Applying Vertebral Boundary Semantics to CBIR of Digitized Spine X-ray Images

Sameer Antani, L. Rodney Long, George R. Thoma
Lister Hill National Center for Biomedical Communications
National Library of Medicine, NIH,
Bethesda, MD 20894, USA

ABSTRACT

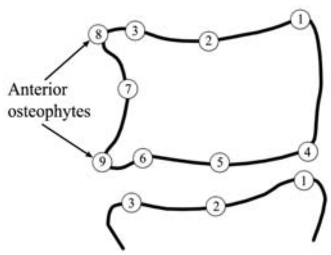
There is a growing research interest in reliable content-based image retrieval (CBIR) techniques specialized for biomedical image retrieval. Applicable feature representation and similarity algorithms have to balance conflicting goals of efficient and effective retrieval while allowing queries on important and often subtle biomedical features. In a collection of digitized X-rays of the spine, such as that from the second National Health and Nutrition Examination Survey (NHANES II) maintained by the National Library of Medicine, a typical user may be interested in only a small region of the vertebral boundary pertinent to the pathology: for this experiment, the Anterior Osteophyte (AO). A previous experiment in pathology-based retrieval using partial shape matching (PSM) on a subset from the above collection; about 89% normal vertebrae were correctly retrieved. In contrast only 45% of moderate and severe cases were correctly retrieved, and on the average only 46% of the pathology classes were correctly determined. Further analysis revealed that mere shape matching is insufficient for *semantically correct* retrieval of pathological cases. This paper describes an automatic 9 point localization algorithm that incorporates reasoning about boundary semantics equivalent to that applied by the content-expert as a step in our enhancements to PSM, and results from initial experiments.

Keywords: Semantics, Content-Based Image Retrieval, Biomedical Image Databases, Shape Matching, NHANES II

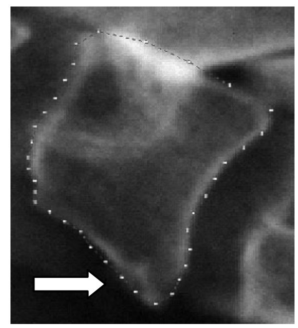
1. INTRODUCTION

To overcome the high cost and imprecise nature of manual annotation there has been increasing research interest in developing content-based image retrieval (CBIR) methods for biomedical images[1]. The Lister Hill National Center for Biomedical Communications, an R&D division of the U.S. National Library of Medicine, maintains a collection of 17,000 digitized spine X-rays from the Second National Health and Nutritional Examination Survey (NHANES II). These X-rays, in which anterior osteophytes are present, serve as a rich data source for research into pathology-based retrieval of biomedical images. An osteophyte, a bony protuberance on normal bone surface, is a characteristic feature of degenerative joint disease of the spine. After careful study of the NHANES II image collection medical experts have previously determined that the anterior osteophyte (AO) is a pathological feature that can be reliably and consistently detected in the data set, along the superior or inferior parts of the anterior vertebral boundary. An example of superior and inferior AO is illustrated graphically in Figure 1(a) and shown in 1(b). In Figure 1(a), points 1, 3, 6 and 4 define the corners along the vertebral boundary, points 2, 5, and 7 indicate mid-points along the superior, inferior and anterior, edges and points 8 and 9 are indicative of the presence of anterior superior and anterior inferior osteophytes, respectively. In case of a normal vertebra these points would coincide with points 3 and 6. For example, points 2-3-8-7 describe a superior anterior osteophyte on a sagittal spinal X-ray and points 7-9-6-5 describe an inferior anterior osteophyte. Often, as in such cases, only a small region of the vertebral body is pertinent to the pathology. A 9-point labeling system is often used by experts for marking significant intervals along the vertebral boundary and use in vertebral morphometry. Other systems include use of 6- and 10-point labeling systems[2].

Methods for querying vertebrae through visual means would be immensely useful to radiologists, bone morphometrists, medical students, and researchers of musculoskeletal diseases. Pathology in a vertebra can be captured in the outline of its body seen in a 2D projection in the sagittal spinal X-ray. In query-by-sketch and query-by-example paradigms of shape-based CBIR, traditional *whole* shape matching methods employed for retrieval of these shapes from a database are unable to retrieve vertebrae that precisely match the pathology classification of the query vertebral shape. This may be due to users' tendency to focus on the particular segment of interest on the shape boundary while disregarding shape characteristics in other boundary regions; a characteristic not designed into the algorithms. Thus, the *whole* shape similarity methods match the entire boundary and often result in less than acceptable results[3]. To address this drawback, we have proposed the use of partial shape matching (PSM) methods in retrieving images of interest by allowing the user to sketch or identify the specific region of interest on the vertebral boundary [4, 5]. This significantly improved quality of retrieval. A subsequent experiment using an expert-marked ground-truth database revealed that when pathology was taken into account, however, the results were distributed differently[4]. Further analysis of these results showed that mere shape matching was insufficient for enabling *semantically correct* retrieval. It was important to incorporate geometric equivalents to the reasoning applied by the medical expert into the algorithm. This paper describes the steps in the design and evaluation of such an algorithm and results from initial experiments on an aspect of the method. Currently the method devised is heuristic in nature. We plan to consider other classification approaches, such as neural networks, upon further development of this technique.



(a)



(b)

Figure 1. (a) Anterior osteophytes illustrated on vertebral body outline. Points marked indicate regions of interest. (b) Cropped spinal X-ray image showing inferior AO on vertebra with 36 boundary points superimposed.

Pathology	**Claw**	**Traction**	**Slight**	**Moderate**	**Severe**
Example Images					

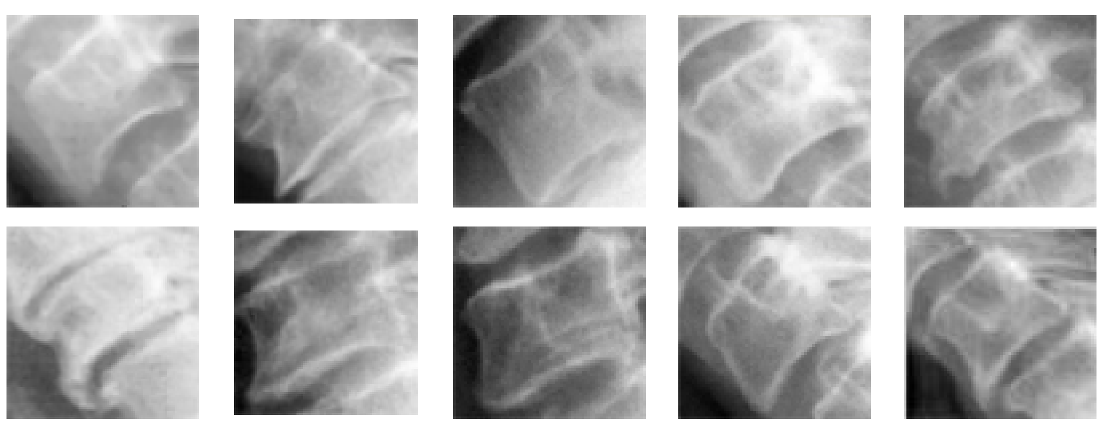


Table 1. Macnab's classification and osteophyte severity grading scheme developed by us.

2. DATA SET DEVELOPMENT

The data set for this experiment was generated from a total of 206 spinal X-ray images (106 cervical and 100 lumbar) from subjects who were 60 years of age or older, selected from the NHANES II collection. This age criterion was used because of higher incidence of degenerative joint disease in this population. Two classification schemes for anterior osteophytes were established by a medical expert to evaluate the accuracy of the PSM algorithm. One is Macnab's classification, established by Macnab and his coworkers in 1956 on radiological and pathological bases [6, 7]. Two types of osteophytes are adapted from Macnab's classification: claw and traction, as shown in Table 1. Their visual characteristics are:

- Claw spur rises from the vertebral rim and curves toward the adjacent disk. It is often triangular in shape and curved at the tips.
- Traction spur protrudes horizontally, is moderately thick, does not curve at the tips, and never extends across the intervertebral disk space.

The second classification is a grading system which was defined by the medical expert consistent with reasonable criteria for assigning severity levels to AO. Three grades of AO are *slight*, *moderate*, and *severe*, also shown in Table 1. Their visual characteristics are:

- Slight grade includes normal, where the corner angles on the vertebral boundary are approximately right angles. It may have a slight protuberance, where the tip of the osteophyte is round and no narrowing is observed at the base of the protuberance.
- Moderate grade is characterized by evident protuberance from the ideal horizontal or vertical edge of the vertebra. The bounding edges of the AO form an angle of at least 45 degrees and the osteophyte has a relatively wider base than severe grade.
- Severe grade is characterized by presence of hook, the angle is less than 45 degrees and has a narrow base, or protrudes far (about 1/3 of the length of the horizontal border) from the *normal* (ideal 90 degree) vertebral corner.

Vertebrae from the selected 206 spinal X-ray images were segmented using an Active Contour Segmentation algorithm which implements orthogonal curves as gridlines[8]. The set consists of 896 segmented vertebrae, composed of 407 cervical (C3-C7) and 489 lumbar (L1-L5) vertebrae. Each vertebra is represented by a fixed number (36) of boundary points which start at the superior posterior corner of the vertebra and follow the boundary in a counterclockwise fashion. The boundary points are sampled to roughly correspond with the 9 landmark regions identified in Figure 1 such that 3 boundary points would be located between each pair of landmark points. Due to unclear edge on the posterior of the vertebrae in these images, the sampling of the boundary points on that edge is sparse.

3. PRIOR WORK

There is little in the literature about incomplete or partial shape matching or on recognizing occluded objects[4]. We have continued to direct our research efforts on PSM based on the Procrustes distance[9] applied to shapes described by a fixed number of boundary points. The Procrustes matching process does a point-to-point match on the user selected query shape and the target shape in the database. Our interface allows the user to select a region of interest along the vertebral boundary, as shown in Figure 2 (a). The selected query partial shape is then compared with every other region in the target shape. The matched shapes are listed in decreasing order of similarity with the region of interest highlighted, as shown in Figure 2(b).

Prior results using PSM[4] that wasn't trained for vertebral shape characteristics showed that for queries for slight grade, 88.3% of vertebrae were correctly retrieved. It should be noted that slight grade included normal vertebrae since the distinction between normal and slight is highly subjective. Results were relatively mixed, however, for moderate and severe grades (45% correct, for each). In the proportion of retrieved vertebrae whose Macnab class matched with that indicated in the query shape, again, the results showed a 87.5% match for normal vertebra, 43.3% for claw and 49.2% for traction. It was also interesting to note that claw and traction queries resulted in nearly identical confusion with normal vertebrae (near 30%) and with each other (near 17.5%).

Our earlier design of PSM could not determine the location of a given point on the shape with respect to landmark intervals identified in Figure 1(a). As such, a *superior anterior* query could, for example, result in matches from the posterior or inferior region of a vertebra. Localizing the queried interval along the shape boundary could help improve retrieval results. In addition, the algorithm suffered from the lack of training on particular shape characteristics of claw and traction pathology and measurement of severity. Local angles on the osteophyte tip and their direction tendency could help distinguish vertebra pathology and its severity. These hypotheses have helped define goals for improved pathology-sensitive shape-based retrieval of digitized spine X-ray images.

(a) (b)

Figure 2. (a) Selecting region of interest on the query shape. (b) Result of PSM on inferior anterior osteophyte.

4. GOALS

The goals can be itemized as three separate, but related, tasks. When a partial shape query is posed, the resulting shapes should accurately exhibit:

1. Position: feature similarity at the same location as the query partial shape,
2. Severity: severity similar to that of the query shape following the grading system described above, and
3. Pathology class: same Macnab's class as that of the query shape.

In the case of goals 2 and 3 exceptions may be considered when the medical expert has marked more than one category. Such an indication is not uncommon in medical images where an image may exhibit a particular pathology that has not sufficiently matured to enable classification into a single class or a single grade of severity. In these cases, the truth is marked to indicate both possibilities, e.g., traction – claw, moderate – severe, etc.

5. APPLYING BOUNDARY SEMANTICS

Bone morphometrists and radiologists often use the 9-point model to indicate intervals of interest along the vertebra boundary. Automatically identifying these landmarks along the vertebral boundary are an important step in the pathology sensitive shape-based retrieval process. Results from this step can enable the shape matching method in utilizing available position information of the queried interval along the vertebral boundary, making the retrieval more accurate and efficient. More importantly, knowledge of these regions along the boundary could be used to identify the class and severity of the pathology by heuristically applying the visual characteristics particular to the pathology class and severity. In this section we describe techniques used to address the goals for pathology-sensitive shape-based retrieval of digitized spine X-rays.

5.1. Positional accuracy in shape based retrieval

The vertebral boundary offers very little in image features as anchors for localizing intervals on it. It is, thus, necessary to use artificial anchors, such as those used by bone morphometrists in the 9-point model. In order to accurately identify these landmarks certain heuristics need to be applied to the segmented boundary. This, in turn, requires all vertebrae be consistently segmented. This has been achieved in our dataset by segmenting all vertebrae starting at the *superior posterior* corner and traveling along the boundary in a counterclockwise fashion, as described in Section 2. Since all vertebral boundary segmentations currently in use by us are 36 point descriptions, we have developed an automatic 9-

point labeling algorithm that identifies these points along the vertebra boundary. This method is based on an enhanced version of a polygon approximation algorithm.

5.1.1. Automatic 9-point localization

5.2. We describe the steps in the automatic 9-point localization method below. Figure 3 shows a screenshot of an automatic 9-point labeling..

1. The method first finds the four corners defining the vertebral boundary. These corners are defined as the most critical angles after eliminating all points along the vertebral boundary.
2. These four points are labeled as 1, (3 and 8), (6 and 9), 4. The labels in the parentheses indicate that these are tentative and the points could be either of these (or both if no AO is present). It is also possible that other points in the vicinity may, based on geometric characteristics, be labeled with these.
3. Next, the location of point 7 is determined as the median point on the anterior edge. This is done by finding the closest point to the *mean point* along the anterior boundary between the tentatively labeled (3,8) and (6,9) points . The closest point on the segmented boundary is computed using the Euclidean distance metric. This point 7 is also a tentative label.
4. Locations of points 2 and 5 are similarly computed as the median points along the superior and inferior edges between points (3,8) and 1 and (6,9) and 4, respectively.
5. The next step in the algorithm is to finalize labeling points 3, 8, 6, 9, and 7. The points are labeled after local shape analysis between 9-point pairs 2 and 7 and 7 and 5 on the 36-point vertebral boundary. For this discussion, let the 36-point shape be called *S* and the 9-point approximation called *N*.
    a. Point 3 is assigned as the point in *S* between the tentatively labeled point (3,8) and point 2 in *N* that makes an angle closest to 90 degrees with points 7 and 2 in *N*.
    b. Point 8 is assigned as the point in *S* between points 3 and 7 in *N* that is a result of polygon approximation of the local shape defined by these in *S*. If the angle between these points is greater than or equal to an empirically determine threshold of 0.85π radians, then points 8 is considered coincident on point 3.
6. Similar steps are adopted for labeling points 6 and 9 along the inferior boundary.
7. Point 7 is finalized as the median between points 3 and 6.

While this algorithm does not guarantee *perfect* 9-point localization it is very good for most vertebrae provided a proper 36 point segmentation is used as input. In case of exceptions, the expert can review and correct the localization. Generally, however, this localization is sufficient for the purposes of pathology sensitive PSM.

5.2.1. Location sensitive partial shape matching

The next step in achieving positional accuracy is to incorporate the advantages of automatic 9-point localization into the partial shape matching algorithm. PSM can be achieved using a fixed point Procrustes-distance based method or by using the Fourier descriptors. The technique is done as follows:

1. The query partial shape needs to be localized on the vertebral boundary. For this, the query shape is approximated using the automatic 9-point localization method discussed above.
2. These 9-points are then interpolated to 36-points.
3. Closest points on this 36-point boundary to the query partial shape endpoints are computed using Euclidean distance metric and the index numbers of these points on the boundary are identified.
4. The index numbers of these query points are then used to extract the partial shape from each qualifying database shape. This results in accurate and efficient localization of the interval on the resulting vertebra.

5.3. Retrieving vertebrae with similar severity in pathology

The next goal is to retrieve vertebrae that in additional to geometric similarity also exhibit similar severity of pathology. This goal seems trivial at first since one expects that successful vertebral (partial) shape matching should also result in retrieval of those that exhibit similar pathology severity. As described in Section 2, however, there are several feature overlaps between different grades, and determining the real grade can be subjective. Incorporating these features into the algorithm can help further improve the retrieval quality.

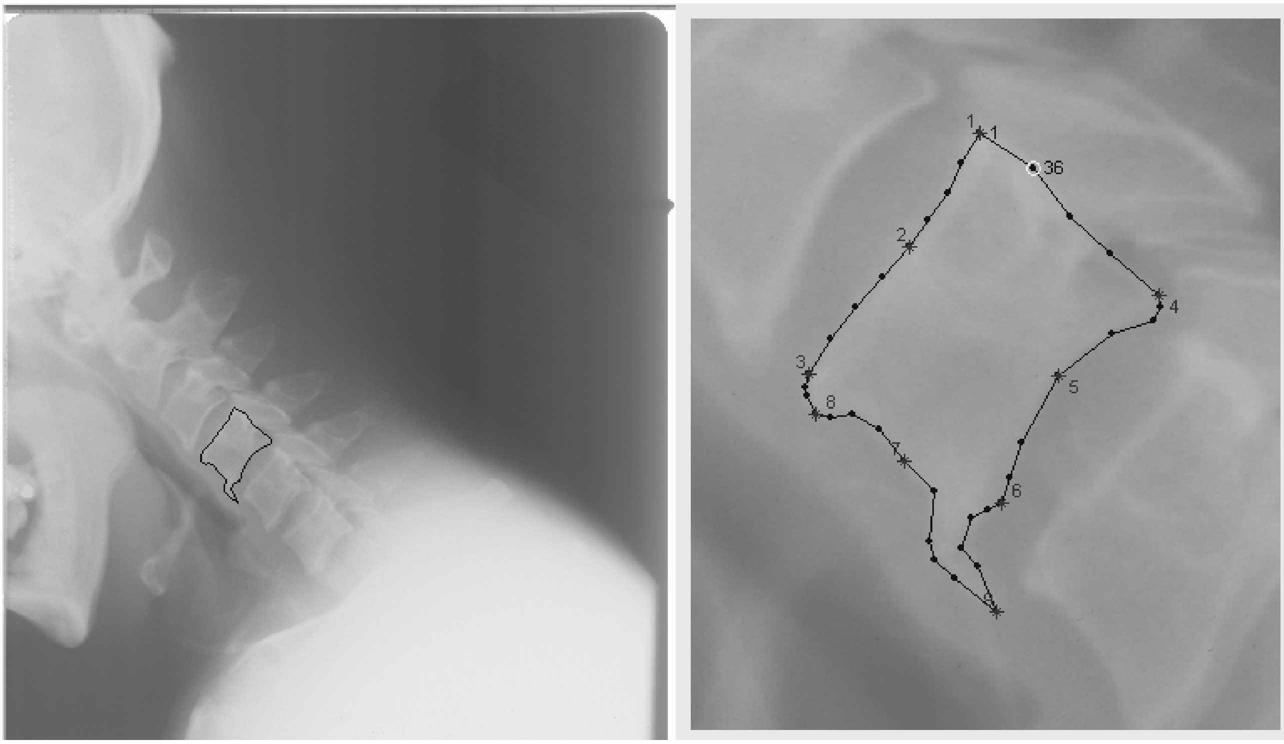


Figure 3. 9-point localization on a 36-point segmentation of a C4 vertebra.

Assigning the vertebra a slight grade label requires computing the internal corner angles along the anterior vertebral boundary. Such vertebrae typically exhibit angles close to 90°. Also, they may have only a slight protuberance. The corner angle can be localized by applying the polygon approximation algorithm subsequent to the automatic 9-point localization algorithm. Approximating the corner to 3 points between points 2 and 7 (if points 3 and 8 are not distinct, 3 and 7 otherwise) localizes the corner angle. The angle is computed using vector geometry. If $\vec{x}$ and $\vec{y}$ are vectors defining the corner angle, then the internal angle is defined as

$$\theta = \cos^{-1}\left(\frac{\vec{x} \cdot \vec{y}}{|\vec{x}| \; |\vec{y}|}\right)$$

It is also important to compute the ratio of lengths of the boundary segment between points 3 and 8 to the length of the superior edge between points 1 and 3. For a grade of slight, this ratio should be close to 0 and no more than 0.1, i.e. 10% of the length.

Similarly, moderate grade can be detected by evident protuberance and an internal corner angle of at least 45°. In addition, the osteophyte has a relatively wider base than severe grade. This particular characteristic can be used to distinguish moderate grade pathology from severe grade. The base is computed as the Euclidean distance between point 3 and the osteophyte base point. The base point is a point on the vertebra boundary between points 8 and point 7 that, when connected with point 3, results in a segment that most parallels the segment connecting points 3 and 7. This is illustrated in Figure 4. This point it not necessarily the point adjacent to point 7, rather it is the first point along the boundary path starting at point 8 and ending at point 7. For a wide base this ratio will be closer to 1.0. This feature is used only when angle and protuberance are insufficient in making a decision.

Severe grade is characterized by presence of an angle that is less than 45 degrees and has a narrow base, or protrudes far (about 1/3 of the length of the horizontal border) from the *normal* (ideal 90 degree) vertebral corner. The osteophyte angle can be measured as described for normal pathology. A narrow base is where, for example from Figure 4, the length of segment B is less than half the length of segment A. Finally, the protuberance measure can also be made as described above. These measurements can be used to make decisions on the severity of the pathology exhibited by the vertebrae.

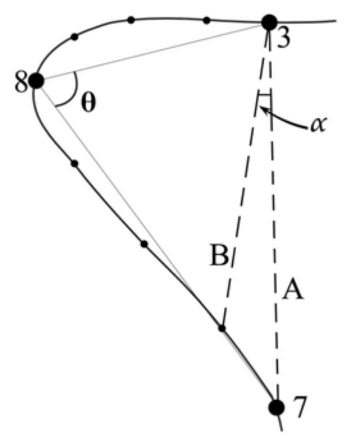


Figure 4. Computing the ratio of the base length (B) of an osteophyte with the median anterior height (A) of the vertebra. α indicates the angle between the line segments. Points 3, 8, 7 (from the 9-point model) along with other points form the 36-point boundary.

5.3.Retrieving vertebrae with similar pathology type

The final goal is to achieve retrieval of vertebrae exhibiting similar pathology class. Two types of osteophytes are adapted from Macnab's classification: claw and traction. Their visual characteristics are as described in Section 2. To detect these, it is necessary to analyze the position and curvature along the osteophyte. As mentioned earlier, a claw is a triangular spur that curves toward the adjacent disk. It is often triangular in shape and curved at the tips. In contrast, a traction spur protrudes horizontally, is moderately thick, does not curve at the tips, and never extends across the intervertebral disk space. Developing a technique for correctly classifying this remains a goal for us and is a part of our ongoing research into pathology-sensitive shape-based CBIR of digitized spine X-ray images.

6. RESULTS

This section presents the results following the evaluation of the developed method for the two of the outlined goals, viz., automatic 9-point localization and location sensitive retrieval. Research into pathology severity and class identification is ongoing and will be presented upon completion.

For automatic 9-point localization, a visual test was conducted on 50 vertebrae boundaries which were equally selected from cervical and lumbar segmentations. In this 10 cases were marked as severe, 10 as moderate and 5 as slight for each vertebra type. It was found that more than 900% localizations the 9-points were correct. In the few with errors, the position of points 3, 6, and 8 was found to be off by only 1 point. It is clear that the position of these points is highly dependent on the quality of the segmentation and distribution of the 36 points along the vertebral boundary. In a couple cases, point 3 was found to be much closer to point 2, but this vertebra also exhibited degeneration in the anterior superior region. The reasons for this incorrect localization are immediately unclear and are being further analyzed. Even so, the errors in the localizations are insignificant for purposes of severity computation and provide a robust tool to medical experts' analysis. Examples correct, and incorrect localizations are shown in Figure 5. Figure 5 (a) and 5 (b) are correct localizations for a cervical and lumbar vertebra, respectively. Figure 5(c) is an example where point 3 could be 1 point closer to point 8 and Figure 5 (d) is an example of localization with greater error, possibly due to vertebrak boundary exhibiting bone degeneration.

For PSM retrieval based on positional accuracy a 100% rate was achieved for the top 10 retrieved results over 10 randomly selected queries. This test was performed both for inferior and superior anterior osteophytes. Screenshot of PSM retrieval using Fourier descriptors is shown in Figure 6.

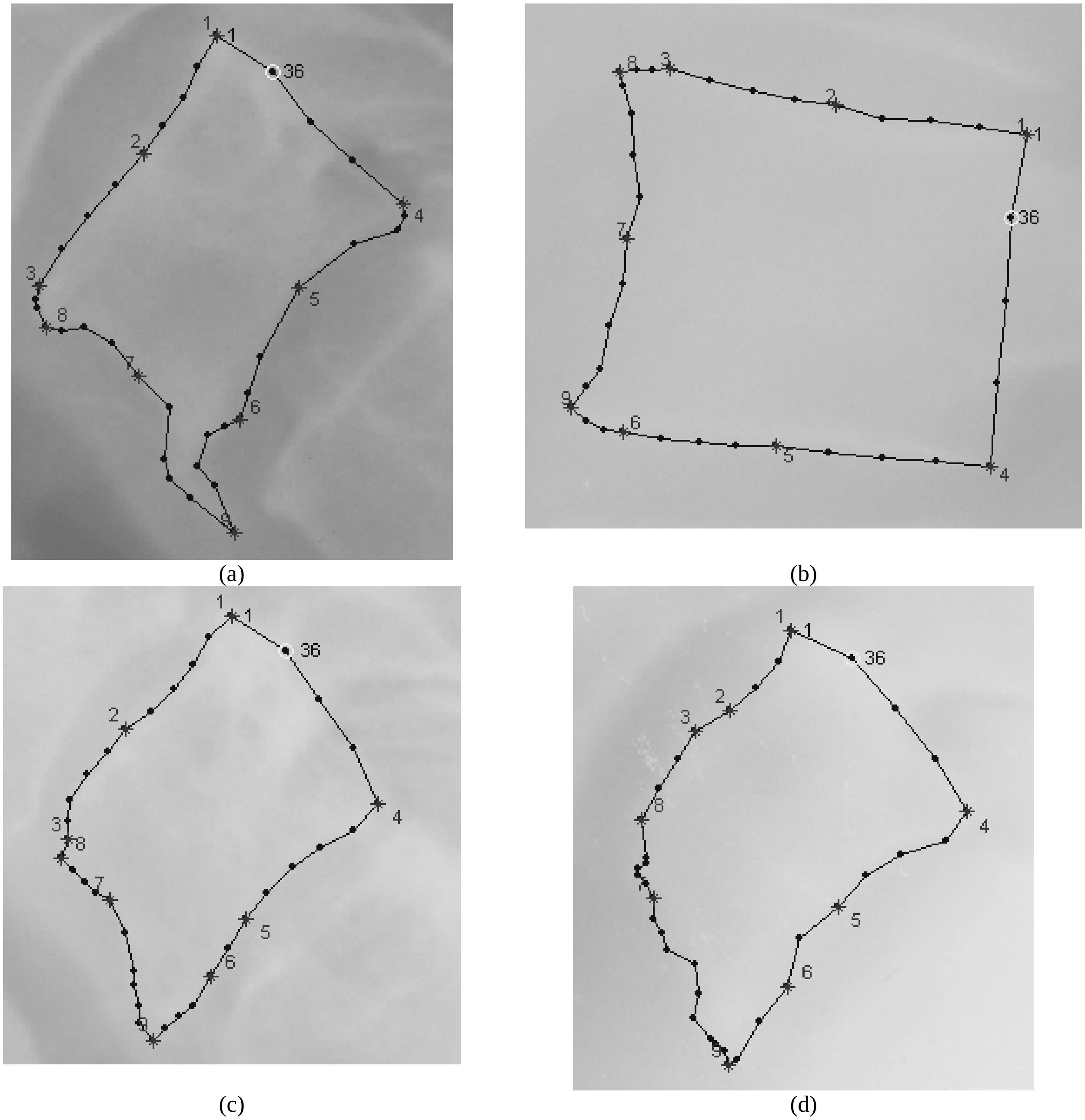


Figure 5. Examples of results from automatic 9-point localization. (a) and (b) demonstrate successful localization on cervical and lumbar vertebrae, respectively; (c) shows an example where point 3 could be 1 point closer to 2 and (d) shows an error in localization.

7. CONCLUSIONS

This paper presents techniques for incorporating vertebral boundary semantics in CBIR of digitized spine X-ray images. An evaluation was conducted of a partial shape matching algorithm enhanced with some of these techniques automatic localization of pathology. Further enhancements for differentiating among severity of pathology and Macnab's classification types using partial shape of a vertebra are ongoing. The evaluation has yielded promising results from PSM and pointed to the need for further work on the topic. It has provided important insights into the behavior of the algorithm in classifying the vertebra on its severity and pathology.

An important issue that this study reinforces is the need for a standardized ground truth data set that can be used to evaluate the methods. The ground truth set should be developed from multiple expert inputs that are suitably combined. Additionally, the evaluation results must be validated by a number of medical experts to minimize the effect of inter- and intra-observer variability. Such a development is in progress and we expect to test these methods on that larger dataset in the future. Our work in this area and further development of shape algorithms is continuing as a part of a larger framework of developing CBIR for medical images.

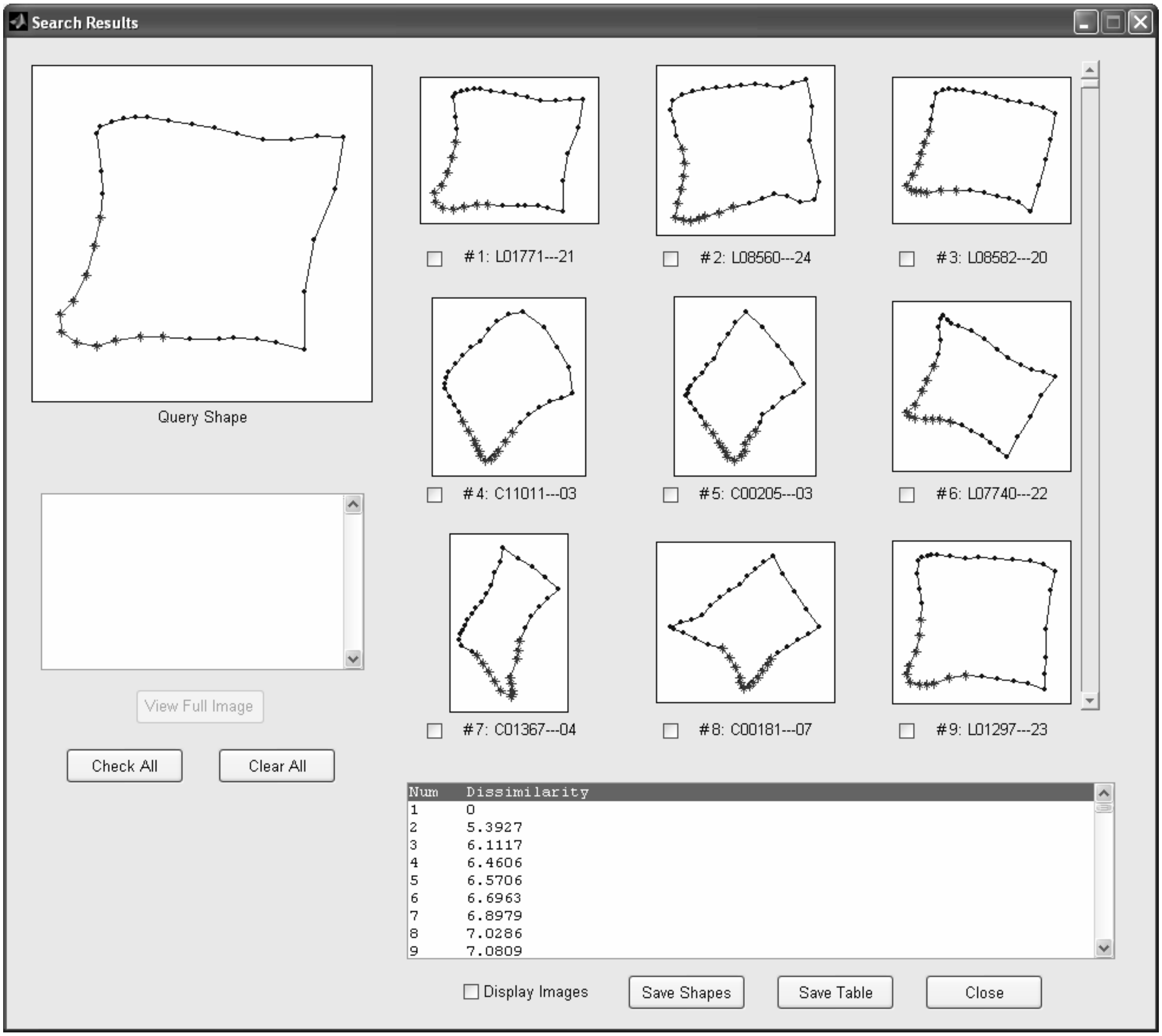


Figure 6. Screen shot of partial shape matching retrieval results showing successful location sensitivity. Portions of partial query shape and successful matches are indicated by asterisks (*). The remainder of the shape is indicated by dots (.).

ACKNOWLEDGEMENTS

Code development support, ground truth development and other assistance was provided by Mukil Natarajan (Rice University), Jonathan Long (Thomas S. Wootton High School), Xiaoqian Xu (Brigham Young University), Daniel

Krainak (Northwestern University), D.J.Lee (Brigham Young University) and a medical expert (Jason Shou, University of Medicine and Dentistry of New Jersey) during their respective internships at the U.S. National Library of Medicine.

REFERENCES

1. Long LR, Antani S, Lee DJ, Krainak DM, Thoma GR. "Biomedical Information from a National Collection of Spine X-rays: Film to Content-based Retrieval" Proceedings of the IS&T/SPIE Medical Imaging 2003 – PACS and Integrated Medical. Information Systems: Design and Evaluation, Huang HK, Ratib OM (Eds.), *SPIE Vol. 5033*,70-84, San Diego, CA, 2003.
2. Jergas M, Valentin RS. "Techniques for the Assessment of Vertebral Dimensions in Quantitative Morphometry" Chapter 10 in *Vertebral Fracture in Osteoporisis*, Genant HK, Jergas M, van Juijk C (Eds.), San Francisco: Osteoporosis Research Group,University of California at San Francisco, 1995.
3. Antani S, Long LR, Thoma GR, Lee DJ. "Anatomical Shape Representation in Spine X-ray Images" Proceedings of the 3rd IASTED International Conf. on Visualization, Imaging and Image Processing (VIIP 2003), *Vol. 1*, 510-515, Benalmadena, Spain; 2003.
4. Shou, J, Antani S, Long LR, Thoma GR. "Evaluating Partial Shape Queries for Pathology-Based Retrieval of Vertebra". Proc. 8th World Multiconference on Systemics, Cybernetics and Informatics (SCI 2004), *Vol.12: Applications of Cybernetics and Informatics in Optics, Signals, Science and Engineering,* Callaos N, Chambah M, Gaburro Z, Loutfi M (Eds),. 155-60, International Institute of Informatics and Systemics; Orlando, FL, 2004
5. Antani S, Xu X, Long LR, Thoma GR. "Partial Shape Matching for CBIR of Spine X-ray Images" Proceedings IS&T/SPIE Electronic Imaging - Storage and Retrieval Methods and Applications for Multimedia, *SPIE Vol 5307,*Yeung MM, Lienhart RW, Li C-S (Eds.), 1-8, San Jose, CA; 2004.
6. Heggeness MH, Doherty BJ. "Morphologic Study of Lumbar Vertebral Osteophytes". Southern Medical Journal, **91(2)**,187-189, 1998.
7. Pate D, Goobar J, Resnick D, Haghighi P, Sartoris DJ, Pathria MN. "Traction Osteophytes of the Lumbar Spine: Radiographic-Pathologic Correlation". Journal of Radiology, **166(3)**, 843-846, 1988.
8. Tagare H. "Deformable 2-D Template Matching Using Orthogonal Curves" IEEE Transactions on Medical Imaging, **16(1)**, 108-117, 1997.
9. Dryden IL, Mardia KV. *Statistical Shape Analysis***.** John Wiley & Sons, Inc. 1998.