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AUTOMATED DETECTION AND EVALUATION OF LUMBAR DISCS IN CT IMAGES

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Abstract—Lumbar spondylolis thesis is one of the most common spinal diseases. It is caused by the anterior shift of lumbar vertebrae relative to its subjacent vertebrae. In current clinical practices, staging of spondylolis thesis is often conducted in an empirical and qualitative way. Although meyerding grading system opens the door to diagnose and stage spondylolis thesis in a more quantitative way, it relies on the manual measurement of the relative shift between neighboring lumbar vertebrae, which is time consuming and irreproducible. Thus, an automatic algorithm to measure lumbar vertebrae shift becomes desirable for spondylolis thesis diagnosis and staging. However, there aretwo challenges: (1) Accurate detection of the most anterior andposterior points on the superior and inferior surfaces of eachlumbar vertebrae. Due to the small size of the vertebrae, slighterrors of detection may lead to significant measurement errors,hence, wrong disease stages. (2) Automatic localize and label eachlumbar vertebrae is required to provide the semantic meaning ofthe measurement. It is difficult since different lumbar vertebraeshave high similarity of both shape and image appearance. To resolve these challenges, a new auto measurement framework is proposed and the main contributions lie in the following aspects:
First, a learning based spine labelling method that integrates both the image Appearance and spine geometric information is used for detection of each Lumbar vertebrae. Second, a hierarchical method which uses both the population Information from atlases and domain-specific information in the target image is proposed for most anterior and posterior Points positioning. Our method has been extensively evaluated on 258 CT spondylolis thesis patients, and experimental results show that our method achievesvery similar results to manual measurements by radiologists andsignificantly increase the measurement efficiency.

I.INTRODUCTION

Lumbar spondylolisthesis is one of the most commonspinal diseases. Previous studies demonstrated that about4% to 6% of population has spondylolisthesis and spondylolysis. Lumbar spondylolisthesis is

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mainly caused bythe anterior shift of one lumbar vertebrae relative to itssubjacent one. Patients with spondylolisthesis may not havesymptoms in the early stage. In addition, different treatmentplans shall be selected for different disease stages. Therefore,early detection and proper staging of spondylolisthesis becomeimportant clinical tasks. In today's musculoskeletal (MSK)clinical workflow, the stage of spondylolisthesis is determinedby the amount of anterior shift of the lumbar vertebrae (i.e., namely the meyerding grading system). More precisely, the percentage of the anterior shift relative to the subjacent vertebrae's upper surface length is calculated, and it falls in one of the five stages: 0-25 percent - Grade 1, 26-50 percent - Grade 2, 51-75 percent - Grade 3, 76-99 percent - Grad- 4, 99 percent or more - Spondyloptosis. For different stages of spondylolisthesis, different treatment methods will be used in the MSK clinical workflow. For instance, for Grade 1 spondylolisthesis, normally physical therapy and exercise will be the first option for treatment. For more severe spondylolisthesis grades, patients may need to receive surgical treatments such as spinal fusion.

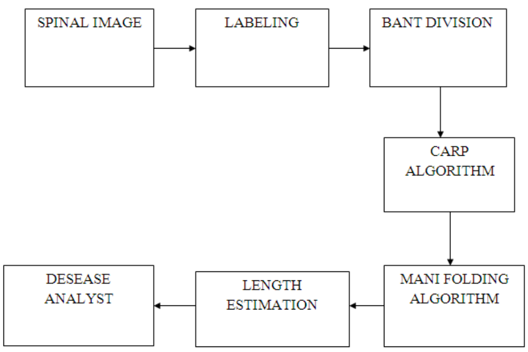

Fig. 1 System structure

II PROPOSED METHOD

New framework for automatic spondylolisthesis measurement which can resolve the above two challenges. In this paper, we mainly focus on the measurement on CT images, which is one of the most commonly used image modalities for spondylolisthesis diagnosis. First, a learning based spine labeling method that integrates both the image appearance and spine geometric information is used for detection of each lumbar vertebrae. Second, a hierarchical method which uses both the population information from atlases and domain-specific information in the target image is proposed for most anterior and posterior points positioning.

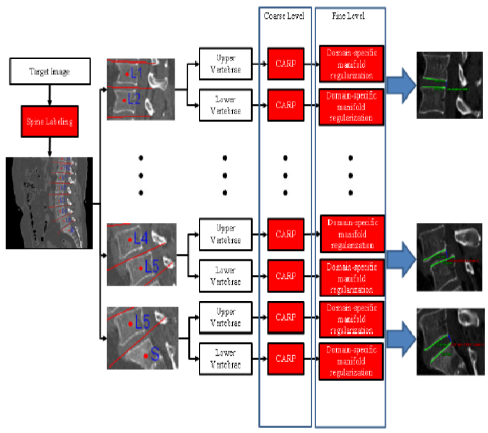

Fig.2 Flowchart of proposed method

III.AUTOMATIC SPINE LABELING WITHHIERARCHICAL LEARNING

In the first step of our framework, it is necessary to automaticallydetect and label vertebrae centers and intervertebral discs.The output of the spine labeling algorithm provide useful informationto spondylolisthesis measurement in two-fold: 1) thelocations of the vertebrae will

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be used to initialize the atlases,and 2) the labels of the vertebrae will provide semantic informationto report the spondylolisthesis measurements. We design arobust algorithm using hierarchial learning approach.

IV.AUTOMATIC PONDYLOLISTHESIS MEASUREMENT

In this section, a hierarchical framework to automaticallymeasure the anterior shift of each pair of lumbar vertebraebased on the spine labeling results obtained in Section III is introduced. In flow chart of the proposed method the coarse level, the populationInformation is used to give a robust yet rough estimation for the superior andinferior surfaces of vertebrae with a critical anatomy regionpropagation (CARP) method. In the fine level, the domain-specificinformation in the target image is used to refine the criticalregions estimation and the most anterior and posterior pointsare extracted.

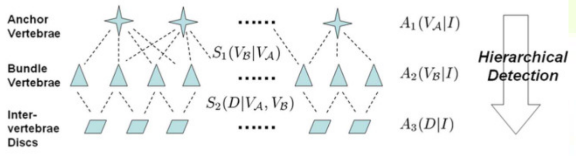

Fig. 3 Proposedspine detection framework

V.EXPERIMENTAL RESULTS

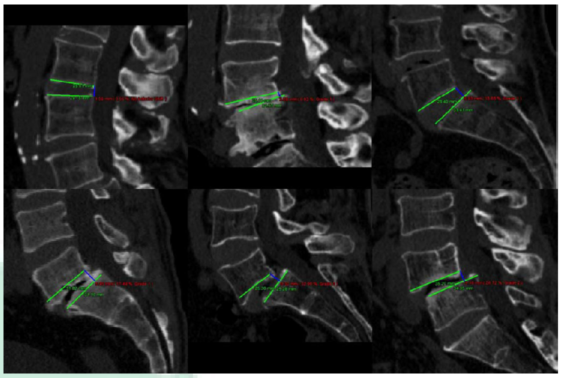

Fig. 4 Typical spondylolisthesis measurement results obtained by ourmethod

The proposed method has been extensive evaluatedon a CTlumbar spondylolisthesisdataset consists of 258 patients. Eachimage has in-plane resolution of 512×512, with voxel size0.98×0.98mm^{2}and the inter-slice voxel size around 0.7 mm.Each image is obtained from a SiemensSomatom DefinitionCT scanner with various scanning parameters. For instance,the peak kilovoltage (KVP) is ranged from 80 to 120, andthe CT reconstruction kernel is ranged from B30s to B60s. Therefore, there are large image appearance and noise levelvariations in the database. The most anterior and posterior points of the upper andlower surfaces of each vertebrae are also manually annotatedby three clinical experts independently. One of the clinicalexperts has also annotated the dataset twice independently tostudy the intra-rater differences. From the annotation results,the anterior shift percent and the stage of the disease for eachpair of adjacent lumbar vertebrae can be determined.

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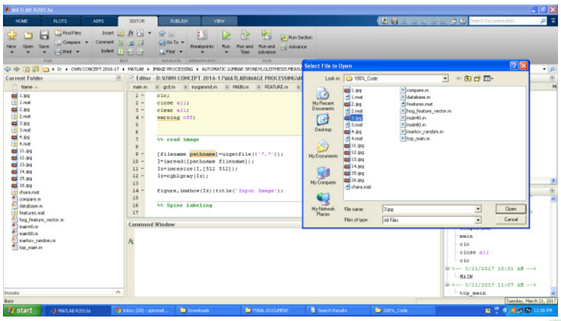

Fig.4 Input image

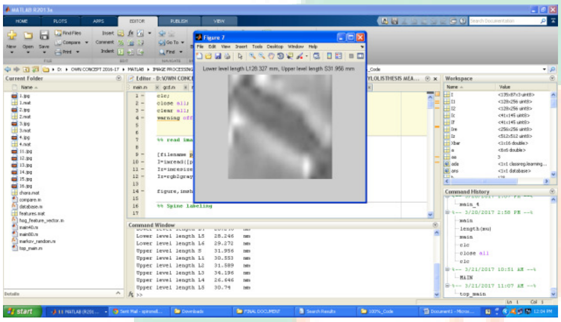

Fig. 5 Output image

VI.CONCLUSION

In this paper, we propose an automatic lumbar spondylolisthesis grade estimation method. It mainly consists of two main stages: automatic spine labeling, and critical region determination. In the spine labeling stage, anchor landmark detectors are first trained to locate vertebrae with salient anatomical context, and it is integrated with an articulated spine model to detect and label the remaining vertebrae with bundle landmark detectors trained on less salient vertebrae. After spine labeling, a hierarchical learning method is used to determine the critical regions in each vertebrae to estimate the spondylolisthesis grade. In the coarse level, the critical region is roughly yet robustly located by a multi-atlases kernel sparse representation method using the population information. In the fine level, the patient-specific information is used to further refine the critical region with a semi-supervised manifold regularization method. Our method has been extensively evaluated on a CT lumbar spondylolisthesis dataset consists of patients and possible alternatives are compared. Experimental results show that our method achieves inter-rater level measurement accuracy. Our method is also efficient as it only takes several seconds in average to estimate the spondylolisthesis grade of each lumbar vertebrae pair for one CT spine image. Future research includes to train the vertebrae detectors using deep learning or random forests to improve the robustness of the detection.

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