A SNR Comparison Study of Multiple Mouse Embryo MRI

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Introduction:

The mouse is an important model for studying human genetic diseases. Magnetic resonance microscopy can be used to identify developmental malformations in mouse embryos. However, signal-to-noise ratio (SNR) is usually a key limiting factor in achieving high resolution images. Two methods have been used to improve throughput of mouse embryo imaging: (a) multiple embryos are imaged in one tube with a single RF coil[1] compared to (b) multiple embryos each is scanned individually but simultaneously in a tube with a close-fit RF coil similar to multiple-mouse MRI[2]. The objective of this study is to compare SNR for these two high-throughput mouse embryo MR imaging methods. Differences in field strength, T1 and T2 relaxation time, RF coil and scan time will be corrected.

Methods:

Experiment 1 (Multi-embryo/single coil): 32 mouse embryos were prepared[3] and loaded into a tube with 8 layers and 4 embryos on each layer. First multiple embryo imaging was performed in Oxford, UK on a 9.4 T horizontal magnet interfaced to a Varian VNMRS DirectDrive console (Varian Inc, Palo Alto, CA) and a quadrature-driven birdcage coil with an inner diameter of 28 mm (Rapid Biomedical, Wurzberg, Germany). A 3D spoiled gradient echo sequence (TR/TE=30/10 ms, a 60^o excitation pulse with rectangular pulse shape) was used to obtain strong T1 contrast.

Experiment 2 (Multi-embryo/multi coil): The same embryos were then melted out and re-suspended in the same agarose solution in small NMR tubes (diameter: 13 mm, length: 18 mm) to perform the second multiple embryo imaging. The second experiment was conducted in Toronto, Canada on a 7 T horizontal Varian VNMRS system using a custom-built array of solenoid coils to image multiple embryos simultaneously with identical pulse sequence and same spatial resolution as experiment 1. Details of the imaging parameters for both experiments are listed in Table 1.

Table 1: Protocols for the two SNR comparison experiments.

	Field strength(B_0)	RF Coil	FOV (mm^3)	Matrix size	Resolution (μm^3)	NEX	Scan time (hours)
Multi-embryo/single coil	9.4 T	Quadrature birdcage	26 x 26 x 50	608 x 608 x 1408	43 x 43 x 36	4	12.3
Multi-embryo/multi coil	7 T	Solenoid	25 x 14 x 14	580 x 328 x 390	43 x 43 x 36	4	4.3

T1 and T2 for different tissues at both field strengths were measured to account for signal difference caused by T1 and T2 relaxation time. T1 measurements was performed by using an inversion-recovery pulse sequence, 16 inversion times (TI) were exponentially arrayed between 10 ms and 2000 ms. TR/TE=2100/1.4 ms, matrix size 128 x 128, FOV=30 x 30 mm^2, 8 slices, slice gap 4 mm. T2 measurements were achieved by using a spin echo sequence with TE varied in 10 values from 8 ms to 100 ms and TR=2000 ms. The quality factors (Q) for each of RF coils were measured to give an indication of noise contributed by the conducting embryo(s) compared to the RF coil. The signal for a spoiled gradient echo is given by $S=M_0*\sin\theta*(1-\exp(-TR/T1))/(1-\cos\theta*\exp(-TR/T1))*\exp(-TE/T2^*)$ where M_0 is the magnetization, θ the flip angle. The correction factor $\varepsilon=(1-\cos\theta*\exp(-TR/T1))/(1-\exp(-TR/T1))/\exp(-TE/T2^*)$ was used to correct signal cause by different relaxation times. Since MR signal is proportional to B_0^2 (magnetization $M_0 \propto B_0$), and noise by the sample $\sqrt{Rs} \propto B_0$, a factor of $1/B_0$ is used to correct SNR for these two experiments at different B_0. MR noise is proportional to $\sqrt{(RsTs+RcTc)} \propto \sqrt{RsTs(1+Q_LTc/(Q_U-Q_L)/Ts)}$ where Rs and Rc are sample and coil resistance, Ts and Tc sample and coil temperature, Q_U and Q_L unloaded and loaded quality factor. Correction factor $\alpha=1+Q_LTc/(Q_U-Q_L)/Ts$ where Tc=Ts=290K was to correct for coil difference other than dimension scaling. The SNR for both experiments was measured for brain, liver and heart.

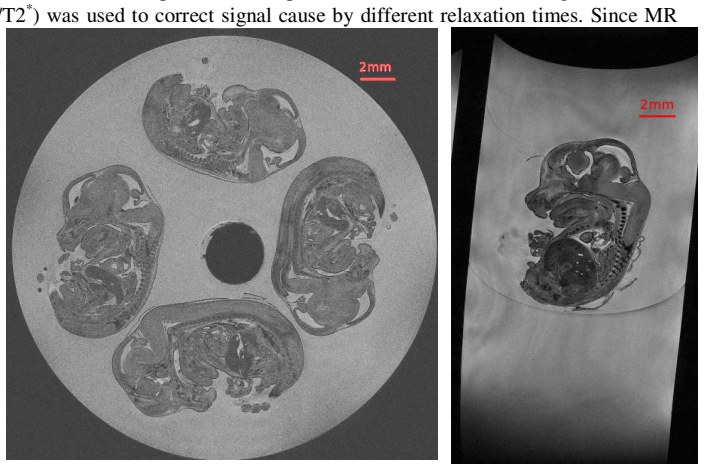

Figure 1: Mouse embryo images: (L) Multi-embryo/single coil: 32 embryos with one coil, (R) Multi-embryo/multi coil: each embryo with a closely-fit coil.

Results:

Figure 1 illustrates the embryo images obtained from each method. SNR from both images are shown in Table 2. The SNR ratio between two experiments is 1.91±0.14, the ratio is 3.23±0.23 when the difference in scan time is taken into account. The SNR ratio after correcting T1, T2 relaxation time, B_0, RF coil and scan time is 3.78±0.24. The unloaded and loaded quality factor for the birdcage coil are Q_U/Q_L=326/188 and 279/168 for two driven ports. This corresponds to sample-to-coil resistance ratio of $Rs/Rc=Q_U/Q_L-1$=0.73 and 0.66. The quality factor for the solenoid coils are Q_U/Q_L=140/76, 152/70 and 126/58, which translates to sample-to-coil resistance ratio of 0.84, 1.17 and 1.17.

Table 2: T1, T2 SNR measurement and SNR correction for the two experiments.

	Experiment 1 (Multi-embryo/single coil)			Experiment 2 (Multi-embryo/multi coil)							
	SNR_{meas}	T1(ms)	T2(ms)	SNR_{meas}	T1(ms)	T2(ms)	Scan time correction	T1,T2 correction(ε)	B_0 correction	RF coil correction(α)	SNR_{corr}	SNR ratio
Brain	11.4	148	23.9	23.6	134	23.9	1.69	0.93	1.34	0.92	45.7	4.01
Liver	6.7	162	23.9	12.3	160	23.9		0.99			25.4	3.79
Heart	13.4	111	29.7	24.4	94	26.2		0.93			47.3	3.53

Discussion and Conclusion:

This study compared the SNR for two approaches for high-throughput mouse embryo MR imaging. Both methods provide adequate image quality for image processing. The first approach is relative easy to implement for general mouse embryo phenotyping. After compensating for the differences in the experiments such as field strength, T1 T2 relaxation time, RF coil and acquisition time, the second method provides about 3.8 times higher SNR. However this poses the challenge of developing multiple-embryo imaging systems interfaced to the MR console. Also the number of embryo that can be imaged simultaneously is limited by the number of receiver channels (in our case 16). When imaging early stage embryos, the noise will be dominated by coil noise, the RF coil needs to be cooled to reduce coil noise. This is technically very challenging for small animal MR systems and multiple coils due to the limited space inside the gradient coil.

References: 1. J.E.Schneider et al., BMC Dev Biol (2004)4:16-27 2.N.A.Bock et al., MRM (2003)49:158-167 3.J.E.Schneider et al., J Anat (2003)200:239-247