B_1 reduction annular cylinder (rigid sleeve) creates realistic body quantitative MR phantom – a proposal

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The concept of quantitative MR (qMR) has existed for over two decades, offering direct access to biology and physiology, yet its implementation is still not straightforward or widespread. Multi-centre studies show large differences between MR machines; good and convenient accuracy (closeness to the true value) and precision (repeatability) are still elusive.

Phantoms (test objects) for qMR, particularly head MRI, are now well-designed and quite widely available. Often they contain materials whose quantitative parameters (e.g. relaxation times, mean diffusivity) are traceable to metrology standards [1]. Thus the performance of a qMR procedure in phantoms can be regularly monitored, accuracy and repeatability can be measured, and a variety of machine failures can potentially be detected, thus aiding the use of qMR. If a measurement procedure can produce good performance in phantoms, it is tempting to deduce the procedure is good.

Good phantom performance is a *necessary* but not *sufficient* criterion to establish the validity of *in-vivo* measurements. A measurement procedure could perform perfectly on a phantom yet fail *in-vivo*. This is because there are often other imperfections in *in-vivo* measurements which are absent in phantoms (e.g. flip angle errors). Thus it is important to develop and use *realistic* phantoms (i.e. those which contain the imperfections encountered *in-vivo)* – see table 1*;* if a procedure works well on a *realistic* phantom, in principle this proves it works *in-vivo* (provided that the phantom really is realistic). Realistic phantoms are therefore the key to increasing the performance, acceptance and use of quantitative MR methods.

B_1 imperfections are probably the most important factor in degrading in-vivo measurements. They vary according to the tissue composition, the size of the subject being imaged, and the location being examined. They may be more of a problem for body imaging than head imaging, and for higher values of static field B_0. Probably no single phantom can replicate the variety of encountered B_1 imperfections.

B_1 imperfections arise from two distinct phenomena. Firstly, RF penetration of the more central tissue is limited by eddy currents in the more superficial tissue. The effect of this is to reduce the transmitted RF field B_1^+ [2]. An opposing phenomenon is that dielectric resonance [3] can increase B_1^+ near the centre of the object (independent of any electrical conductivity effects); this phenomenon is most pronounced in non-conducting phantoms. The effect is to produce a range of incorrect values of flip angle FA within the subject [4,5] (see fig 1). This defect can be mitigated by

the vendor's procedure to set the FA inside the subject, although it cannot be accurate at all locations. The 2nd effect is that the RF signal B_1^- from the precessing magnetisation inside the subject may have difficulty in 'escaping' to the receive coil; then the observed signal and SNR will be reduced.

The primary consequence of incorrect FA is in Variable Flip Angle (VFA) T_1 and in DCE measurements; a 1% error in FA directly translates to an error of 2% in the estimated T_1 value [6]. The loss of SNR is often less serious, although in T_2 and ADC measurements the attenuated signal value may be difficult to estimate (and biased) in the presence of noise. Thus B_1 imperfections can be significant in *in-vivo* measurements whilst being absent in phantom measurements.

It is proposed here to place a set of annular cylinders (rigid sleeves) one at a time around an established head phantom to give a variety of unknown B_1 imperfections, and thus a set of realistic (virtual) body phantoms (figure 2). The sleeves would contain aqueous NaCl solutions of various concentrations, thus giving a range of unknown B_1 attenuations. The performance of a well-designed sequence would give correct values of T_1 even in the presence of several different B_1 values.

Each B_1 sleeve can be made from two concentric plastic cylinders. It should be large enough to contain a typical head phantom (200 mm diameter), and small enough to fit inside the body transmit coil with enough clearance to place a wrap-around receive coil around the sleeve. Diameters of 350mm (internal) and 400mm (external) would enable the head phantom to be placed at different positions with respect to the magnet isocentre (figure 2). The length should be at least twice the diameter, to prevent B_1 access through the ends of the sleeve; thus a length of 800 mm might be appropriate. If a set of say three sleeves was to be made, they could perhaps be made to slide inside each other for more convenient storage.

To establish suitable values for the NaCl concentration, some experimental MRI measurements would be needed at several B_0 values to determine i) how much B_1^+ is altered in body imaging, for a range of locations and body types (although published studies [4] give guidance), and ii) what values of concentration provide a comparable range of B_1^+ values. Alternatively, published models [5] could perhaps be used to estimate both of these.

In summary, it is proposed that a set of B_1 sleeves be used in routine body QA for qMR. These would be cheap and simple to manufacture, and could be used widely. Existing head phantoms could then be used to validate measurement procedures in a realistic way. Note that the proposed sleeve is not designed to calibrate the procedure in any way; it is to validate an existing procedure. It could then be established how a measurement procedure performs under a variety of B_1 imperfections. Maybe the B_1 sleeve will play a part in creating the perfect body qMR machine [7].

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References:

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Figure 1:

An example of B_1^+ distribution in the body at 3T (from Sacolick et al [4]). The colour images (lower row) show B_1 values with an approximate range from 0.04 to 0.09 gauss.

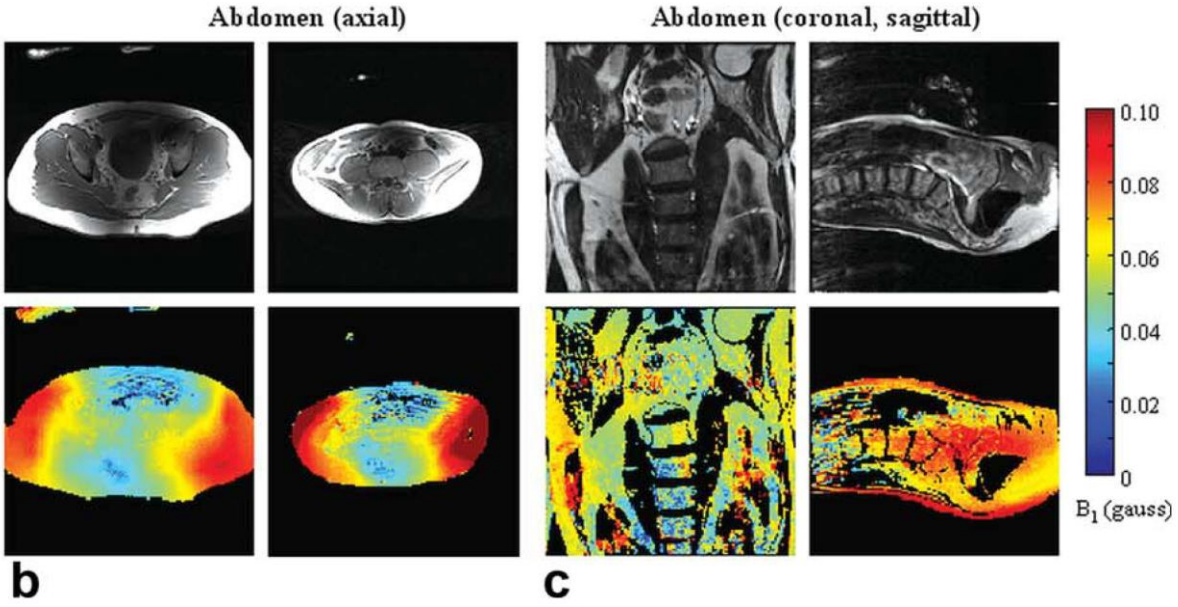
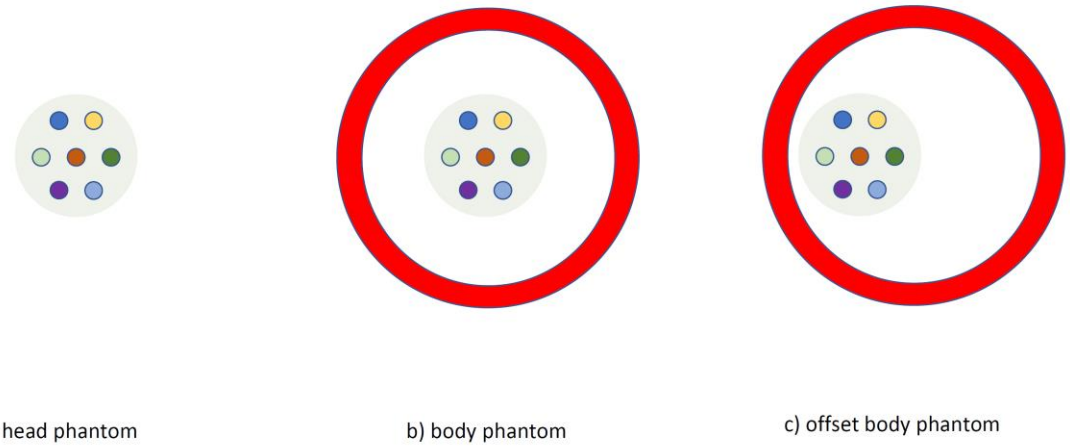


Figure 2:



An existing head phantom (a) can be converted to a body phantom (b) by the addition of a concentric cylinder containing NaCl solution (**red**). Measurements offset from the isocentre are possible (c)

Table 1:

Establishing the validity of an *in-vivo* quantitative MR procedure using phantoms

Phantom type	Testing for *in-vivo* validity in presence of imperfections	Role of good phantom performance[c] in establishing validity of *in-vivo* procedure
#1 traceable[a]	some imperfections	necessary
#2 realistic[b] and traceable	all imperfections	necessary and sufficient

[a] traceable: true value of parameter is known (measured in a metrology lab).

[b] to establish realism the types of imperfection in the *in-vivo* measurement procedure have to be identified, then replicated in the phantom.

[c] to demonstrate good phantom performance the procedure measurements should be: 1. accurate (close to true value) 2. reproducible (at different centres) and repeatable (at one centre) and 3. sensitive (accurate over a range of true values).