Evaluation of Internal MRI Coils using Ultimate Intrinsic SNR

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Abstract
In this work, we calculated an upper bound for signal-to-noise ratio (SNR) that can be obtained using internal coils. These calculated values can be used as a reference to evaluate the performance of internal MRI coils. As an example, we tested the performance of the loopless antenna design.

Introduction
Various disposable internal coils exist for use in the rectum[1], vagina, esophagus[2], urethra[3], and blood vessels[4]. Although there is a clear increase in SNR in the MRI images when these coils are used, it is not known if whether they perform better than the best external coil and there is also always the question of whether it would be possible to design a better internal coil. Currently, there is no formal method of evaluating the performances of these internal coil designs.
Earlier, with a similar motivation, we calculated the ultimate value of the intrinsic SNR (UISNR) for external coils[5] and proposed to use the ratio of the intrinsic SNR value of a coil design with UISNR as a measure of coil performance. In this work, we reformulated the problem in order to evaluate internal MRI coils[6], and use it to test the performance of the loopless antenna design[4].

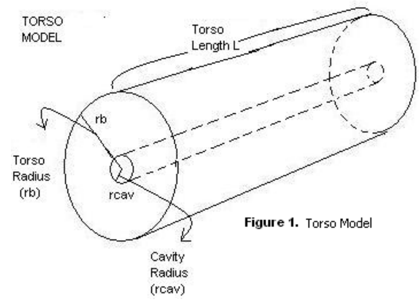

Figure 1. Torso Model

Theory
In the calculation of the ultimate value of the SNR that can be obtained by internal coils, we chose to optimize the associated electromagnetic field without considering the coils that produce these electromagnetic waves, rather than determining the optimum coil design. The calculated UISNR value depends on the object dimensions and electrical properties, as well as on the position of the point of interest.
Our formulation was based on a cylindrical torso model as shown in Figure 1. To simplify the problem, we assumed that the model had uniform electromagnetic properties with a small cavity at its center, where internal coils can be placed. By formulating electromagnetic waves as the weighted sum of the cylindrical waves and using the cylindrical symmetry of the object, we reduced the complexity of the problem.

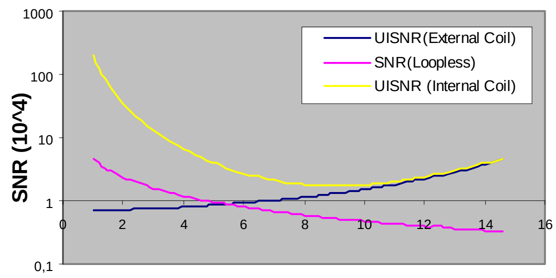

Figure 2. Comparison of 3 SNR Curves

Methods and Results
A MATLAB (version 6.0,Mathworks Inc., Natick, MA) program was developed to calculate the UISNR values. In all calculations, we assumed proton imaging at 1.5Tesla, a uniform conductivity of 0.37 $\Omega^{-1}m^{-1}$, and an epsilon of 77.7. We used the SNR calculations in [Ocali, 97] and compared the loopless antenna design with the UISNR values. First, we plotted the UISNR value for a 20cm-radius torso with a 3mm-radius cavity as a function of the position of the point of interest (see Figure 2). As the point of interest, approaches the internal or external surfaces, the SNR that one can obtain increases. In the same figure, we plotted the UISNR value that can be obtained from external coils. The UISNR values are very similar for radii larger than 10cm. On the other hand, at 2cm away from the cavity, the best internal coil may produce 100 times more SNR than the best external coil. In the same graph, we also plotted the intrinsic SNR value of a loopless design. As can be seen, although there is significant room for improvement in the SNR of the loopless design, it produces significantly higher SNR than is possible with an external coil. The SNR curve of the loopless design intersects with the external coil UISNR value. This intersection point determines the useful radius of the loopless design. The loopless design outperforms any external coil at any point of interest that is located closer than this intersection point. The useful radius is approximately a linear function of the torso radius and is plotted in Figure 3. For the loopless design, the useful radius is approximately one-quarter of the radius of the body. We divided the intrinsic SNR of the loopless design to the UISNR of the internal coil to understand how much room there is for SNR improvement. At, for example, 5cm away from the loopless antenna, it appears that there may be a design that might perform 5 times better than the loopless design, but, as yet, it is not clear what that design might be.
It should be noted that the loopless design we tested was 0.5mm in radius and the cavity used in this example was 3mm. Conclusion of this analysis is that for relatively large cavities, designs that provide better performance than a loopless design are possible.

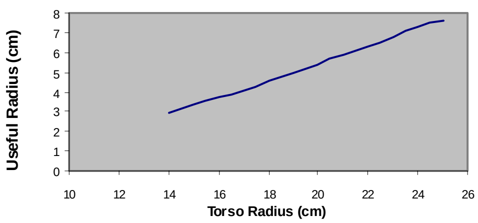

Figure 3. Loopless and External Coils Comparison

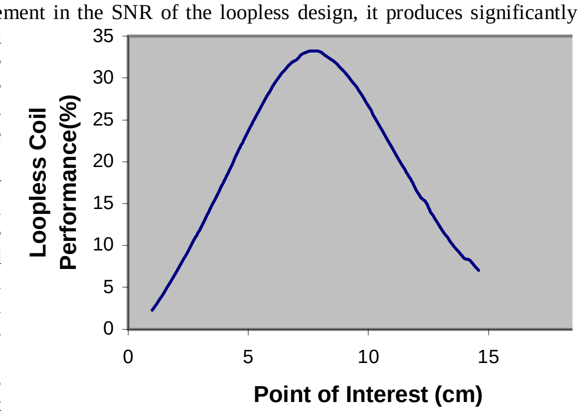

Figure 4. Loopless Coil Performance

Conclusion
We have developed a method to calculate the ultimate value of the SNR that can be obtained with internal MRI coils. We propose to use this value as a reference to evaluate internal MRI coils. As an example, we have evaluated the performance of the loopless antenna, determined useful radius, and assessed the extent of improvements required.

References: (1) MD Schnall, et al. Prostate cancer: local staging with endorectal surface coil MR imaging.Radiology. 1991 Mar;178(3):797-802. **(2)** K. Shunk, et al. Transesophageal magnetic resonance imaging. Magn Reson Med. 1999 Apr;41(4):722-6. **(3)** Quick HH, et al. Endourethral MRI, Magn Reson Med 2001 Jan;45(1):138-46 **(4)** O. Ocali, and E. Atalar, Intravascular MRI Using a Loopless Catheter Antenna. Magn Reson Med. 1997 Jan;37(1):112-8. **(5)** O. Ocali, and E. Atalar, UISNR in MRI, Magn Reson Med. 1998 Mar;39(3):462-73. **(6)** Imad Amin Abdel-Hafez, UISNR in MRI by Optimizing EM Field Generated by Internal Coils, Masters Thesis, Bilkent University, 2000.

Acknowledgments: This work was supported by NIH grants RO1RR15396, R01HL61672 and R01HL57483. We would like to thank Ms. Mary McAllister for her valuable editorial support.