NOTE

A comparison of two methods for measuring the signal to noise ratio on MR images

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Abstract. The signal to noise ratio (SNR) is one of the important measures of the performance of a magnetic resonance imaging (MRI) system. The object of this study was to compare a single acquisition method, which estimates the noise from background pixels, with a dual acquisition method which estimates the noise from the subtraction of two sequentially acquired images. The dual acquisition method is more exact, but is slower to perform and requires image manipulation. A comparison between the two methods gave a good correlation, and a regression equation of $SNR_{single} = 1.1 + 0.94\, SNR_{dual}$. The single acquisition method is therefore appropriate for use in a quality assurance programme, since it is quicker and simpler to perform and is a good indicator of the more exact measure.

1. Introduction

The signal to noise ratio (SNR) is one of the important measures of the performance of a magnetic resonance imaging (MRI) system (Lerski and de Certaines 1993, McRobbie 1996, Redpath 1998, Sijbers *et al* 1998).

SNR can be used to compare different MR scanners, as part of acceptance testing, or as part of a quality assurance programme. For comparison of scanners and acceptance testing, standard methods of comparing results from different scanners are necessary (McRobbie 1996). For routine quality assurance testing, however, it is sufficient that the SNR is measured in a consistent fashion, so that variations can be monitored. The signal to noise ratio is defined as the ratio of the mean signal of a region of interest (ROI) to its standard deviation. However, a relatively poor image uniformity is fairly common in MR systems (Simmons *et al* 1994, Lerski and de Certaines, 1993), and the standard deviation of pixel values is more strongly influenced by the image uniformity than random noise.

One method to minimize the influence of image non-uniformity on SNR is to collect two sequential acquisitions of the image, obtain the mean signal from an ROI on one of the images, and a value for noise from the subtraction of one acquisition from the other (Price *et al* 1990, Lerski and de Certaines 1993). However, this can be difficult to perform if appropriate software is not available on the scanner. The method also relies upon the scanner remaining stable between acquisitions, so that the only difference between the images is due to random noise.

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A single acquisition method (Kaufman *et al* 1989) involves measuring the noise in a region drawn over an area of no signal (i.e. air). This has the advantage that no image processing is required, and that only one image is required. However, artefacts projected into background areas may spuriously increase noise. These artefacts are either ghost images in the phase encoding direction on the image, or non-uniformities due to bandwidth-limiting filtering of received data (Wicks *et al* 1993). The presence of non-uniformities due to filtering can be determined by obtaining an image with an empty receiver coil (i.e. imaging air). On our scanner, such non-uniformities are restricted to the pixels at the very edge of the image.

The purpose of this study was to validate the single acquisition technique of determining the signal to noise ratio by comparing the SNR estimated using both single acquisition and dual acquisition (subtraction) techniques.

2. Methods and materials

Images were taken with a 1.0 T system (Siemens Magnetom Impact, Siemens AG, Erlangen, Germany) using a quadrature send–receive head coil to scan a quality assurance phantom supplied by the manufacturer (a 17 cm diameter sphere filled with a solution of 1.25 g $NiSO_4 \times 4H_2O$ per 1000 g H_2O which sits in a 40 cm long cylindrical annulus filled with a solution of 2 g NaCl and 3 g $MnCl_2 \times 4H_2O$ per 1000 g H_2O). The NaCl in the annulus provides a similar degree of resistive loading to the coil as a person, and the $MnCl_2$ gives the annulus fluid a very short relaxation time, so that it does not appear on the images. Images were obtained using a spin echo sequence with relaxation time (TR) of 500 ms and an echo time (TE) of 12 ms. Bandwidth per pixel was 130 Hz. A 5 mm thick slice was used, with a field of view (FOV) of 250 mm and 256 × 256 pixels. The phantom was placed in the head coil and driven into the magnet. A period of 3 min was allowed to elapse so that the fluid in the phantom settled before the images were taken. Two identical single images were then acquired sequentially. Images were acquired in axial, coronal and sagittal planes. Measurements were taken daily over one year as part of a quality assurance programme.

Measurements with slice thicknesses of 3, 4, 6 and 7 mm were also made in the axial plane. The variation of measured SNR was determined by performing 15 consecutive scans, repeatedly repositioning the phantom inside the magnet.

Using the dual acquisition, subtraction method, the SNR_{dual} was calculated thus:

$$SNR_{dual} = \sqrt{2}\frac{S_1}{SD_{1-2}} \tag{1}$$

where S_1 is the mean signal intensity in the ROI on the first image, and SD_{1-2} is the standard deviation in the ROI on the subtraction image. The $\sqrt{2}$ factor arises because the noise is derived from the difference image.

This analysis was carried out on an offline workstation, using Analyze (Mayo Foundation, Minnesota, USA) to perform the image subtraction and calculate the SNR in five 20 × 20 pixel regions.

For the single acquisition technique, three regions were drawn: a large circular region covering most of the test object, and two smaller circular regions (35 pixel diameter) placed on the background air pixels. The scanner software was used to draw the regions on the image and calculate their mean and standard deviation. Care was taken to avoid placing the background region over ghosting and filter artefacts, which result in an increased signal near the edge of the image. The signal to noise ratio SNR_{single} in this case is given by

$$SNR_{single} = 0.655\frac{S}{SD_{air}} \tag{2}$$

where S is the mean signal in the large circular region and SD_{air} is the average of the standard deviation in the two smaller regions placed over air. The 0.655 factor arises because the (Gaussian) noise present on the raw data is centred about zero. The raw data are Fourier transformed and made into a magnitude image with all positive values, so the noise distribution is skewed, and the factor accounts for this (Kaufman *et al* 1989).

3. Results

The 15 repeated measurements of SNR gave a mean value of 80.6 (SD = 1.45) for the single acquisition technique and 84.8 (SD = 1.42) for the subtraction method. Assuming that the measurement uncertainties are uncorrelated, the standard deviation of the difference between the two methods should be $\sqrt{(1.45)^2 + (1.42)^2} = 2.0$.

To compare the two measures of SNR, the method of Bland and Altman (1986) was used, whereby the difference in SNR by the two methods is plotted against the mean value of SNR. Thus, figure 1 shows a plot of $SNR_{single} - SNR_{dual}$ versus the mean of SNR_{single} and SNR_{dual}. The regression line is also shown in figure 1, with ±2SD (SD as calculated above = 2.0). The slope is 0.065 (±0.01) and the intercept 1.1 (±1). This corresponds to

$$SNR_{single} = 1.1 + 0.94 \times SNR_{dual}.$$

The graph shows that the difference between the two methods is small, and, since 96% (237/248) of the data points lie within the 2SD lines, the SNR_{single} method can be used as a good predictor of SNR_{dual}.

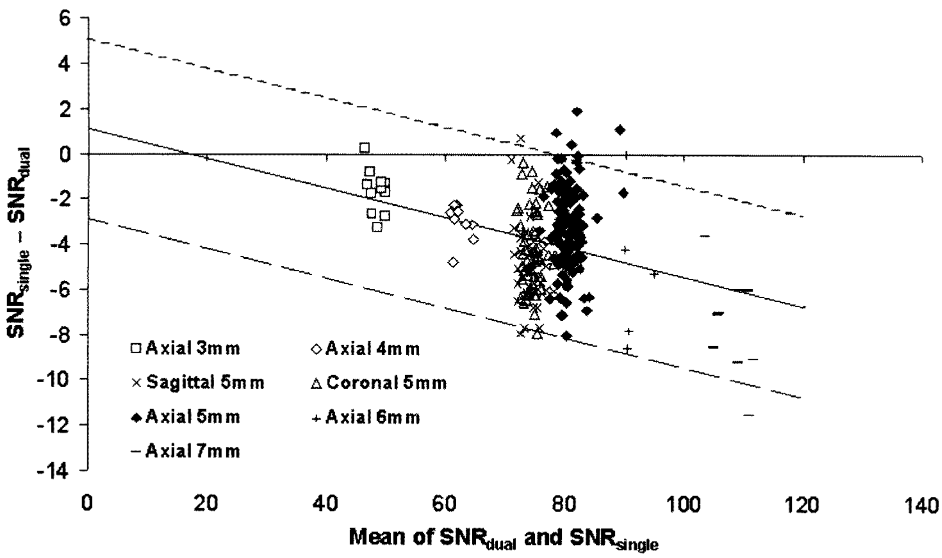

Figure 1. Difference between SNR_{single} and SNR_{dual} plotted against their mean value. Data are shown for a 5 mm thick slice for axial, coronal and sagittal planes (116, 50 and 47 data points respectively), and for 3, 4, 6 and 7 mm thick slices for the axial plane (11, 9, 5 and 10 data points respectively). The regression line and ±2SD (broken lines) are shown.

4. Discussion and conclusions

The single acquisition technique shows a good correlation with the subtraction method, although SNR_{single} is 6% lower than SNR_{dual} for the imaging sequence and scanner which we used. This underestimate should not be a problem when the SNR is being used as a quality control monitor, but should be borne in mind if the SNR is being compared against values obtained by other means.

The relatively low values of SNR_{single} as compared with SNR_{dual}, caused by the noise level in the single method being high relative to the noise in the dual method, could be due to ghosts or other systematic artefacts in the background, which it may be difficult to avoid completely when positioning the region for determining the single method noise. These artefacts will increase the SD in the region, and hence lower the calculated SNR_{single}.

If care is taken to position regions so that they avoid structured background noise, the single acquisition technique is a good substitute for the double acquisition method for measuring the SNR for quality control purposes. The single acquisition technique has the advantage of being quicker and simpler to calculate, since only one image is required, and the regional statistics can be calculated directly on this image.

References

Bland J M and Altman D G 1986 Statistical methods for assessing agreement between two methods of clinical measurement *Lancet* **i** 307–17

Kaufman L, Kramer D M, Crooks L E and Ortendahl D A 1989 Measuring signal to noise ratios in MR imaging *Radiology* **173** 265–7

Lerski R A and de Certaines J D 1993 Performance assessment and quality control in MRI by eurospin test objects and protocols *Magn. Reson. Imaging* **11** 817–33

McRobbie D W 1996 The absolute signal to noise ratio in MRI acceptance testing *Br. J. Radiol.* **69** 1045–8

Price R R, Axel L, Morgan T, Newman R, Perman W, Schneiders N, Selikson M, Wood M and Thomas S 1990 Quality assurance methods and phantoms for magnetic resonance imaging: report of AAPM nuclear magnetic resonance task group no 1 *Med. Phys.* **17** 287–95

Redpath T W 1998 Signal to noise ratio in MRI *Br. J. Radiol.* **71** 704–7

Sijbers J, den Dekker A, van Audekerke J, Verhove M and van Dyck D 1998 Estimation of the noise in magnitude MR images *Magn. Reson. Imaging* **16** 87–90

Simmons A, Tofts P S, Barker G J and Arridge S R 1994 Sources of intensity nonuniformity in spin echo images at 1.5 T *Magn. Reson. Med.* **32** 121–8

Wicks D A G, Barker G J and Tofts P S 1993 Correction of intensity nonuniformity in MR images of any orientation *Magn. Reson. Imaging* **11** 183–96