Extraction Method for Blood Vessels, Based on the Velocity Profile Measured by Phase Shift Method

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Abstract: *In the computational biomechanics, the proper model has to be constructed. Most of the models are based on MRI and CT images. In the region extraction, the boundary decision in the obscure region has received attention. Hence, these methods have been estimated by the appearance of the extracted region, not quantitative data. In this study, we propose the extraction method and the accuracy.*

I. Introduction

The computational biomechanics needs the realistic model based on MRI and CT images. Many researchers have worked in the development of the extraction method [1]-[4]. Most of the methods have satisfied with the geometrical correctness, especially the smoothness. One of the methods characteristics is the ability to decide the boundary in the obscure image. Because the boundary was in the obscure image, most methods have not been evaluated quantitatively. Usually these methods were evaluated by the appearance of the extracted region.

If the extraction method is the last process and the operator needs the appearance, the method is enough. However, in the computational biomechanics, one of the purposes is providing the quantitative data to support the clinical operation. Hence, the model has to be evaluated quantitatively.

In MR images, the blood vessel is recognized with the region, where something moves and the blood flow influences the intensity. TOF (Time of Flight) and PS (Phase Shift) are well known as the sequences which emphasize the region of the blood vessel. In TOF, the intensity in the blood vessel is proportional to the velocity, but indicates the relative value of the velocity. On the other hand, the intensity in PS is corresponding to the velocity, and it is easy to measure the velocity of the blood flow.

In this study, we show the accuracy of the velocity measurement in PS images, and propose the extraction method based on PS images and evaluated quantitatively.

II. Accuracy of the flow measurement in PS images

The accuracy was estimated in some studies [5]-[6]. But these studies did not consider the effect of the parameters: Relaxation time of the blood, Velocity and its range in each data of the image, TR (time of repetition), TE (Time of Echo) and VENC (Velocity Encoding Number).

We examined the accuracy of the flow measurement and its robustness. In all the experiments, we used 1.5 T EXCELART MR System (TOSHIBA Corporation, JAPAN) .

A. Relaxation Time

T1 (Spin – Lattice relaxation time) was reported about 700-1500 msec [7]-[8] . We adjusted the concentration of $MnCl_2$ salt solution so that its relaxation time was in the range.

T1 was measured by Inversion – Recovery Sequence. TR was set at 4500 msec and TI (Time of Inversion) was ranging from 10 to 500 msec. The relationship between the intensity and the inversion time is the following equation [8]:

$$SI = Ao + A1 * \exp\left[-\frac{TI}{T1}\right]$$

where SI is the intensity in the image, Ao and A1 is the constant.

We estimated T1 from the measured data and the equation, using the least square method. The result is showed Table 1. -

Table 1 T1 (msec) estimated by Inversion- Recovery Sequence

Concentration [mM]	T1 [msec]	R^2
0.01	$2.5X10^3$	0.946
0.05	$1.7X10^3$	0.950
0.1	$8.4X10^2$	0.997
0.2	$5.6X10^2$	0.996

T1, Spin – Lattice relaxation time; R, correlation coefficient.

B. Velocity Measurement

With the roller pump and the flask for the damper, we measured the velocity in the glass vessel. Reynolds number was 3 X 10^2.and the diameter of the vessel was 8 mm. Other parameter is shown in Table 2. The flow was the laminar flow.

In the experiment, the maximum velocity was used for estimating the accuracy. The flow quantity was measured in each experiment. In each category, the image was taken 5 times. In the statistical analysis, we used Student t test, and used the value of the error in the effect of the relaxation time and the maximum velocity in other parameter effect. Table 3 shows the results in all the experiments.

Table 2 Parameters in the experiment

TR	50,100
TE	10,16
VENC	integer nearest to the maximum velocity and twice the value

Table 3 Robustness of the velocity measurement in PS images

Parameter					Value in PS image			
T1 [msec]	Vtmax [cm/s]	TE [msec]	Venc[cm/s]	TR [msec]	Vmax[cm/s]	SD	Error[%]	t_test
$2.5X10^3$	7.4	10	8	50	6.7	0.19	-10.7	+,++
			8	100	6.8	0.24	-9.4	
			16	50	6.9	0.35	-8.1	
			16	100	7.1	0.43	-4.6	
		16	8	50	6.8	0.28	-8.3	**
			8	100	7.0	0.20	-5.9	
			16	50	7.3	0.26	-2.8	**
			16	100	7.3	0.29	-2.2	
$1.7X10^3$	6.6	10	7	50	6.2	0.07	-5.7	*,+
			7	100	6.1	0.14	-7.5	
			14	50	5.9	0.33	-9.8	
			14	100	6.0	0.14	-8.5	
		16	7	50	6.0	0.18	-9.1	*
			7	100	6.0	0.11	-8.8	
			14	50	6.1	0.20	-7.4	
			14	100	6.1	0.30	-7.8	
$5.6X10^2$	7.4	10	8	50	6.9	0.13	-7.4	++
			8	100	7.0	0.25	-5.8	
			16	50	6.8	0.20	-7.7	
			16	100	6.6	0.34	-10.4	
		16	8	50	6.8	0.20	-7.7	
			8	100	6.8	0.21	-7.7	
			16	50	7.0	0.27	-5.9	
			16	100	7.0	0.25	-5.2	

Vtmax, the maximum velocity calculated by the flow quantity; Vmax, the average of the maximum velocity; t-test, there is significant difference between the same notations. $p<0.05$.

(1) The effect of the relaxation time

Between $5.6X10^2$ msec and $1.7X10^3$ msec, there is no significant difference. However, there is the significant difference between $2.5X10^3$ msec and others when TR was 50 msec and TE was10 msec. Because $2.5 X 10^3$ msec is far from the range of the blood relaxation time, these results indicate that the relaxation time does not effect on the velocity measurement in the blood vessel. Also the shorter TR and TE could have an effect on the measurement in the longer relaxation time.

(2) The effect of TR

There was no difference in the results. From the result, the effect of TR would not important.

(3) The effect of TE

When the relaxation time was 1.7 $X10^3$ msec and TR was 50 msec, there was the significant difference. Because the velocity difference was less than 1 cm and the error was in the range of other error values, this difference would not so valuable, especially for the measurement in the blood flow. But the effect of TE would be considered in the experiment..

(4) The effect of VENC

When the relaxation time was 2.5 $X10^3$ msec, TR was 50 msec, and TE was 16 msec, there was the significant difference. In other categories, there was no significant difference. The degree of the relaxation time might make the signal sensitive to the parameter, VENC.

Each effect would receive attention, but the difference could be negligible in the blood flow. These results indicate that the measurement in PS images is available.

III. Extraction Method

A. Method

The intensity histogram in MR image is unique and difficult to decide the threshold value. The flow velocity near the vessel wall is so small that the blood vessel could not be extracted at the same time. This method uses the continuity of the blood vessel. First, the operator set that the minimum velocity, which is recognized as the blood flow in the blood vessel, and one point in the blood vessel. The selected point is thought as the parent point and the surrounding points are thought as the daughter points. If the daughter point is more than the minimum velocity, it is recognized as the point in the blood vessel, and the next parent point. The point is given the value, which indicates that the point is in the blood vessel. The value is decided by the operator. In the case that the value in the daughter point is less than the minimum value, the daughter does not become the parent point. The daughter point is given the value which indicates that the point is on the boundary. This value is set by the operator.

B. Example

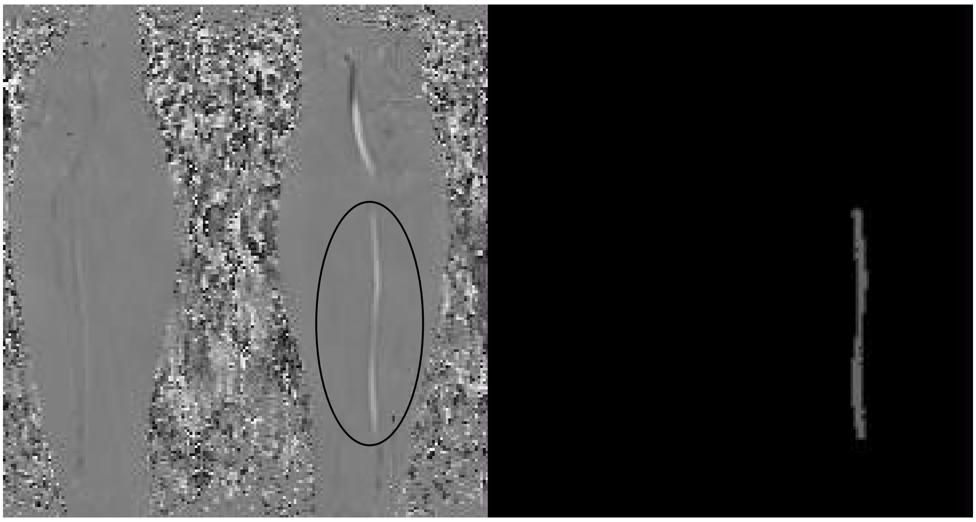
We applied this method to some PS images. The value of the boundary point of the blood vessel is set at 50 and that of the inner point is set at 100. The results of 3D images were displayed by Volume Pro 1000 (TERARECON, INC).

(1) Femoral Artery (2D)

Table 4 shows the parameter of the image. The minimum velocity was set at 1 cm/sec. Fig. 1 shows the original image and the extracted region.

Table 3 Parameters in the image (PS images)

Parameter	Value
TR	50msec
TE	16msec
Matrix	176*192
Pixel spacing	2.0833mm*2.0833mm
Slice Thickness	2.0mm
Flip angle	20
Phase encoding direction	Right-Left
Read out direction	head - foot
Velocity encoding number	20cm/sec



(a) (b)

Fig. 1 Femoral artery (2D). (a), the original image; (b), the result image; Circle area, the applied region.

(2) Femoral Artery (3D)

The sequence of the images, which included Fig. 1, was also applied. Fig. 2 shows the result.

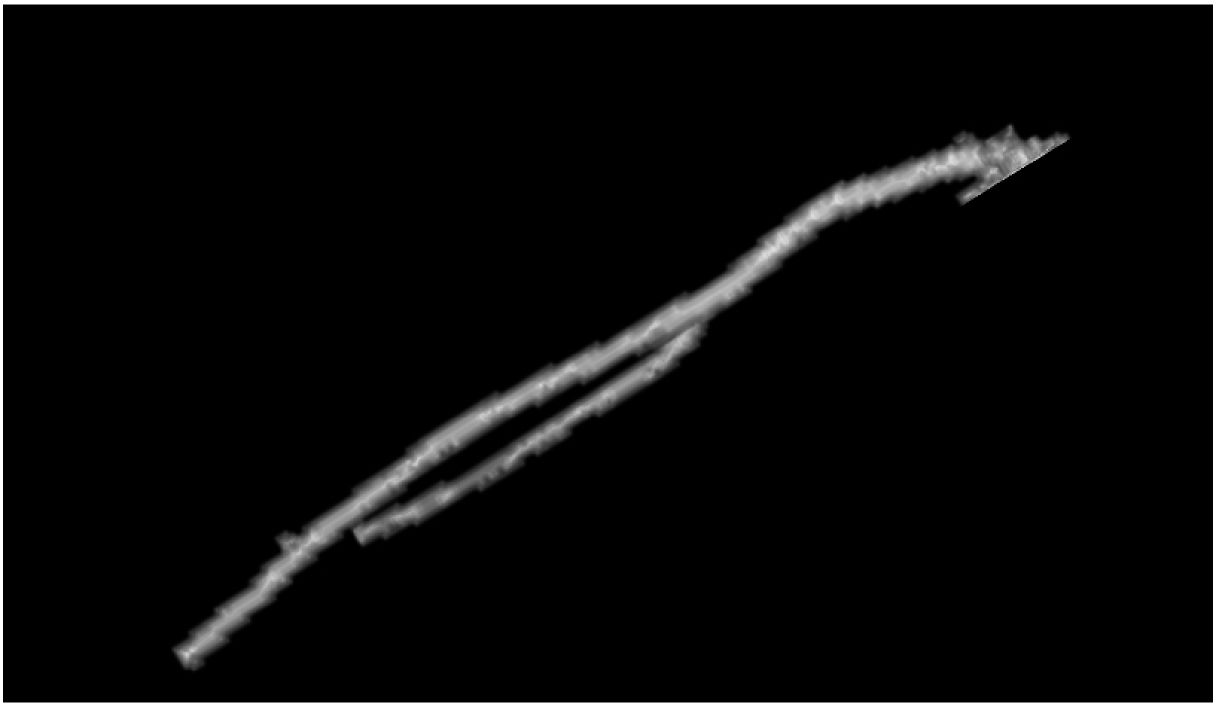


Fig. 2 The extraction result of the femoral artery (3D).

The intensity in TOF image does not show the actual velocity. Because it is parallel to the velocity, it could be thought as the relative velocity. We applied the same method to TOF image. The values of the boundary and the inner points are the same as the application to PS images..

(3) Cerebral Artery (3D)

The parameters in the image are shown in Table 4. The minimum value was set at 20 % of the maximum velocity. Fig. 3 shows the result.

Table 4 Parameters in the image (TOF images)

Parameter	Value
TR	30msec
TE	6.8msec
Matrix	160*256
Pixel spacing	0.6641mm*0.6641mm
Slice Thickness	1.0mm
Flip angle	20
Phase encoding direction	Right-Left
Read out direction	Anterior-Posterior

Fig. 3 The extraction result of the cerebral Artery (3D)

IV. Discussion

In this study, we examined the accuracy of the velocity measurement in PS mage, and proposed the region extraction method, where the operator set the minimum velocity in the blood vessel and one point in the image only. The advantage of the method is using the image whose accuracy is known, and the boundary point and the inner point are divided. Both points could be useful for the computation. We will apply this method for the various MRI images in the future.

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