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Segmentation of Lumbar Intervertebral Discs from Spine MR Images

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Abstract— **Degeneration of the intervertebral disc is a very common issue these days and results in protracted and persistent back pain, and finally in most of the spine surgical procedures. MRI is the modality of preference, for diagnosing these disc degeneration issues. In this paper, both normal and degenerated lumbar intervertebral discs (T2-weighted sagittal MR images of the spine) are being considered for a fast and robust unsupervised watershed segmentation algorithm.**

This task is very much challenging because of: partial volume effects and overlapping gray-level values between neighboring tissue classes. In order to overcome these problems preprocessing has been done in which normalization of the MRI images is done by performing CLAHE operation followed by de-noising by morphological opening and filling of the holes and then applying segmentation algorithm to the MR spine images. Also we have implemented a level set segmentation for the same data base. Level set segmentation is a robust technique but very much time consuming compared to the watershed algorithm used.

***Index Terms*— segmentation, watershed segmentation, level set segmentation, intervertebral disc, nucleus pulpopus, annulus fibrosus, MRI, hernia.**

I. INTRODUCTION

Segmentation is a very essential analysis function and is all about segregation of structures of interest either from the background or from each other and a number of algorithms have been developed in the field of image processing [1].

Image segmentation is an important step toward the analysis phase in many medical image-processing tasks such as characterization of different image components for analyzing anatomical structure and tissue types, spatial distribution of function and activity, and pathological regions, image guided operation, tumors radiotherapy, and evaluation of therapies [2].

Segmentation of medical images is very crucial for doctors to give a correct diagnosis, surgical planning and early disease detection. At the same time, the structure and conFigureuration of human body are very complicated, there are great differences between different individuals, and low resolution and strong noise are two common characteristics in most medical images. With these characteristics, medical images cannot be precisely segmented and extracted for the visual content of their features. To overcome these limitations many segmentation techniques have been proposed in the literature [3 - 8]. Introducing new methods into medical image segmentation and combining many algorithms effectively is a very hot topic of research these days [3].

Research shows that there has been harsh scarcity of radiologists in the past decade and as per the projectionists there will be a very high demand of the radiologists, much greater than the supply, in near future [9]. Since PACS (picture archiving and communication system) has almost solved the retrieval and visualization part of the problem, [10] so a CAD (computer-aided diagnosis) system, to generate diagnostic results from clinical MRI(magnetic resonance imaging) and CT (computed tomography)scans, would reduce the burden on a radiologist and would also help with proper diagnosis. This cognizance inspires us to strive towards the development of an algorithm to detect lumbar abnormalities.

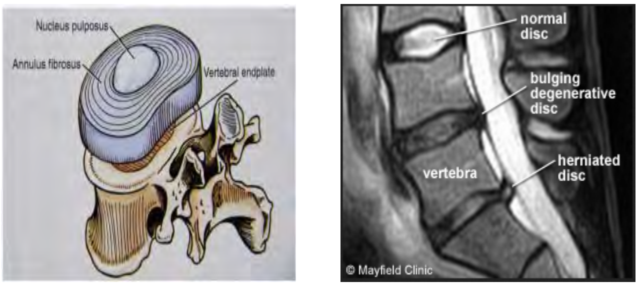
Requirements for CAD systems of the spine are unique as we need to localize and correctly identify each intervertebral disc and label them, before we can proceed to the important task of detecting abnormalities. Localization of lumbar discs is a challenging problem due to a wide range of variability in the size, shape, count and appearance of discs and vertebrae [11].

The intervertebral discs are cartilaginous in nature and behave as shock absorbers and provide flexibility to the spine. It is composed of a soft mucoid center, the nucleus pulposus, surrounded by a strong but flexible ring of collagen fibers the annulus fibrosus (Figure. 1a).

Factors responsible for degeneration in the intervertebral disc are: aging, mechanical loading, trauma, nutritional, and genetic factors [12], and are summarized under the term "intervertebral disc degeneration" [13]. The consequences of disc degeneration are associated to chronic back pain [12] and also are responsible for over 90% of surgical spine procedures [14].

Spinal magnetic resonance (MR) imaging is widely used non-invasive diagnostic techniques, for diagnosis of intervertebral disc abnormalities [14]. In sagittal T2-weighted MR images, a normal disc appears as a bright ellipse (the nucleus) surrounded by a dark ring (the annulus) [Figure.

1(b)]. On the other hand, a degenerated disc appears darker; the nucleus is not well distinguished from the annulus, while its shape is somewhat irregular [Figure. 1b]. [14], [15].



(a) (b)

Figure 1a. The intervertebral disc is shown lifted up somewhat in order to reveal the endplate. Neumann, 2010, page 329. Figure 1b. normal and degenerated intervertebral disc. (http://www.abcswfl.com/advanced_back_care.html).

Manual disc assessment is very much time consuming. Any system which offers an accurate delineation of discs can facilitate diagnosis to a very great extent. Developing such an algorithm to locate or segment the discs in MR images is very much challenging because (a) non-uniformity of intensities over the same class of tissues existing between patients, (b) difference in shape and position of structures between patients because scoliotic deformity, (c) relative variation of intensity along the spine because of different structures surrounding the spine at different levels.

Accurate segmentation of intervertebral discs would be useful in quantification of disc degeneration and computer-aided diagnosis of the disease as well as computer-assisted spine surgery. So far, most studies dealing with the quantification of disc features for diagnostic or surgical purposes have been based on manually segmented data [16–19].

In this paper, both normal and degenerated lumbar intervertebral discs are being considered for unsupervised watershed segmentation [20]. Watershed along with other techniques has been widely used in cardiology and in neurological images using different modalities. Such as ultra sounds in cardiology [21] and MR on neurological images [22-24]. It has also been used on MR spine images but the pre and post processing steps taken were altogether different [30].

As we know that, the use of the watershed method on gradient image leads to over-segmentation problem [24-26] and the searched contours are lost in a bunch of irrelevant ones. In this paper markers, based on morphological operations, are used to reduce the effect of over-segmentation. In such a method inferred knowledge of the shape of the concerned object is included by introducing internal markers, which may be defined as sets of connected pixels of the concerned region and external markers that correspond to the background. The external markers, representing the deepest valley lines, inundate every internal marker.

Level set segmentation method, which has already been implemented on MR brain and breast images, has also been implemented here on MR spine images [27].

In the consecutive sections, we discuss the related work (Section 2), material and methods and our approach for disc detection (Section 3) and discussion and conclusion in the section 4.

II. RELATED WORK

In this section, review of some of the primary techniques of segmentation available in the literature for MR spine images is presented.

Multi-feature boundary classification along with mesh inflation has been used for segmenting verbtebral bodies in MR images. This approach, however, significantly decreases the reliability of any subsequent diagnosis [28].

in another research Hough transform has been used for tracking discs using self-adaptive window. But it fails in patients with severe scoliosis because there would be insufficient spine coverage [29].

Watershed segmentation technique along with morphological operations was used for the segmentation of intervertebral disc and spinal canal from MR images [30].

Articulate mesh models were used optimized with a higher order Markov random field framework for the segmentation of CT and MR spine images. A novel conditional regression kernel was used to map samples. [31].

A graph cut algorithm in conjunction with morphological operations for preprocessing has been used for the segmentation of intervertebral disc. Initial seeds for the algorithm were obtained from extracting several features from training images and comparing them with images blocks [32].

Fuzzy C-Means algorithm combined with atlas approach was also developed for spine MR images. The combined algorithm minimizes the severe leakage of disc border due to overlapping grey-level values between disc and surrounding tissues [33].

Spectral and statistical texture features have also been used in conjunction with watershed segmentation. Over here k-NN classifier has been used with the selected statistical and spectral texture features for automatic segmentation of intervertebral disks of scoliotic spines from different types of magnetic resonance (MR) image sequences. [34].

Adaptive boosting algorithm, which is an statistical learning approach, having three major contributions; namely the ID3-like balance tree quantization, paired feature representation, and Bayesian weak classifiers, has also been proposed but for vertebrae detection from MR images [35].

Probabilistic atlas based robust fuzzy C-means clustering along with elastic atlas robust fuzzy C-means approaches were also introduced for the segmentation of lumbar intervertebral discs, suffering from different degenerations', from spine MR images. But there was a slight drop in classification accuracy [36].

III. MATERIALS AND METHODS

A. *IMAGE ACQUISITION SYSTEM*

The MR images were taken and gathered from MEDICARE Diagnostic imaging center, Srinagar, Jammu and Kashmir, with a 3T Magnetom Skyra system from Siemens. The RF trans-receiving unit consisted of body coil. The following acquisition parameters were implemented in the sagittal plane of a 3D multi echo data image combination sequence: repetition time (TR) = 3300 ms, echo time (TE) = 117 ms, flip angle = 90°, field of view = 32 cm, slice thickness = 3 mm, inter-slice gap = 0.8 mm, matrix = 512 × 512, voxel size = 0.625 × 0.625 × 4mm3 , number of averages = 1.

In the present study, 100 lumbar intervertebral discs from T2-weighted sagittal MR images, originating from 20 patients, were studied and visually analyzed.

A disc was characterized as “degenerated” by an experienced radiologist if it indicated at least one of the following image findings: desiccation, fibrosis, narrow disc space, diffuses bulging of the annulus beyond the disc space, extensive fissuring (i.e., numerous annular tears) defects and sclerosis of the endplates, or osteophytes at the vertebral apophyses.

B. Elementary Steps Taken For the Segmentation of the Intervertebral Discs from Spine MR Images.

- *Image Normalization*

In order to have the same contrast from slice to slice in the sagittal plane all the images of the volume go through an image normalization step. Image normalization attempts to reduce the effect of variation in the input images. Two common methods of normalization are contrast stretching and histogram equalization. Contrast stretching applies a linear transformation to the input image so that the intensity histogram is stretched across the full range of possible pixel intensity values (e.g. 0-255 for the 8-bit gray level images). In order to prevent a relatively small number of outlier pixel intensities adversely affecting the result, it is normal to allow a certain percentage (say, 0.5%-3%) of pixels to become saturated (set to 0 or 255).

Image normalization also attempts to resize the input image using either nearest-neighbor interpolation or bilinear interpolation or bicubic interpolation. When the specified output size is smaller than the size of the input image and method is 'bilinear' or 'bicubic', resizing applies a lowpass filter before interpolation to reduce aliasing. The default filter size is 11-by-11. Resizing reduces the processing time.

In our work Contrast-limited adaptive histogram equalization (CLAHE) was performed at the very first step for the standardization of all the images.

- *Image De-noising:*

In order to extract the exact shape information of the vertebrae and intervertebral disc image de-noising is done. In such a process, the contrast enhanced image is thresholded and the level argument is computed automatically. The result of this process is the binary image shown in Figure 5. The noise present in the image can disrupt the shape information; therefore the de-noising process is an essential preliminary task in image segmentation. Different sources of noise can be identified as: Partial volume effect, intensity inhomogeneity, presence of artifacts, closeness in gray level of different soft tissues and also the electronic noise from the instrument.

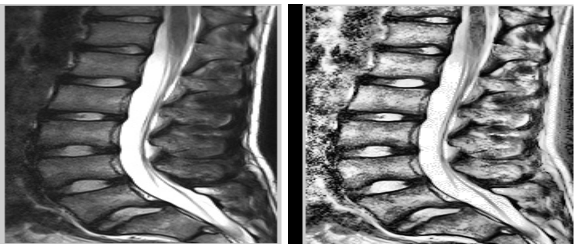

(a) (b)

Figure 2a. The normal intervertebral disc is shown. Figure 2b. Contrast enhanced image of a normal intervertebral disc is shown.


(a) (b)

Figure 3a. The herniated intervertebral disc is shown with arrow. Figure 3b. Contrast enhanced image of a herniated intervertebral disc is shown (with arrow).

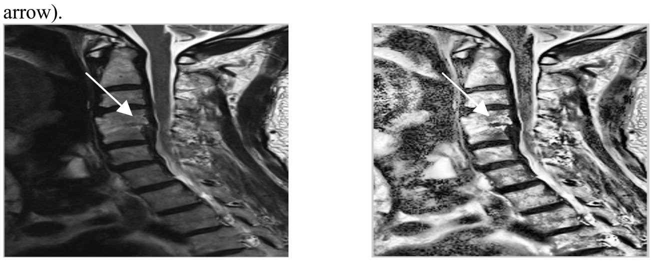
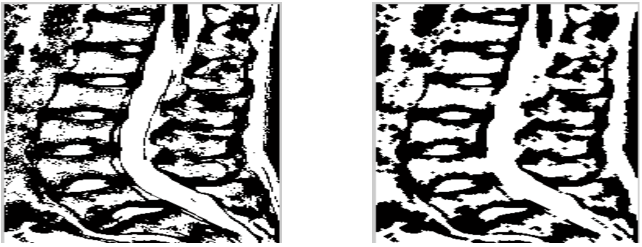

(a) (b)

Figure 4a. The joined vertebrae is shown with no space in between with arrow. Figure 4b. Contrast enhanced image of the same.

For the saggital view, the spinal canal which appears very bright in the image is to be removed and in order to accurately reconstruct the object shape; the de-noising process is used to improve the signal-to-noise ratio, faithfully preserving the edges position and definition. To clean up the image, the small particles and holes are removed by doing some morphological processing, such as morphological closing is done on the grayscale or binary image using a disc structuring element with radius equal to 1 and N equal to 0 and then image is dilated, in order to get the exact contour of the disc and the vertebrae, using line structuring element having length equal to 2 and degree of line is 25. Image de-noising still remains a challenge for researchers because noise removal introduces artifacts and causes blurring of the images, also de-noising process may remove image fine structures.



(a) (b)

Figure 5a. The normal intervertebral disc is shown before de-noising. Figure 5b. The normal intervertebral disc is shown after de-noising.

(a) (b)

Figure 6a. The herniated intervertebral disc is shown before de-noising. Figure 6b. The herniated intervertebral disc is shown after de-noising. (arrow showing hernia)

- *Watershed Segmentation:*

Before the implementation of the watershed algorithm perimeter pixels are found resulting in the following images: Figure 7. Here we can see that in Figure7b indicated by the red arrow that nucleus pulpous is missing. There is no round bright disc and the darker portion is protruded more towards the cervical canal. It is all surrounded by the darker ring, the annulus. And in the Figure7c two vertebrae are joined together leaving no space, also no nucleus no annulus is present in the whole image as it is showing spine degeneration due to aging.

Before the implementation of the watershed algorithm, which is, Fernand Meyer algorithm, the distance transform of a binary image, which is, the distance from every pixel to the closest non-zero value pixel, is calculated for the de-noised image. It computes the Euclidean distance transform between 2 points u=(x1,y1) and v=(x2,y2) of the binary image.

$$D(x,y) = \sqrt{(x_1 + x_2)^2 + (y_1 - y_2)^2}$$

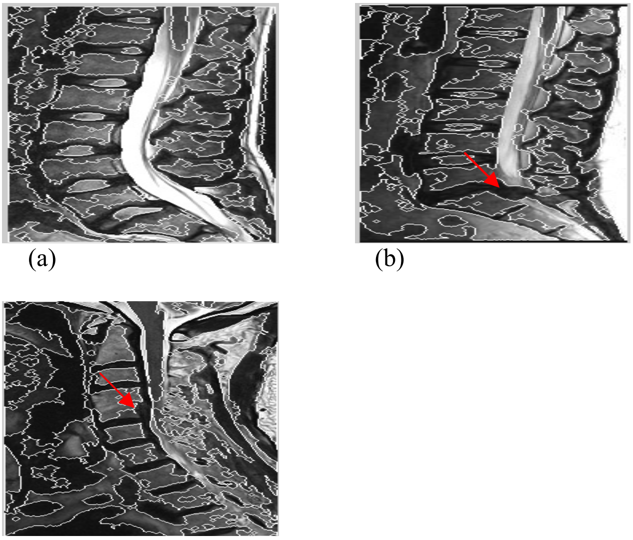
where *d* measured a straight line between 2 pixels. After calculating the distance transform watershed is applied to the same and we get the Watershed ridge lines, as show below in the Figure 8.

Combined binary marker F^m is then imposed as minima on the gradient image.

$$F^m = F^m_{\text{int}} \cup F^m_{ext}$$

This minima imposition eradicates the problem of oversegmentation that occurs with watershed directly applied on gradient image to a very large extent.

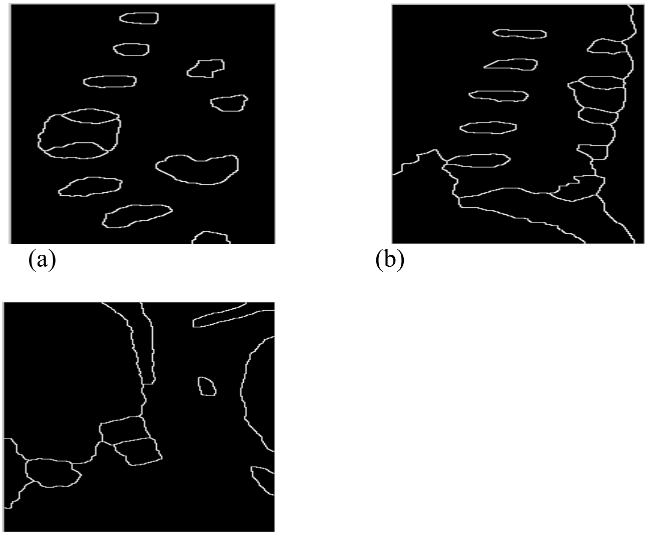
Figure 9 depicts the superimposed images. The bold red lines give the boundary of the nucleus pulpopus of the intervertebral disk. In Figure9a normal nucleus pulpopus is found. We can see in the Figure 9b where the arrow is indicating that there is no bold red disc shaped boundary indicating hernia and in the Figure9c there are no nucleus pulpopus at all because of the aging effect and also two vertebrae are joined leaving no space in-between (shown by arrow).



(a) (b)

(c)

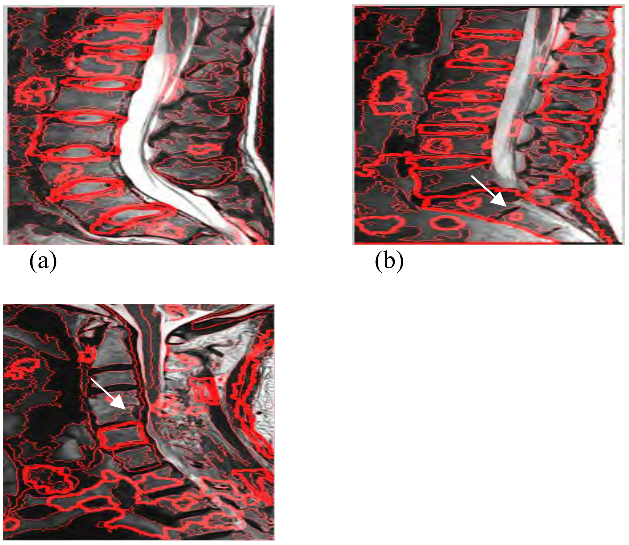
Figure 7a. The normal intervertebral disc is shown. Figure 7b. The herniated intervertebral disc is shown. (arrow showing hernia). Figure 7c. The joined vertebrae is shown with no space in between. (arrow showing)



(a) (b)

(c)

Figure 8a. The ridge lines for normal intervertebral disc is shown. Figure 8b. The ridge lines for herniated intervertebral disc is shown. Figure 8c. The ridge lines for interrvertebral disc is shown.

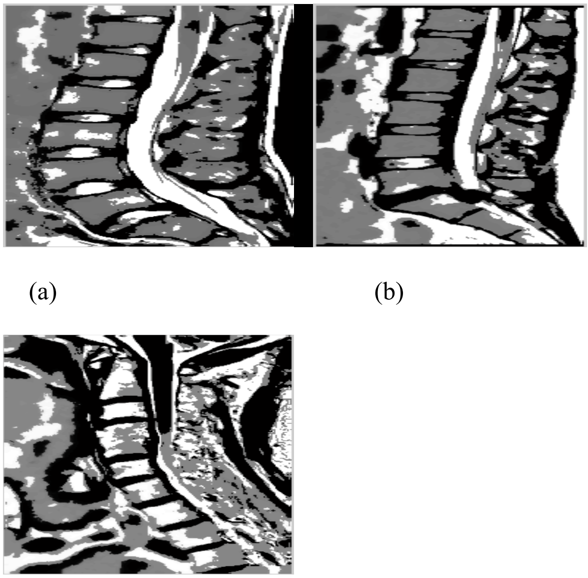

(a) (b)

(c)

Figure 9a. The normal intervertebral disc is shown. Figure 9b. The herniated intervertebral disc is shown. (arrow showing hernia). Figure 9c. The joined vertebrae is shown with no space in between. (arrow showing)

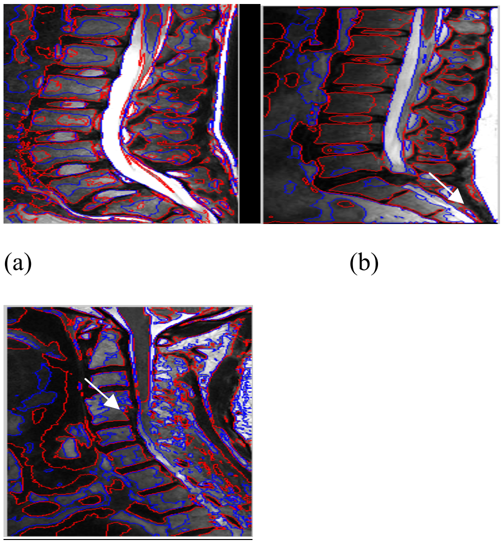
- *Level Set Segmentation:*

  We have also implemented level set segmentation on our data base of MR spine images. It has already been implemented on MR brain and MR breast images [chunming]. The results for the same abnormalities are shown in the Figure 11.


(a) (b)

(c)

Figure 10a. The de-noised normal intervertebral disc is shown. Figure 10b. The de-noised herniated intervertebral disc is shown. (arrow showing hernia). Figure 10c. The de-noised joined vertebrae is shown with no space in between. (arrow showing)


(a) (b)

(c)

Figure 11a. The normal intervertebral disc is shown. Figure 10b. The herniated intervertebral disc is shown. (arrow showing hernia). Figure 10c. The joined vertebrae is shown with no space in between. (arrow showing)

IV. DISCUSSION AND CONCLUSION

In our other paper on segmentation of microscopic images of living cells: A study the preprocessing steps for normalization and de-noising taken are the same and the results obtained over there were pretty much accurate [37].

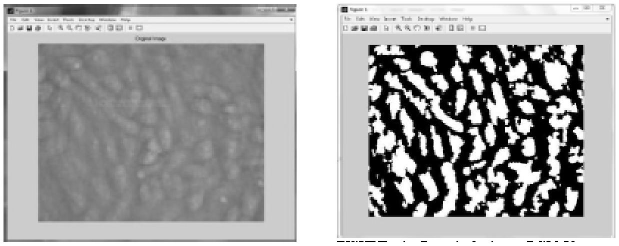

(a) (b)

Figure 12a Input image-BGM-70 Cells on 3rd. Figure 12 De-noised image-BGM-70 Cells on 3rd day of the culture.

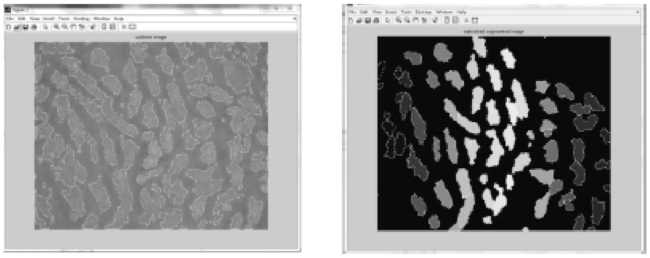

(a) (b)

Figure13a Outlined image after De-noising-BGM-70 Cells on 3rd day of the culture. Figure13b Watershed Segmented Image-BGM-70 Cells on 3rd day of culture.

In a paper on Watershed Segmentation of Intervertebral Disk by Claudia Chevrefils, Farida Chérie, et al., the preprocessing steps taken are altogether different. Instead of contrast enhancement by CLAHE contrast stretching based on a simple linear mapping is used. Also the structuring elements used are different [29].

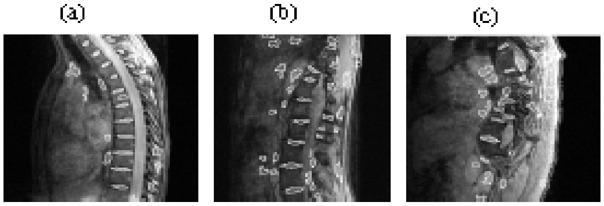


Figure14a Results for different severities of spine deformities. Saggital view of (a) normal spine, (b) moderate spine deformation, (c) important spine deformation. [29]

It is clearly visible from the visual inspection that our method is more accurate as it is able to show the exact contour of the nucleus pulpopus and it also shows the contour of the vertebrae so that degeneration is properly and accurately detected. Also in our methodology difference between nucleus pulpopus and annulus fibrosus is to a very large extent visible. In addition to better visual perception our method is faster and unsupervised, produces more accurate closed contours, and is based not only on intensity information but also on prior knowledge of the shape to be detected.

In future we can improve on the normalization and de-noising techniques as de-noising is still a valid challenge. We can improve on normalization by using interactive enhancing techniques instead CLAHE. But for finding the anatomical structure CLAHE is giving a good result. Interactive enhancement can be used for the analysis rather detection and diagnoses of pathologies. We can also improve the algorithm by making the quantitative analysis to support the visual inspection.

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