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ORIGINAL ARTICLE

Comparison of three approaches for defining nucleus pulposus and annulus fibrosus on sagittal magnetic resonance images of the lumbar spine

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Summary *Objective:* To compare three methods commonly used in the literature to define intervertebral disc nucleus pulposus (NP) and annulus fibrosus (AF) on magnetic resonance (MR) images.
Methods: Fifty-two patients (26 males and 26 females; age range, 23—76 years) were recruited for this study; they underwent standard T1/T2-weighted MR imaging, and T2 and T1rho mapping acquisitions. The corresponding midsagittal images were analysed and a total of 256 discs were evaluated, using three different region-of-interest (ROI) drawing methods: (1) radiologist-guided manual ROI (M-ROI); (2) five square ROIs where each measured 20% of the midline disc diameter (5-ROI); and (3) seven square ROIs placed horizontally from anterior to posterior (7-ROI) to define NP and AF. The agreement between the three ROI methods was assessed using intraclass correlation coefficient values and Bland—Altman plots.
Results: Inner AF and NP could not be differentiated on T1/T2-weighted MR imaging, T2 maps, or T1rho maps. The intraclass correlation coefficient values were all > 0.75 when comparing the 5-/7-ROI methods with the M-ROI methods for NP, and 0.167—0.488 for AF when comparing the 7-ROI method with the M-ROI method. The intraclass correlation coefficient values for AF increased to 0.378—0.582 for the M-ROI method compared with the 5-ROI method. Comparable results were obtained with Bland—Altman plots.

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Conclusion: The 5-/7-ROI methods agreed with the M-ROI approach for NP selection, while the agreement with AF was moderate to poor, with the 5-ROI method showing slight advantage over the 7-ROI method. Cautions should be taken to interpret the MR relaxometry findings when 5-/7-ROI methods are used to select AF.

Introduction

Intervertebral disc degeneration is the consequence of a variety of genetic, mechanical, traumatic, and nutritional factors, as well as normal ageing [1]. Early signs of disc degeneration are manifested by biochemical changes, including loss of proteoglycans, loss of osmotic pressure, and dehydration [1]. In the later stages of disc degeneration, morphological changes occur, including loss of disc height, disc herniation, annular tears, and radial bulging [2]. Elderly women tend to have more severe disc degeneration than elderly men, and elderly women are more likely to have a narrow lumbar disc space than elderly men [3—5]. Magnetic resonance imaging (MRI) has become the standard noninvasive imaging modality to assess intervertebral discs [2,6—19]. Morphologically, on T2-weighted MR images, disc degeneration is seen as a reduction in the signal of the nucleus pulposus (NP) and inner fibres of the annulus.

The Pfirrmann 5-level grading system is widely used for the evaluation of disc degeneration on MR images [20]. To increase the discriminatory power, the Pfirrmann system has been modified by increasing the number of grades from 5 to 8 [21]. While the 5- and 8-level grading systems provide semiquantitative evaluation of disc degeneration, quantitative MR T2 relaxation time, T1rho relaxation time, and glycosaminoglycan chemical exchange saturation transfer (gag-CEST) measurements of the disc reflect the intrinsic material properties of disc tissues [17,22—30]. These molecular imaging approaches may have the potential to detect subtle differences in tissue composition that may not be apparent in T2-weighted image anatomical assessment and, therefore, would probably be more useful for detecting early disc changes.

T2 relaxation time measurement has been reported to be sensitive to changes in collagen and water content in intervertebral discs, and T2 relaxation time decreases with disc degeneration [17,22—24]. By contrast, T1rho relaxation measurement, which probes the interaction between water molecules and their macromolecular environment, is suggested to have the potential to identify early biochemical changes in intervertebral discs. It was shown that T1rho strongly correlates with proteoglycan content in NP in cadaveric human discs [25]. *In vivo* studies also demonstrated differences in mean T1rho values between NP and annulus fibrosus (AF), and a correlation between T1rho values and degenerative grades was observed [14,26—28]. It has been shown that gag-CEST indicates a correlation between gag-CEST measurement and glycosaminoglycan concentrations. As disc degeneration increases, gag-CEST in NP decreases [29—31].

Recently, MR relaxation time-based techniques and their relationship to disc degeneration [8,12,15,18], dehydration [19], diurnal changes of composition [16], and other functional disc mechanics such as stiffness [11] have been investigated. However, the role of specific biochemical changes in the altered MR signal intensity is still not well understood. An articular cartilage study showed that the loss of proteoglycan results in an increase in T1rho relaxation time [32]. By contrast, T1rho is reported to increase with sulfated glycosaminoglycan content in degenerative discs [17]. The AF functions as a rigid containment for the NP, which is composed of abundant sulfated glycosaminoglycans in a loose network of Type II collagen. It is a hydrated gel containing approximately 25% (dry weight) of collagen and 50% (dry weight) of proteoglycan [33]. Proteoglycans of the nucleus osmotically exert a "swelling pressure", which enables it to support spinal compressive loads. By comparison, AF is made up of coarse Type I collagen fibres, and contains 67% (dry weight) of collagen and a low concentration of proteoglycans [22,33]. During the initial phase of disc degeneration, loss of proteoglycans and Type II collagen in NP is observed [34]. Proteoglycan loss reduces the capacity of NP to bind water and leads to loss of hydration. Later, Type I collagen fibres replace Type II collagen fibres in NP. Tensile properties of the AF tissues are also altered in degenerated discs [35]. On T2-weighted images, T2 map, or T1rho map, both NP and inner AF show nearly the same level of high signal intensity, and the boundary between inner AF and NP is often indistinct [14,30,36—38].

It was suggested that discs can be characterized by T2 mapping and that changes in the integrity of the discs can be assessed before there is a change in the Pfirrmann score [23,32]. However, accurate MR relaxivity mapping at spine discs can be difficult due to the extensive susceptibility effect in the regions. With disc degeneration, the collagen lamellae of the AF increase in thickness and become fibrillated. It is known that AF degeneration is a critical factor in disc stability [2]. In the lumbar spine, the posterior AF is particularly a target for disc abnormalities. For example, annular tears can be identified in MR images by the presence of a high-intensity zone in the posterior AF, which is a marker of a painful posterior annular tear [39]. Recently, Ogon et al [40] reported that the T2 relaxation time of the discs tended to be lower in chronic low back pain patients, and these values were significantly different within the posterior AF. However, chronic low back pain did not show correlations with T2 values in the anterior AF or NP, because of low sensitivity against noxious stimuli in the front part of the disc. This finding further heightens the importance of accurate disc component segmentation, as