Evaluation of a Manganese Chloride Phantom-Based Magnetic Resonance Imaging Technique as a Quantitative Tool for Predicting Human Lumbar Intervertebral Disc Condition

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Introduction

Degeneration of lumbar intervertebral discs is characterised biochemically by a decrease in glycosaminoglycan concentration and a resulting loss of hydration in the central nucleus pulposus [1]. Such a loss of hydration reduces the discs’ ability to evenly distribute and transmit compressive forces between adjacent vertebrae by maintaining a central region of constant hydrostatic pressure, leading to progressive structural and mechanical degradation [2]. Application of magnetic resonance imaging (MRI) as a non-invasive, quantitative tool for assessing disc condition is currently an area of active research, with T2-weighted signal intensity shown to correlate with disc water and glycosaminoglycan content [3]. A factor limiting the translation of such techniques to routine clinical use is the intrinsic radio field heterogeneities which exist between different MRI scanning platforms, in turn leading to inconsistent signal intensities. Recently, a set of manganese chloride (MnCl₂) based phantoms capable of producing an approximately linear signal intensity response series was proposed as one means of overcoming this challenge [4]. The objective of this study was to evaluate, in-vitro, the efficacy of a manganese chloride phantom-based magnetic resonance imaging technique for predicting lumbar intervertebral disc condition. It was hypothesised that MRI rankings would correlate significantly with intervertebral disc water content, glycosaminoglycan content and macroscopically determined disc grade.

Methods

14 human lumbar spines (levels T12 to S1) from cases ranging in age from 28 to 87 years were obtained at autopsy following research ethics and next of kin approvals. From these a total of 16 intervertebral discs were selected for analysis (6 x T12-L1, 4 x L2-L3 and 6 x L4-L5). Nine cylindrical phantoms were constructed, containing serially graded concentrations of MnCl₂: (1: 0.01000 mM; 2: 0.07125 mM; 3: 0.13250 mM; 4: 0.19375 mM; 5: 0.25500 mM; 6: 0.31625 mM; 7: 0.37750 mM; 8: 0.43875 mM; 9: 0.50000 mM) suspended in gelatin. These phantoms were mounted radially around a custom-made magnetic resonance-inert cradle device (Figure 1, left).

Each lumbar spine was inserted into the central tube of the cradle device, and both were placed inside a transmit-and-receive knee coil for signal enhancement and imaged using a 1.5 tesla magnetic resonance scanner. Spin-echo sequence images were acquired with the following parameters: a repetition time of 2000 ms; an echo time of 50 ms; a slice thickness of 3 mm; a field of view of 160 mm; and an acquisition matrix of 512 x 512. Intervertebral discs were imaged using a seven slice acquisition block with the central slice orientated through the centre of the disc, transverse to the axis of the spine (Figure 1, right). The central slice of each disc was identified and the T2-weighted signal intensities of the disc and the nine phantoms at that location were calculated. For each disc, phantom number (MnCl₂ concentration) plotted against phantom signal intensity was approximated by a 3rd order polynomial. Using this polynomial each disc signal intensity was converted to an MRI ranking in the range one to nine. Macropscopic disc grades were determined using a four point adaptation of the Thompson scheme [5] modified for transverse sections. Discs were then weighed before and after drying for 24 hours at 60°C to determine water content. Finally, following proteinase K digestion, the uronic acid content of each disc was measured as an indicator of total glycosaminoglycan content. Relationships between MRI ranking, water content and uronic acid content were assessed using linear regression analyses. For comparisons with degenerative condition, discs were classified as either non-degenerate (grades 1 or 2) or degenerate (grades 3 or 4). The influence of disc condition on MRI ranking, water content and uronic acid content was assessed using Student’s t-tests. Significance was reported for two-tailed p values less than 0.05.

Results

Macroscopic grading revealed seven grade two discs, six grade three discs and three grade four discs. MRI ranking exhibited significant, moderate and negative correlation with total disc hydration (r = 0.56, p = 0.03, Figure 2, left), and significant, strong, negative correlation with total disc uronic acid content (r = 0.80, p < 0.001, Figure 2, right). To assess the capacity of MRI ranking to predict disc macroscopic grade, discs were classified as either non-degenerate (grades 1 or 2, n = 7) or degenerate (grades 3 or 4, n = 9). A Student’s t-test revealed MRI rankings were significantly higher for degenerate specimens (p = 0.03, Figure 3). Water content was found to be significantly reduced for degenerate specimens compared with non-degenerate specimens (p = 0.01), while uronic acid content was not (p = 0.11) (Figure 3).

Discussion

In this study, MRI combined with a set of MnCl₂-based phantoms was investigated as a quantitative tool for predicting human lumbar intervertebral disc condition. The technique described has strong promise as a viable clinical tool for the diagnosis of lumbar disc degeneration as it provides a standardised series of reference phantoms which exclude the effects of intrinsic field heterogeneities, requires short scan times and simple T2-weighted signal intensity measurements, utilises predefined regions-of-interest requiring minimal knowledge of disc anatomy by imaging staff, and facilitates accurate prediction of disc glycosaminoglycan and water contents and degenerative condition. Future studies should focus on establishing ‘normal’ and ‘degenerate’ ranking criteria similar to those used for classifying osteoporosis.

References


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