases without the RBP. In addition, the mean value of E_{max} during assistance was basically close to that during no assistance, and the deviation of E_{max} during assistance was not so large. This fact implies that the effect of the bypassing action with the RBP on the value of E_{max} is small.

5 Conclusion

Our experiments have suggested that E_{max} could be used as an index to evaluate cardiac function of the heart assisted by the RBP. Our next goal is to develop a method to estimate E_{max} with non-invasive sensors.

Acknowledgements

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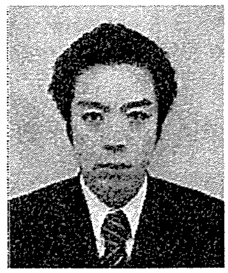
Peristaltic Linear Actuator for an Assistance of Diseased Digestive Organs



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Abstract

We have studied about an artificial peristaltic linear actuator using helicoidal shape memory alloy (SMA). A shape memory alloy (SMA) was used to make the peristaltic contraction for the elastic artificial digestive pipe. We use a special SMA, Bio Metal Helix 150(BMX150). BMX150 has some high potential characteristics which could demonstrate as an artificial muscle. At this paper we studied the contraction variation under the X-ray observation, and the inner pressure variation measurement test filled with saline.

The peristaltic actuator using BMX had shown good performances as a peristaltic device in vitro. The maximum contraction ratio of silicone pipe was around 75% and the maximum inner pressure was increased for 50 mmHg. These results showed the possibility of this actuator as an assist device for peristaltic motions failure of digestive organs

1. Introduction

About a half of patients have been diseased digestive cancer in Japan. A surgical excision is the most popular and reliable treatment for digestive carcinoma, because of excluding from the risk of metastatic carcinoma to regiones cervicales or pectorals. However, it would cause a rack of spontaneous peristaltic motion. To solve that problem, we have developed an artificial digestive device which could make the artificial peristaltic motion to assist the transportation of liquid bolus inside the digestive pipe[1]. Basic properties of this actuator are mechanical peristaltic motion with helicoidal SMA and elastic artificial digestive pipe made by silicone rubber. But this design was not evaluated in a dynamical point of view. So we studied this prototypic actuator about the contraction variation of cross sectional area, the variation of inner pressure, and the pump performance of peristaltic movement.

2. Materials and Methods

Specially designed and manufactured shape memory alloy(SMA), BioMetalHelix(BMX; Toki Corporation, Tokyo, Japan) was used as an artificial muscle. On this study, we selected and used BMX150 which was composed and made helicoidal coil by 150□m of wired SMA. The BMX produces a remarkable long stroke, 100%-200% of the length that contracted.

The artificial digestive pipe was substituted by silicone pipe by reason of its flexibility and biocompatibility. At this study, silicone pipe (OD20mm, ID19 mm) was used and wrapped round the half of pipe with half-piped poly-ethylene terephthalate(PET, t=0.5) body case. PET free side of combined silicone pipe was round with BMX150 per half winding and fixed with terminal on two point of PET symmetry. Two point of terminal was set apart an electrode. This half-piped SMAs were prepared for six segments of contraction parts. The artificial peristaltic motion was made by six SMAs and sequential power input, axially. The radial systolic force and sequential time-delayed control made a physiological peristaltic motion.

To study the contraction variation of this actuator, in vitro peristaltic motion was observed under 2 dimensional radiography. The test was conducted on cardiac catheter room of clinical installation with an assist of technical radiologist. The test condition was, a) observation was only one direction from the way that place the edge of half-piped PET as a median line, to a cast shadow on the half side was shown SMA behaviour on the other half immovable PET. b) SMA was heated at a current of 400 mA per segment, and 0.6 s intervals of switching on, sequentially. c) the room temperature was set at 25 degree of Celcius. d) the contraction of actuator was observed and recorded with DV format(30 frame/s), and the variations on edge of SMA were analyzed on each SMA segments and frames.

We also measured a static inner pressure variation of this actuator which is the important parameter on evaluation in the dynamical point of view. A low compliance flexible tube(poly-urethane) was inserted into the silicone pipe, and a pressure transducer was also inserted inner side of the flexible tube with clamped on the one edge. The inner side of flexible tube was filled with saline, after that degassed to measure the systolic pressure precisely. The actuator was driven at several current setting, and the contraction interval of each SMA segments was set on 0.6 s. A test interval was set on 10 s to exclude the residual heat of the last test. The trend data of inner pressure change was amplified and recorded.

The most interesting point of view is, whether the peristalsis actuator could transport a liquid bolus as a typical motility of the digestive organs. To evaluate this factor, the transportation of liquid bolus was conducted using a nutrition supplement jerry. The inside of silicone pipe was filled with 20 mL of the jerry. The test was evaluated for 3 times of peristaltic motion and after that, the transported volume was measured.

3. Results

From 2D radiography observation, the contraction ratio of actuator was almost changed between 80% to 100%, and the maximum contraction was 73%. Typical results of one trial is shown in Fig.1. These appearances showed on all tests.

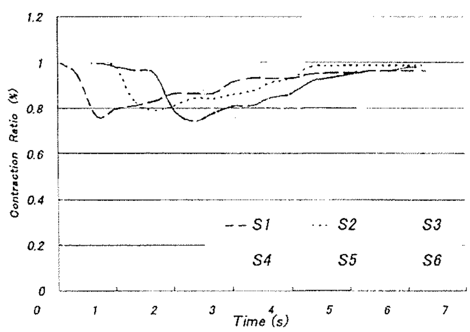

Fig. 1 Results of cross sectional variation on contraction

The inner pressure variation tests were conducted in several current conditions to observe typical results of this actuator. Fig.2 shows the results of maximum pressure at 500 mA of SMA heating. An arrow shows the systolic timing of SMA. The inner pressure was gradually increased with the sequence and time-delay contractions of silicone pipe. It derives the prevention of reflux from the start of artificial peristalsis to 3rd contraction.

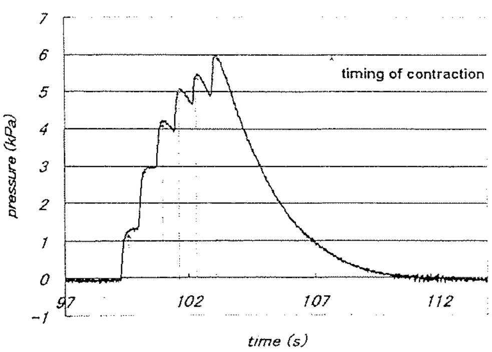

Fig. 2 Results of static inner pressure measurements

The food delivery tests conducted 10 times, and the delivered and residual jerry was measured. The mean amount of delivered jerry was 13.2 ±2.1 mL (n=10). As far as the DV camera recording, no dynamic reflux was shown in all of tests. And the residuals were mainly remained through the whole area of the base on the PET side.

4. Discussion

The results of 2D radiography meant an insufficient contraction of the silicone pipe, compared to our design concept that estimate at a 50% of contraction ratio. Such results were caused on that the silicone pipe we used on this study doesn't have elasticity but flexibility, relatively. So its solid characteristics behave as a resistance to systolic power of SMA. So, the mechanical improvement should be done to imitate the human peristalsis with higher contraction variation.

On the contrary, the typical results of static inner pressure variation showed the sufficient pressure amplitude as the assistance of digestive peristaltic motion. The maximum inner pressure was about 50 mmHg at the end point of peristaltic duration.

Furthermore, this study shows the prevention of reflux because of the relation to the time span of heating and cooling. From our preliminary study, a time constant at heating and cooling was studied using BMX150 at 40 degree of Celcius, based on physiological environment. These studies showed the short time of heating one, compared to the cooling one that is twice as long as heating. These results derived us a driving condition on this study. This reflux-safe driving mode has much efficiency as an artificial digestive system. This characteristic was confirmed on a swallow test using nutrition supplement jerry.

On observation of video frame of such imitative peristalsis, dynamic reflux has none, though it was only external view..

5. Conclusions

We have developed an artificial esophagus device to assist the swallow and to imitate a physiological peristalsis. The inner pressure variation tests and the imitative swallow observation shows good performance and its potential characteristics of peristaltic device, though the 2D radiographic variation studies showed a low level of systolic ratio. It has smart mechanisms for driving and a small structure, and performed good characteristics compared to physiological parameters of esophagus. From these results, the peristaltic device using specialized SMA, BMX150, showed the possibility of implant as an artificial device.

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Hemodynamic Evaluation of Artificial Abdominal Grafts in a Sophisticated Mechanical Circulatory System

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1. Introduction

In general, vascular prostheses were implanted or transplanted for the patients having diseased lesions with aortic aneurysms or coarctations. There are various configurations of the arterial grafts in order to achieve the complicated anatomical blood distributions, as shown in Figure 1.

As the shape of conventional abdominal Y-grafts (Figure 1-B) is different from that of natural abdominal aorta as shown in Figure 2, it was anticipated that the patients' hemodynamic functions might be affected by the implantation of vascular grafts. The purpose of this study was to evaluate hemodynamic characteristics of the two different types of the commercially available conventional vascular Y-grafts, as well as the newly-developed anatomically-identical vascular graft which was invented and fabricated by Dr Iwamura, using a sophisticated mechanical circulatory system.

2. Methods

2.1 Abdominal vascular prostheses: Three different types of abdominal vascular prostheses with the same size of inflow diameters were employed in this study: a) conventional (16 x 8; 16mm in inflow and 8mm in outflow diameters), b) anatomically-identical model (16 x 12). The shape of the anatomically-identical graft was designed by combining three elliptical cones, and the structure of bifurcation portion was decided by the suture of two different vascular grafts so that the shape and position of natural bifurcation of each patient can be reproduced.

2.2 Steady flow test and hemodynamic examination in the mock circulatory system: Firstly, the characteristics these vascular grafts were examined under the steady flow condition. And secondly, the dynamic functions were evaluated in the originally-designed mock circulatory system (MCS) [1-2]. The MCS consisted of several mechanical components as follows: a) a silicone left ventricular model with mechanical inflow and outflow valves representing mitral and aortic heart valves

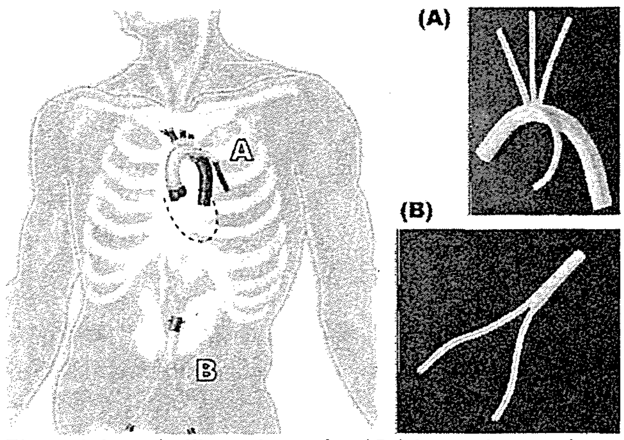

Fig. 1 Schematic illustrations of artificial vascular prostheses for the aortic arch (A) and the abdominal bifurcation (B).

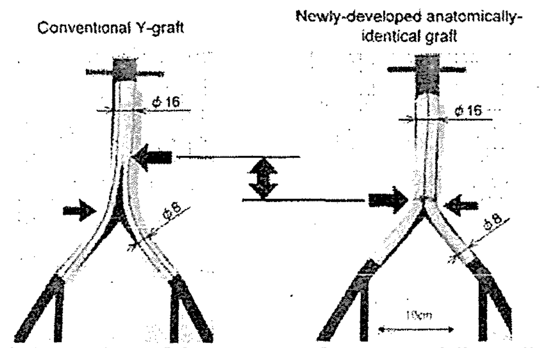

Fig. 2 Comparison of the structure of a commercially available conventional Y-graft (left) and the anatomically-identical graft (right)

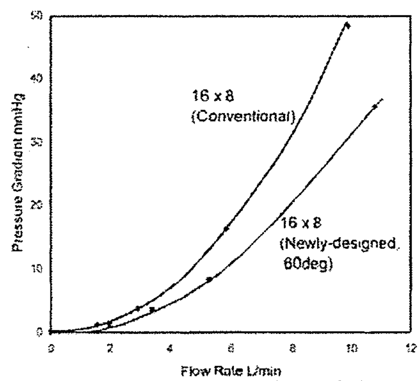

Fig. 3 Comparison of pressure gradient of the two types of abdominal Y-grafts obtained from the steady flow test.

respectively, b) a computer-controlled actuator for driving the mock ventricle, c) a silicone anatomically-identical aorta with aortic arch, as shown in Figure 3. The grafts were actually installed into the MCS, and the hemodynamic characteristics were compared under the constant flow conditions (pump rate: 72bpm, cardiac output: 4L/min).

3. Results and Discussion

In the steady flow test, pressure loss coefficient of the modified-conventional and the anatomically-identical grafts were very low, and it showed only around 60% and 20% of that of the conventional one, respectively as shown in Figure 3, 4. When the conventional model was employed instead of the silicone artery, the left ventricular systolic pressure in the MCS (Figure 5) was elevated from 130 to 165 mmHg, whereas the systolic elevation caused by the installation of the anatomically-identical graft was smaller. Moreover, the changes of the input impedance were calculated (Figure 6), and it was indicated that the increase of the left ventricular external work was closely related to the resistance of each vascular graft.

4. Conclusion

It was suggested that the anatomically-identical sized Y-graft might be effective to reduce the pulsatile resistance of the arterial systems, as well as the ventricular load [3-5].

And it was also anticipated that the development of complications around the anastomosis portions could be related to the elevation of the resistive factor in arterial systems.

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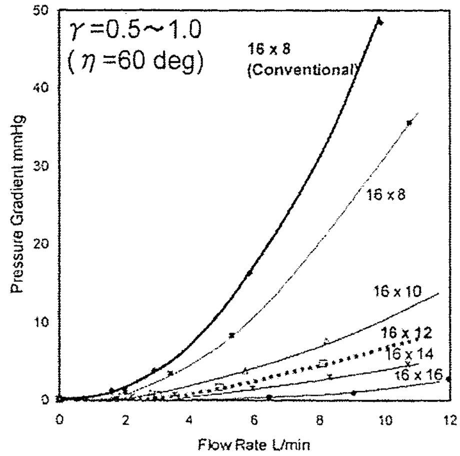

Fig. 4 Changes in pressure gradient with different outflow diameters

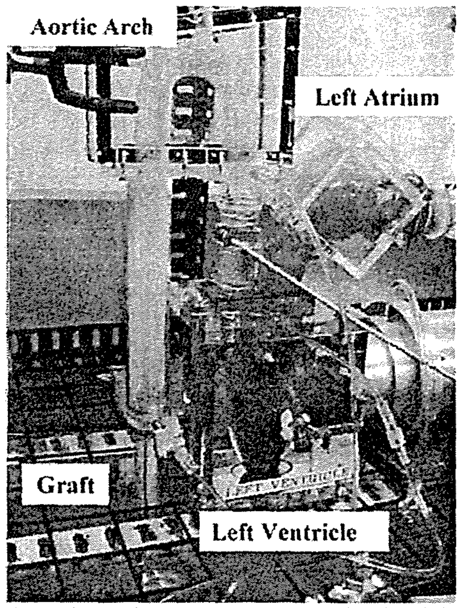

Fig. 5 A mechanical circulatory system with the abdominal bifurcation graft tested.

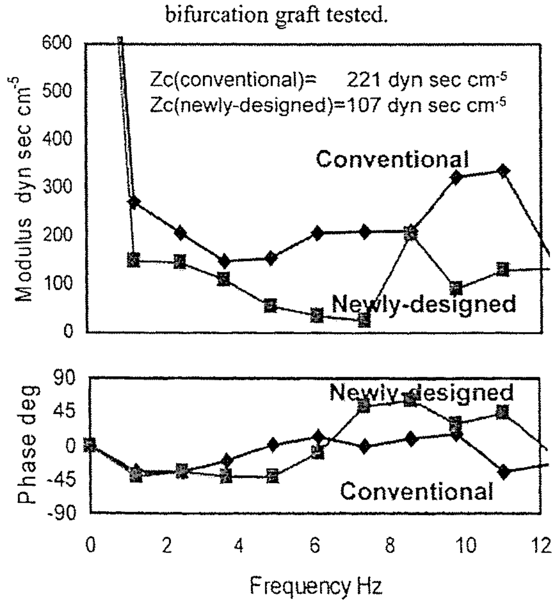

Fig. 6 Comparison of the input impedance obtained from the aortic portion of the MCS with different abdominal Y-graft.

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