PHASE DISTRIBUTION DEPENDENT ON PHASE-ENCODE DIRECTION IN PHASE CONTRAST METHOD

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Abstract: Most diseases in blood vessel are related to shear stress, which is determined by blood flow. Hence, it is important to measure the blood flow precisely. The velocity can be measured noninvasively by phase-contrast method in MRI. The velocity is evaluated as the signal phase in this method, which is proportional to the velocity. Hence, the characteristics in the phase distribution would reflect the measurement accuracy. In addition, the development of an image processing method in MRI needs the characteristics. We examined the phase characteristics in order to improve the measurement accuracy, and develop an image processing method, in this study. The phase distribution in the static region, where the effect of the dephasing is not observed, was evaluated, because the factors worsening the accuracy are often observed at the same time so that each factor is hardly quantified. Baby oil and $MnCl_2$ solution were used as a sample. The results showed that the phase distribution was not uniform but dependent on the phase-encode direction. The results would be effective to improve the accuracy in flow measurement and develop an image processing method.

Introduction

Diseases in blood vessel, especially atherosclerosis, have been discussed frequently. However, the mechanism about atherosclerosis has not revealed yet, but it is certain that endothelial cells have an important role. Endothelial cells cover all the inner surfaces of the vessels and influence the vessel's condition. Moreover, the cells have various properties and functions which should be evaluated to understand the progress in the disease. The response to shear stress has been investigated in many ways because of the importance for the disease progress. Shear stress is decided by flow profile so that the precise measurement for flow velocity in the blood vessel is inevitable to understand the disease.

Whereas a lot of methods to measure a velocity have been proposed, the number of non-invasive methods is limited. Phase contrast method in MRI is representative in the noninvasive methods. Phase contrast method can be applied for any area of a patient and needs nothing to inject into a blood vessel. Therefore, the usage of phase contrast method in clinical situations is proper and effective.

The phase in phase contrast method is proportional to the velocity in each point. The relationship is described by the following equation:

$$v = VENC \cdot \frac{\phi}{\pi} \quad (1)$$

where v is velocity, VENC is velocity encoding and ϕ is phase. Hence, the phase should be evaluated in order to investigate the measurement characteristics. The measurement accuracy in phase contrast method has been examined by the comparisons with other measurement methods and the systematic error evaluation in MR system [1]-[9]. While these investigations indicated the factors to influence the accuracy, their results could not be used effectively to improve phase contrast method. Whereas the condition in each investigation is often observed physiologically, these factors do not exist solely. In addition, it is difficult to decide which factor influences the accuracy most.

Most important factor in the accuracy improvement is the dephasing. The dephasing, which appears in any flow pattern, worsen the accuracy. Like other factors, it is hard for blood flow to analyze the dephasing independently.

Static region is not necessary to measure blood flow, but useful to estimate the influences except the dephasing, because there is no dephasing. In addition, the phase distribution, which could be influenced by the sequence parameters, is essential to develop an image processing method [8]. The statistical parameter such as mean and standard deviation are effective to analyze a distribution quantitatively, but not always suitable for understanding an image because the parameter is not related to geometrical data. Hence, the parameter containing both of the statistical data and the geometrical data should be used.

In this study, we examined the phase distribution in the static region in the phase contrast image. The parameter including the statistical and the geometrical information is also proposed.

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Materials and Methods

All the experiments were performed with 1.5T MR System ExcelART (Toshiba Medical Systems, Tochigi, JAPAN). 2D phase contrast method was used.The sequence parameters were set as follows: TR=50ms, TE=10ms, flip angle=20degree, VENC (velocity encoding) =6cm/s, FOV=25.6cm x 25.6cm, Matrix=256 x 256, phase-encode direction=anterior-posterior, right-left and head-foot, image direction =axial, sagital and coronal, slice thickness=3mm, spacing between slices=12mm, the number of images=10.

Phase-encode direction and read-out direction was exchanged in each image direction in order to examine whether the observed characteristics would be reproductive or not. Similarly, the number of the images was decided.

Baby oil phantom was measured by the phase contrast method. The baby oil was prepared as a standard sample, because the oil was always used to check the condition of the MR system. The baby oil filled the cubic container, whose edge was 14 cm.

If the phase distribution is homogeneous, the segment set by any threshold value will be symmetric. The height and the width of the rectangle which bounds the segment were thought as a parameter to show the homogeneity of the phase distribution. When the height is equal to the width, the phase distribution is thought as homogeneous. On the other hand, when the width is not equal to the height, the segment elongates in phase-encode direction or read-out direction. The direction of the elongation is associated with the phase distribution characteristics, concerning the space.

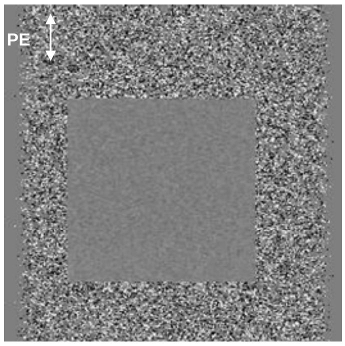
The static region in each image was decided by the operator. The series of the threshold was set at intervals of 9degrees. The height and the width of the rectangle bounding each segment were measured. Which of the height and the width corresponded phase-encode direction was confirmed in each performance. All the segments were categorized into 3 groups by the direction of the elongation: phase-encode direction, read-out direction and symmetric. The number of the segments in each group was counted and compared each other.

In order to examine whether the characteristics observed in the baby oil could be influenced by the relaxation time or not, $MnCl_2$ solution and distilled water were used. The quantity in each sample was 1L. Because $MnCl_2$ shortens the relaxation time, the concentration in the $MnCl_2$ solution was set from 0.2mM to 0.05mM. There are there kinds of the relaxation times, which are T1, T2 and T2*. They were measured by inversion recovery method, spin echo method and gradient echo method respectively: T1=6.5x10^{2}ms– 1.7x10^{3}ms, T2=84ms – 3.1x10^{2}ms, T2*=63ms-2.1x10^{2}ms.

Results

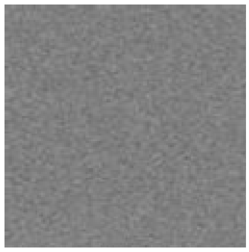
Figure 1 is one of the images in the baby oil phantom. The static region did not seem homogeneous, and to have some pattern. The same characteristic was observed in other baby oil images.

Figure 2 shows the results of the axial image, which indicates the number of the segments in each threshold. The rectangle bounding the segment was set and each edge was measured. The segments were categorized into 3groups, dependent on the direction of the elongation: phase-encode direction, read-out direction and square. The number of the segments whose bounding rectangles were square was most large in any threshold. On the other hand, the number of the segments elongating into read-out direction was larger than that of the segments elongating into phase-encode direction in each threshold, although there were 3 segments elongating in the direction of phase-encode direction and no segment elongating in the direction of read-out direction, at z=48 cm and the threshold= 36 degrees - 45 degrees. Figure 3 shows the difference in the number of segments, concerning the elongation. The result also shows that the segment would have a tendency to elongate in read-out direction.



1mm

(a)



1mm

(b)

Figure 1: The example of the baby oil images. The image type is axial, and phase-encode direction is anterior-posterior direction. (a), the whole image. The arrow indicates phase-encode direction. PE, phase-encode direction; (b), part of the static region in (a). The phase does not seem to distribute homogeneously.

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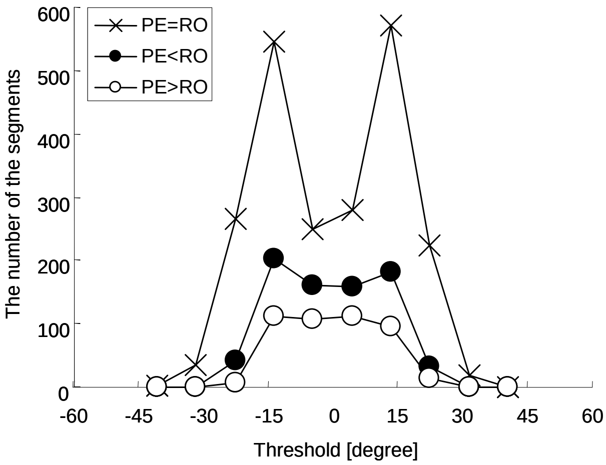
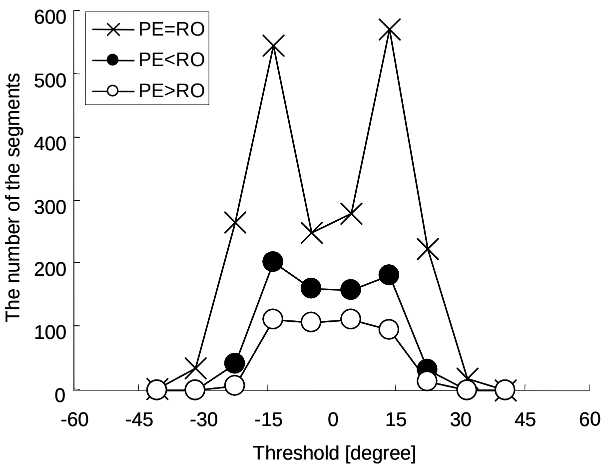
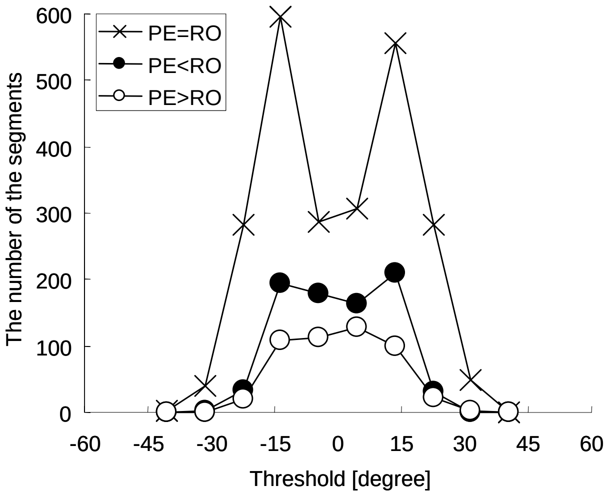


(a)



(b)



(c)

Figure 2: The number of the segment in each threshold. Z-coordinate is perpendicular to the image. The z-coordinate of (a), (b) and (c) were -60mm, -12mm and 48mm, respectively. The threshold was at intervals of 9degrees. The segment was categorized by the direction of the elongation. PE=RO, the bounding rectangle is square; PE<RO, the rectangle is elongated in read-out direction; PE>RO, the rectangle is elongated in phase-encode direction.

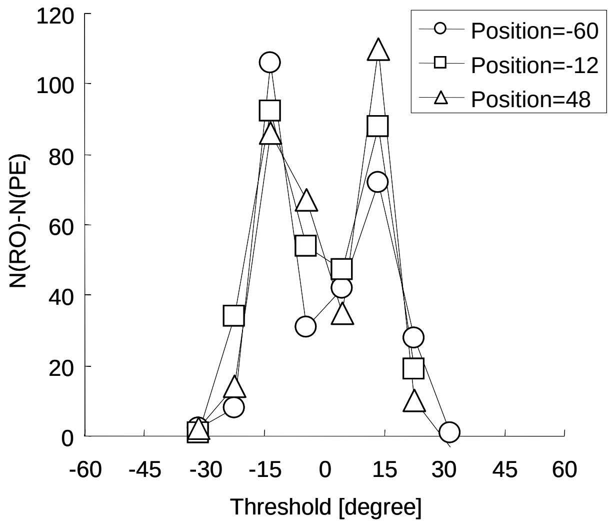


Figure 3: The difference in the number of the segments, dependent on the elongation direction. The direction of the elongation was decided by comparison between the height and the width of the bounding rectangle. Position, z-coordinate (cm); N(RO), the number of the segments elongating into read-out direction; N(PE), the number of the segments elongating into phase-encode direction.

0.2mM $MnCl_2$ showed the same tendency at the same threshold interval. However, when the relaxation time is longer, the tendency in the elongation direction would become obscure. However, the same tendency in the segment elongation was observed in $MnCl_2$ solution and distilled water, by extend the interval of the threshold, whereas part of the segment elongated in phase-encode direction. Hence, the characteristics in the segment elongation could be also observed although the relaxation time becomes longer.

Discussion

Shear stress caused by blood flow is important to reveal blood vessel diseases. On the other hand, phase contrast method in MRI is used to measure the velocity. The phase is proportional to the velocity. In this study, we examined the characteristics of the phase distribution in the static region of the image taken by phase contrast method. The phase characteristic in the static region is corresponding to the characteristic which does not contain the dephasing effect.

In order to measure the velocity accurately and evaluate the velocity profile in blood vessels, the phase characteristics concerning to the space is necessary. In addition, the development of the image processing

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method also needs to evaluate these characteristics. As a representative parameter, the mean and the standard deviation of the distribution are usually used to evaluate the distribution quantitatively. These parameters are useful to understand the whole characteristics of the distribution, but not suitable to evaluate the characteristics concerning the space. At this point, the elongation direction of the segment in each threshold was proper.

The segment was elongated in read-out direction rather than phase-encode direction. The tendency was almost same through all the slices. The threshold should be set larger when the relaxation times become longer, in order to make the tendency clear. If the threshold interval is small, the segment elongation tendency would not seem to have a pattern and be hardly dealt. Hence, the interval of the threshold would be an important parameter to improve the measurement accuracy and the development of the image processing method. On the other hand, the comparison between the characteristic of the elongation and the threshold could be useful to estimate the relaxation times in the region. These characteristics would be also useful for the image processing.

Conclusion

In this study, we examined the characteristics of the phase distribution in the static region of the image taken by phase contrast method. The segment in each threshold would elongate in read-out direction rather than phase-encode direction. Moreover, the interval of the threshold to indicate this tendency clearly would depend on the relaxation times. These characteristics in the static region, which has no effect of the dephasing, would improve the accuracy of the velocity measurement and develop the image processing method for MRI images in the future.

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