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Size-invariant descriptors for detecting regions of abnormal growth in cervical vertebrae

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Abstract

Digitized spinal X-ray images exhibiting specific pathological conditions such as osteophytes can be retrieved from large databases using Content Based Image Retrieval (CBIR) techniques. For efficient image retrieval, it is important that the pathological features of interest be detected with high accuracy. In this study, new size-invariant features were investigated for the detection of anterior osteophytes, including claw and traction in cervical vertebrae. Using a K-means clustering and nearest neighbor classification approach, average correct classification rates of 85.80%, 86.04% and 84.44% were obtained for claw, traction and anterior osteophytes, respectively.

Keywords: CBIR; Cervical spine; Claw; Image processing; K-means clustering; Nearest neighbor classification; Osteoarthritis; Osteophyte; Traction; X-ray; NHANES

1. Introduction

Osteoarthritis, also known as degenerative joint disease, is an orthopedic anomaly affecting millions of Americans, with people over the age of 75 exhibiting increased vulnerability. The condition arises as a result of thinning of cartilage tissue covering the bone joints in the human body, thereby increasing friction during joint movement and causing a sensation of pain. The joints affected by osteoarthritis often exhibit abnormal bone growth, resulting in formation of "bone spurs", also known as osteophytes. Radiographs provide a fast and practical approach for visualization of features such as osteophytes, disc space narrowing, and subluxation, which are of great interest to the osteoarthritis research community. Fig. 1 presents a cervical spine X-ray image example. The boxed region highlights the cervical spine vertebrae.

The Lister Hill National Center for Biomedical Communications, an R&D division of the National Library of Medicine, National Institutes of Health, has been actively conducting and promoting research in the area of computer- assisted analysis of spine X-ray images and has developed the Web-based Medical Information Retrieval System (WebMIRS). This system provides online access to a large database of spine X-ray images and related textual data collected as a part of the National Health and Nutrition Examination Surveys (NHANES). Content Based Image Retrieval (CBIR) techniques can be used to retrieve digitized radiographs of the spine which exhibit one or more specific physiological conditions such as the presence of anterior osteophytes. The reliability of the retrieval process depends on the accuracy with which the pathology sought can be detected. This research focuses on the computer-assisted discrimination of variations of anterior osteophytes in normal cervical spine vertebrae.

Osteophytes manifest themselves as deviations from normal shape of the affected vertebra in certain specific locations. Information from other locations on the vertebra, where the shape is normal, is irrelevant and serves to degrade the efficiency of the retrieval process. Dynamic programming-aided partial shape matching techniques have been used by Xu et al. to detect anterior osteophytes [1,2].

Alternative schemes to classify anterior osteophytes have been developed, including Macnab's classification based on

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Fig. 1. Cervical spine X-ray image example from the NHANES image collection archived at the National Library of Medicine. Vertebrae are highlighted in the box region.

radiology and pathology [3,4], and a grading system defined by a medical expert to assign severity levels to the Macnab classes. Macnab's classification defines claw and traction osteophytes. A claw osteophyte extends from the vertebral rim and curves in the direction of the adjacent disc. A claw region is typically triangular in shape and is curved at the tip of the region. A traction osteophyte tends to protrude horizontally, is usually thick, does not tend to curve at the tips and does not extend across the intervertebral disc space. The severity grading system includes three grades for osteophytes: slight, moderate and severe. If a vertebra does not exhibit claw or traction or slight, moderate or severe grades, the vertebra is considered normal.

Fig. 2 provides borders of cervical vertebrae C3–C6, as determined by an expert at the National Library of Medicine (NLM). The top of each vertebra is referred to as the superior side, and the bottom as the inferior side. The left side of the vertebra is the anterior side, and the right side is the posterior side (along the spinal column). Table 1 shows the verified claw, traction, and anterior osteophytes grades for the vertebrae examples in Fig. 2 for the inferior and superior sides of the each vertebra. Data "truthing" for claw, traction, and anterior osteophytes was performed by an expert from NLM.

The variable quality of the spine X-ray images in the NHANES data set makes it difficult to detect certain subtle pathologies and also results in low inter/intra observer repeatability. The use of relevance feedback along with partial shape matching techniques has been investigated to help refine the content based retrieval process by incorporating judgments made by a skilled human observer [5]. Antani et al. have investigated partial shape matching retrieval techniques. These researchers used information about vertebral boundary semantics determined from an automated localization algorithm based on nine boundary points marked by a skilled radiologist [6]. Also examined are deformable shape models that have been examined and are capable of representing globular shapes as well as subtle localized variations in features for vertebra segmentation [7].

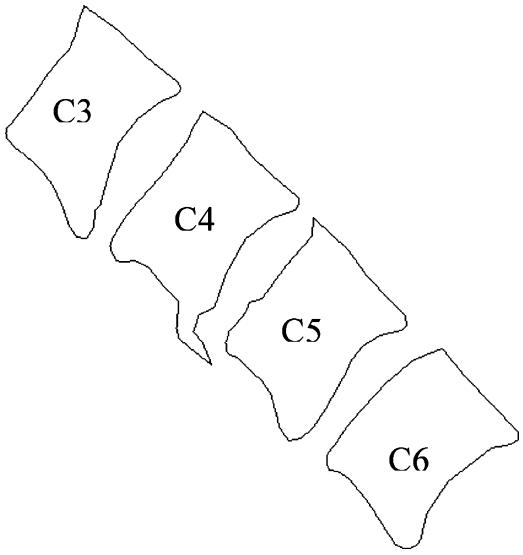

Fig. 2. Image examples of cervical vertebrae C3–C6.

In previous research, we investigated four size-invariant convex hull features to discriminate of anterior osteophytes in lumbar vertebrae [8]. The convex hull of a set of points is the smallest convex set that includes all of the points in the original set [9]. The shape of a normal vertebra is convex and nearly rectangular and is expected to be very similar to the convex hull constructed from its boundary points. The presence of anterior osteophytes results in deviation of the vertebra from its characteristic convex shape. The convex hull features provide a means to quantify the variation in a vertebra's shape from a typical convex shape and to identify and quantify protrusion regions on the vertebra's anterior side; these regions of protrusion are characteristic of anterior osteophytes. Fig. 3 provides examples of images that were used for calculation of the four convex hull-based features.

Table 1
Claw, traction and anterior osteophytes labels and grades for the inferior and superior sides of each vertebra shown in the cervical images from Fig. 1

Vertebra	Location	Claw	Traction	Anterior osteophytes grade
C3	Inferior/superior	True/false	True/false	Moderate/slight
C4	Inferior/superior	True/false	False/true	Severe/slight
C5	Inferior/superior	False/false	True/false	Slight/slight
C6	Inferior/superior	False/false	False/false	Slight/slight

The claw and traction labels are True or False for the inferior and superior sides, and the anterior osteophytes grades are slight, moderate or severe for the inferior and superior sides.