AUTOMATIC QUANTIFICATION OF 3D MORPHOLOGY AND APPEARANCE OF INTERVERTEBRAL DISCS IN HIGH RESOLUTION MRI

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INTRODUCTION

Intervertebral disc (IVD) degeneration is associated with biochemical and morphological changes. Previously, planar morphological IVD measures (height, width and shape) have been studied in the context of IVD degeneration and ageing, to understand the symptoms and factors influencing the lower back pain[1]. Recent advances in MRI hardware, software and pulse sequence design has provided the capacity to acquire 3D volumetric MRI scans of the human spine with nearly isotropic resolution under 0.5 mm[3] (e.g. 3D FSE), compared to traditional 2D scans acquired with inter-slice gaps of around 3mm. Automatic segmentation algorithms have been developed[2] that extract detailed 3D representations of the IVDs from volumetric MRI. In this work, we present an automatic approach to extract and quantify the novel 3D morphological and appearance information from the IVDs and evaluate performance of the proposed descriptors against traditional 2D measurements in an automatic classification task in which we attempt to detect abnormal IVDs in 1) younger asymptomatic subjects and 2) older symptomatic patients.

MATERIAL AND METHODS

Automatically obtained 3D segmentations of IVDs[2] were used to extract 3 sets of features (Planar measurements, 3D shape parameters, Intensity features), used to automatically detect IVDs with degenerative changes and evaluated against ground truth radiological classification.

[Imaging dataset] Two datasets were used in this study to analyse the degenerative changes in lumbar IVDs (T12/L1-L5/S1). The first dataset consisted of T2w 3D SPACE scans (3T, 176 axial sections, 0.34×0.34mm in-plane resolution,1-1.2mm slice thickness) of 28 currently 'asymptomatic' subjects (32±7.5 yo). Signs of early IVD degeneration were identified by an experienced radiologist (DW) in 15 cases (17/140 lumbar IVDs). The second dataset contained 11 symptomatic patients (55±16.0 yo) presenting for MRI investigation of the lower back pain. These images were acquired in the sagittal plane using traditional 2D T2w TSE sequences (11-15 slices, 0.55-0.75×0.55-0.75mm in-plane resolution, 3-3.5mm inter-slice gap). Images were resampled to isotropic resolution using cubic BSpline interpolation. There were a variety of degenerative changes, including severe IVD damage, observed in the patient dataset. Overall, degenerative changes were identified in 44/66 IVDs. IVDs in both dataset were marked by DW as normal/abnormal and used in our experiments as ground truth reference for evaluation of the automatic classification algorithm.

[Planar measurements - A] The extracted 2D metrics (from the mid-sagittal slice) were: IVD average height, IVD middle width and their ratio.

[3D shape parameters - B] For the first dataset (3D SPACE data of asymptomatic subjects), a 3D statistical shape model[3] (SSM) was build from a subset of 14 manually segmented cases. SSMs describe statistical variations of objects in a training database that are represented by corresponding landmarks (mesh point coordinates in this case). Point distributions of the landmarks are analysed and significant modes of variation are computed by principal component analysis. A segmented IVD is projected on the SSM and weights of the first 2 principal modes of variation are used as 3D shape parameters (Fig. 1a). For the second dataset, the SSM was constructed from the results of automated segmentation after manual inspection for segmentation quality.

[Intensity features - C] Disc degeneration is commonly associated with nucleus pulposus (NP) desiccation, observed as signal intensity attenuation in T2w MRI scans, and structural changes manifested as intensity inhomogeneity inside the NP. The degree of attenuation is an apparent mark of the degeneration process and a significant marker for diagnosis. Changes in MRI signal intensities can be well observed from image histograms. A histogram of a healthy disc typically shows two distinctive intensity peaks, corresponding to the hypo-intense annulus fibrosus and brighter NP. In IVDs with degenerative changes, the peak of brighter intensities will decrease and shift towards the lower peak. To automatically quantify the appearance of the disc, we model the disc intensity histogram by a Gaussian mixture model of 2 normal distributions. This model can fit (expectation maximization algorithm was used) and separate 2 distinct peaks in the histogram and will result into 2 largely overlapping distributions if only one peak is present. Consequently, the degenerative changes can be described by the 2 Gaussian means and variances (Fig. 1d).

[Classification] All 3 feature sets were first evaluated independently using support vector machine classification algorithm. Repeated (300 times) stratified 2-fold cross-validation was performed by splitting both imaging datasets into a training (60%) and a cross-validation set (40%) while maintaining the ratio of healthy and degenerative discs in each. The performance was evaluated using accuracy (ACCU), sensitivity (SENS) and specificity (SPEC) metrics. Next, the features A and B were both combined with features C and the same validation procedure was performed.

RESULTS

Features	Dataset 1 ACCU / SENS / SPEC	Dataset 2 ACCU / SENS / SPEC
A: Planar meas.	0.896 / 0.892 / 0.897	0.628 / 0.626 / 0.630
B: 3D shape	0.919 / 0.917 / 0.920	0.709 / 0.703 / 0.716
C: Intensity	0.890 / 0.887 / 0.890	0.923 / 0.930 / 0.926
A + C	0.920 / 0.923 / 0.920	**0.932 / 0.934 / 0.929**
B + C	**0.936 / 0.944 / 0.935**	0.903 / 0.905 / 0.902

Table 1. Classification results.

DISCUSSION AND CONCLUSION

Results (Table 1) on dataset 1 show that the 3D shape descriptors (B) are advantageous compared to planar measurements (A) for detection of early degenerative changes. As expected, the best performance is obtained when combing the appearance and morphological features together. The IVD examples in Fig. 1 show how the descriptors are used to quantify relative IVD changes. In dataset 2, neither of the morphological feature sets (A, B) describe well the advanced
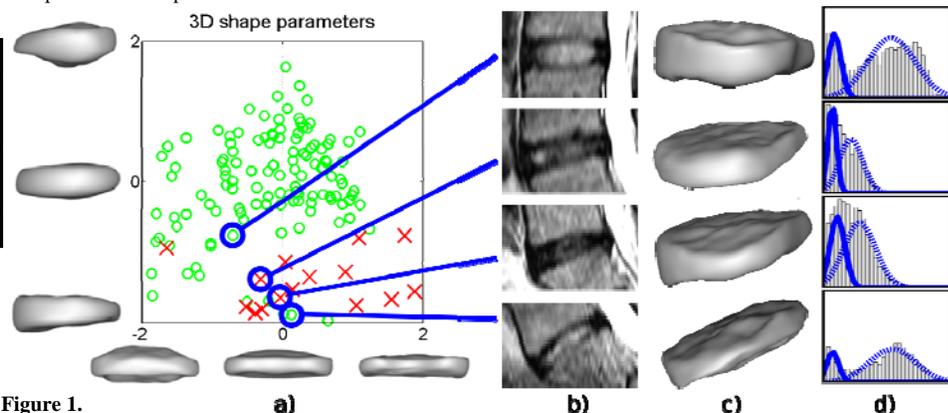

Figure 1. Projection of the dataset 1 onto the first two modes of variation is shown in a). First mode (horizontally) is associated with relative disc thinning, the second mode (vertically) with anterior-posterior wedging. Most of the abnormal discs (red cross) are located in the bottom right area, describing IVD space narrowing. MRIs of four example IVDs are shown in panel b), their automatic segmentations in c) and their histograms in d). The IVDs show a continuous relative space narrowing, which is reflected by the spatial relationship of the corresponding points in a). The NP signal intensity is the lowest in the middle two, resulting into a single intensity peak in the histograms d) and two close and overlapping Gaussian distributions.

degenerative changes and ageing, and the intensity features contain most relevant information (although a slight improvement is achieved when combining A and C). We have presented an automatic way to quantify 3D morphology and appearance of IVDs from 3D MRI and shown some advantages of the novel features for detection of early degenerative changes. Automatic 3D quantification can benefit research studies investigating degenerative processes and ageing, prospective evaluation of pharmaceutical or surgical interventions and have the potential to provide novel CAD tools for clinical practice.

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