INTRODUCTION:
Besides its wide use in routine clinical studies, Fast Spin Echo (FSE) has been applied to vessel visualization such as a bright blood technique for fast flow\textsuperscript{1,2}, and a bright blood technique for slow flow.\textsuperscript{3,4} Recently, several FSE techniques were proposed for bright blood imaging of fast flow\textsuperscript{5,6}, and the following characteristics of the techniques have been pointed out: (1) vessels running in the phase encode (PE) direction are well depicted,\textsuperscript{4,5} however (2) vessels running in the read-out (RO) direction are not well depicted, often accompanied with N/2 ghost artifacts.\textsuperscript{5,6}

There were basic physical studies reported regarding the FSE flow compensation (FC)\textsuperscript{7}. However, the flow dependency of signal in standard FSE imaging has not been reported in detail, even though it is known that a basic understanding will be helpful in clinical applications. In this paper, we report a simulation study on signal behavior in FSE flow imaging, by taking into account the first order phase shift effect in the RO direction.

THEORY and METHODS:
FSE multi-echo signals can be calculated by adding up signals of all possible paths in the FSE phase diagram.\textsuperscript{8} Our simulation method takes into account all effects up to the first order flow phase shift, so that spins in transverse paths are rotated by the amount proportional to velocity, time, and the zeroth moment of RO gradient. The pulse sequence used in the simulations is a typical single-shot half-Fourier FSE sequence with 5msec echo train spacing (Fig.1). Excitation “flip” angle was set to 90º. The portion of the sequence after the first refocusing “flop” pulse was repeated. Other parameters are listed in table 1.

The calculated 32 echo chains with the center at the 16-th echo were Fourier-transformed, and the complex signal intensities of original and ghost images were evaluated. Simulations were carried out for various “flop” angles FA and velocities v. (FA=180, 150, 120, ..., 30º; v=0.5, 1.0, 15, 20..., 50... [cm/s], T1 and T2 decays were not taken into account for simplicity. Experimental flow phantom studies were also carried out under several conditions for comparison.

RESULTS and DISCUSSION:
A typical result of calculated echo signals is shown in Fig.2(a). Odd echoes have a relatively large phase shift, while even echoes have a small shift due to even echo rephasing effect. This results in the oscillation of echo signals in a multi-echo series. Fourier transformed data of (a) are shown in (b). N/2 ghost artifacts, which are intrinsically in the orthogonal direction to the original flow image, show somewhat complicated behavior. Fig.3 shows part of the calculation summary:

Velocity v: The higher the velocity v was, the larger the phase shift and its oscillation became. Even and odd echoes can be located at completely opposite positions in the complex plane to cancel each other, so that the original image vanishes (50cm/s in our case). Flop Angle FA: A sequence with FA of 180º generates pure Hahn spin echoes and they simply oscillate. Smaller FA increases the influence of various paths in the phase diagram, and the oscillation moves into the complex plane. Reducing FA to less than 60º, both original and ghost signal intensity tend to vanish.

Although the phenomena are more complicated, the results of the flow phantom experiment show a similar tendency to those of our simulations. These results indicate that obtaining the data during the slow velocity state is one of appropriate approaches in FSE flow imaging, and supports previous knowledge that appropriately choosing ECG delay time is essential for vessel visualization with higher SNR.\textsuperscript{9}

CONCLUSION:
We have investigated the signal behavior in FSE flow imaging with first order phase shift effect in the RO direction. This basic understanding will surely be helpful in actual clinical applications.

Table 1. Parameters used in this simulation

\begin{tabular}{|c|c|}
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Effective TE (ms) & 80  \\
Effective Echo No. & 16  \\
FOV (RO) & 350 [mm]  \\
Matrix (RO) & 256  \\
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\end{tabular}

REFERENCES:
1) Siebert JE, Cooper TG, Pernicone JR. ISMRM, 1844, 1997.