Towards the Perfect Quantitative MRI machine

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Introduction

There is continued, often intense, activity to improve the performance of quantitative MRI measurement techniques (fig 1). Yet how can we know when our technique is good enough, or even 'perfect' in its used context? The concept of the 'Perfect Quantitative MRI (qMRI) machine' is explored[1]; this offers a perspective on efforts to improve quantitative performance[2].

Proposals

We propose firstly:

A Perfect Quantitative MRI machine is one that, in making a measurement, contributes no significant extra variation to that which already exists from biological variation.

Various grades of performance can be envisaged, depending on the purpose of the measurement. Comparison with normal variation will be the most demanding; comparison with variation within a disease might also be appropriate, depending on the context, and would be less demanding. The grade will depend on the MR parameter being measured. Some might be easy to achieve; others might need a long sustained effort.

Secondly, here a proposal is made for three levels, each with an appropriate medal[3] (see table 1).

***Bronze medal*:** In a group comparison, the Instrumental Standard Deviation (ISD) should be ≪ Group SD (see table 1).

***Silver medal*:** in multicentre studies, inter-centre variation has to be controlled. MTR histogram matching using body-coil transmission[4] is probably a perfect silver-medal MTR machine.

***Gold medal*:** in a serial study, instrumental variation can hide subtle within-subject biological changes. The power of a serial study can be limited by such biological variation; often this is small and unknown, and may be extremely hard to measure.

Gold medals, awarded when ISD is < 30% of the within-subject SD, will be the hardest to obtain; for some MR parameters the gold medal may be impossible. Exceptions are cerebral blood perfusion (measured by ASL) and lesion load in relapsing-remitting MS, where the natural (biological) variation is high and perfect qMRI machines already exist.

Administration of a medal scheme

Awarding of medals might be determined by a journal reviewer, or by perhaps by the ISMRM. Prizes might also be awarded[5].

Table 1: proposed medal system

Abbreviations:
SD = standard deviation;
BCSD = between-centre SD
GSD = group SD
ISD = Instrumental SD
WSSD = within-subject SD

Medal	Target study	Criterion
bronze	Group comparison	ISD < 0.3 GSD
silver	Multicentre study	BCSD < GSD
gold	Serial study	ISD < 0.3 WSSD

Fig 1: The effect of instrumental precision (ISD) on the statistical power of a study, and the required sample size.

By reducing the ISD, the required size can be dramatically reduced, giving a saving in cost and time. (This is a simulation[2] based on a group comparison between controls and patients).

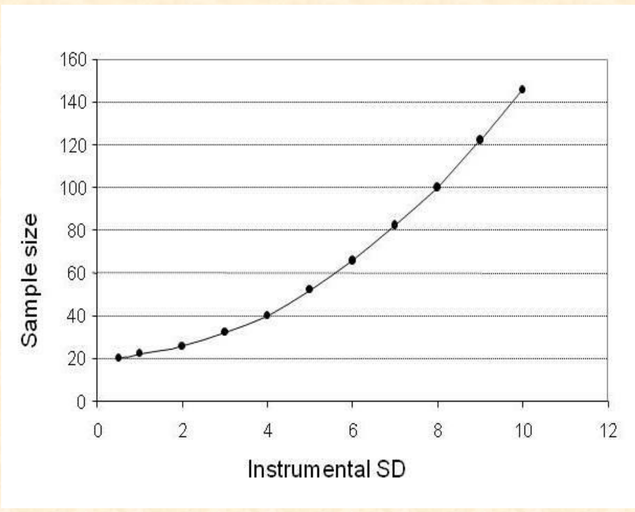

Fig 2: Reported values of normal variation in MTR vary widely, and imperfect machine reproducibility probably increases these. Here the measured normal range was halved after ISD was improved (open circles).

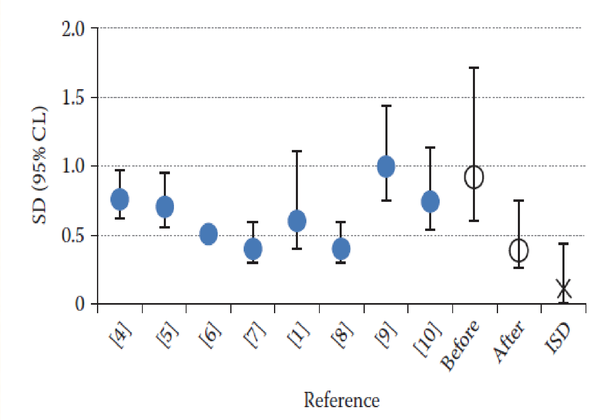

FIGURE 3.8 Normal variation for white matter MTR, and influence of ISD. Blue circles are published values of SD (units for MTR are pu; mean was 38–40 pu) from eight centres; error bars show uncertainty in SD estimate *Before* is authors' first value, almost the highest value of nine centres. After solving a scanner instability problem ISD was low (≃0.2 pu) and the re-measured normal range (*after*) dropped to the lowest value of nine centres. (Adapted from Haynes, B.I., *et al.*, *Measuring scan-rescan reliability in qu imaging reveals instability in an apparently healthy imager and improves statistical power in a clinical study, ISMRM Annual Scientific Meeting, Stockholm*, p. 2999, 2010.)

[1] The concept of the 'Perfect Machine' originates in the building of the 200 inch Palomar telescope in 1933-48.
[2] See PS Tofts *Chapter 1: Concepts: Measurement in MRI* in *Quantitative MRI of the Brain: principles of physical measurement*, eds M Cercignani, NG Dowell and PS Tofts 2018.
[3] Medals are proposed, inspired by the ISMRM scheme
[4] Tofts Magma 2006; 19(4):209-22
[5] a kind of modern day Longitude prize, inspired by the lifetime work of the clockmaker John Harrison; this might be attractive to a philanthropist. The Longitude prize of £20k was offered by the British parliament in 1714.