Computers in Biology and Medicine 73 (2016) 147–156

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Shape, texture and statistical features for classification of benign and malignant vertebral compression fractures in magnetic resonance images

Lucas Frighetto-Pereira [a], Rangaraj Mandayam Rangayyan [b], Guilherme Augusto Metzner [a], Paulo Mazzoncini de Azevedo-Marques [a], Marcello Henrique Nogueira-Barbosa [a,*]

[a] Image Science and Medical Physics Center, Internal Medicine Department, Ribeirão Preto Medical School, University of São Paulo, 3900 Bandeirantes Avenue, Ribeirão Preto, SP 14048-900, Brazil

[b] Department of Electrical and Computer Engineering, Schulich School of Engineering, University of Calgary, 2500 University Dr. NW, Calgary, AB, Canada T2N 1N4

ARTICLE INFO

Article history:
Received 11 January 2016
Received in revised form
8 April 2016
Accepted 9 April 2016

Keywords:
Computer-aided diagnosis
Image processing
Magnetic resonance images
Shape analysis
Statistical analysis of gray levels
Texture analysis
Vertebral compression fractures

ABSTRACT

Purpose: Vertebral compression fractures (VCFs) result in partial collapse of vertebral bodies. They usually are nontraumatic or occur with low-energy trauma in the elderly secondary to different etiologies, such as insufficiency fractures of bone fragility in osteoporosis (benign fractures) or vertebral metastasis (malignant fractures). Our study aims to classify VCFs in T1-weighted magnetic resonance images (MRI).

Methods: We used the median sagittal planes of lumbar spine MRIs from 63 patients (38 women and 25 men) previously diagnosed with VCFs. The lumbar vertebral bodies were manually segmented and statistical features of gray levels were computed from the histogram. We also extracted texture and shape features to analyze the contours of the vertebral bodies. In total, 102 lumbar VCFs (53 benign and 49 malignant) and 89 normal lumbar vertebral bodies were analyzed. The *k*-nearest-neighbor method, a neural network with radial basis functions, and a naïve Bayes classifier were used with feature selection. We compared the classification obtained by these classifiers with the final diagnosis of each case, including biopsy for the malignant fractures and clinical and laboratory follow up for the benign fractures.

Results: The results obtained show an area under the receiver operating characteristic curve of 0.97 in distinguishing between normal and fractured vertebral bodies, and 0.92 in discriminating between benign and malignant fractures.

Conclusions: The proposed classification methods based on shape, texture, and statistical features have provided high accuracy and may assist in the diagnosis of VCFs.

1. Introduction

Vertebral compression fracture (VCF) is a fracture with partial collapse of the affected vertebral body. Clinically, a radiologist will have no doubt about the etiology of a traumatic VCF as a patient typically presents with a recent history of trauma, such as a fall or an accident. However, when the patient develops a recent vertebral collapse without trauma, or when there was a low-energy traumatic incident, the etiology needs to be investigated, and there can be difficulty in arriving at a diagnosis. This problem is common especially in the elderly population due to the higher incidence of VCFs secondary to bone failure. Vertebral fragility fractures secondary to osteoporosis are an increasingly important health issue [1,2]. The elderly population also has a high incidence of VCFs related to metastatic cancer affecting bone [3]. Clinically, a VCF secondary to osteoporosis is labeled as a benign VCF, and a VCF caused by bone metastasis is defined as a malignant VCF [3]. Complaints from patients related to both types of VCFs, benign and malignant, may be similar; however, the differentiation between the two types of VCFs is fundamental for correct diagnosis and appropriate treatment.

Magnetic resonance imaging (MRI) is effective in early detection of vertebral fractures [4,5]. The distribution of the signal intensity abnormality throughout the vertebral body is an important criterion to discriminate between benign and malignant VCFs in MRI, but the analysis of vertebral body shape can also help in this process [6–9]. A malignant vertebral collapse typically exhibits diffuse low signal intensity throughout the vertebral body in T1-weighted MRI.

* Corresponding author.
E-mail address: marcello@fmrp.usp.br (M.H. Nogueira-Barbosa).

http://dx.doi.org/10.1016/j.compbiomed.2016.04.006
0010-4825/

Osteoporotic VCFs, on the other hand, characteristically demonstrate partial preservation of the normal fatty bone marrow signal in the vertebral body in T1-weighted MRI [6]. In clinical practice, a radiologist compares the vertebral body signal intensity with the signal intensity in the intervertebral discs. Usually, normal vertebral bodies exhibit higher signal intensity than the intervertebral discs in T1-weighted MRI because of bone marrow adiposity. A vertebral body with bone marrow signal intensity similar to that of a neighboring disc is suspicious for malignancy [10].

VCFs may cause multiple types of changes in the shapes of vertebrae. Malignant VCFs could result in a posterior bulge or convexity of the posterior vertebral body wall, though this may occur together with a concave deformation of the vertebral plateaus. Malignant processes may cause the contours of vertebrae to be relatively rounded or smoothened due to bulging neoplastic tissue. In the case of benign VCFs, the vertebral plateaus may acquire a more accentuated concave shape, and subchondral bone impaction may result in rough contours with indentations. Benign VCFs may cause posterior wall fragment retropulsion with angulated or irregular contours [6,11].

Vertebrae without any fracture typically present nearly rectangular shapes in the sagittal plane. However, they may include small bone outgrowths and marginal bone proliferation known as osteophytes that may cause shape abnormalities. Such modifications of shape may potentially confound analysis with typical shape factors such as compactness and convex deficiency [12–14].

Link et al. [15] describe common signs of benign VCFs and malignant VCFs in MRI. Benign VCFs can present a concave posterior cortex, retropulsion of posterior fragments into the spinal canal, preserved marrow signal in T1-weighted MRI, and an isointense vertebra on T2-weighted and T1-weighted MRI with gadolinium contrast. Malignant VCFs can present a convex posterior cortex with an epidural mass, diffuse and low T1 signal, heterogeneous or high signal in T2-weighted and in T1-weighted MRI with gadolinium contrast, and pedicles that show low signal in T1-weighted MRI.

Fig. 1 shows two MRIs with both types of VCFs and normal vertebral bodies. Not all cases demonstrate the typical expected characteristics of benign or malignant VCFs in clinical practice, which calls for the development of accurate and reproducible diagnostic methods for VCFs with the aid of computational techniques.

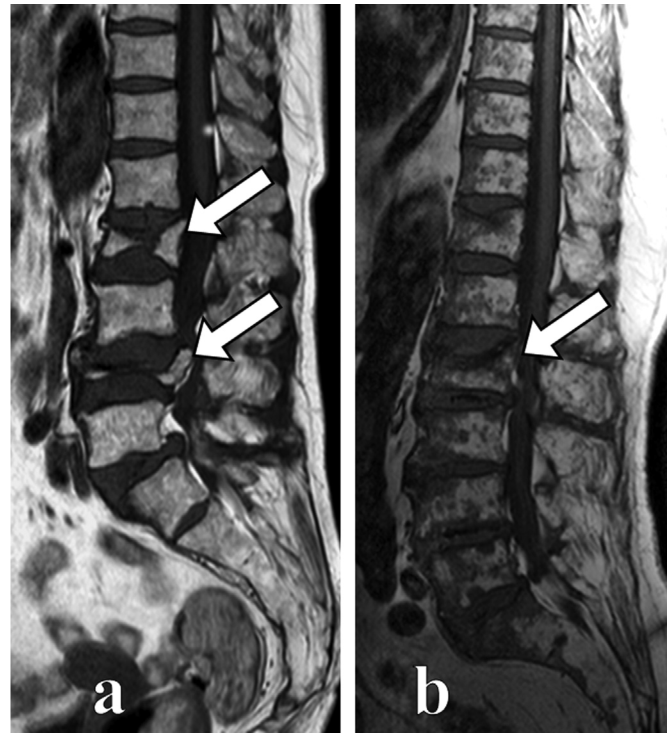

Fig. 1. Examples of MRI used in the study. The arrows in image 'a' show lumbar vertebrae L1 and L3 with benign VCFs; the other lumbar vertebral bodies are normal. The arrow in image 'b' shows a malignant VCF in L2. Note that the other vertebral bodies without fracture of case 'b' have heterogeneous signal intensity representing focii of bone metastasis.

2. Review of previous studies on VCFs

There has been some research interest in the area of imaging of the spine involving VCFs and segmentation of vertebrae and intervertebral discs. Grados et al. [16] presented a review of 149 articles on description and evaluation of osteoporotic vertebral fractures with standard radiographs or dual-energy X-ray absorptiometry (DXA) as well as the role of each method in clinical practice. The grading method of Genant et al. [17] for semiquantitative assessment of VCFs using standard radiographs provides information on the severity and prognosis of osteoporosis, while DXA for bone mineral density measurement may detect vertebral fractures in asymptomatic patients. Guglielmi et al. [18] conducted a morphometric study on benign VCFs in radiographs and evaluated a semiautomatic model-based image analysis software tool using a 6-point morphometry protocol and a manual procedure according to the shape and size measures of Genant et al. [17]. The time consumed for the semiautomatic procedure was significantly less than the time consumed for the manual procedure. The semiautomatic approach resulted in mean $\pm$ standard deviation errors of $2.50 \pm 0.72\%$ and $2.16 \pm 0.5\%$ for anterior–posterior and superior–inferior measurements, respectively. They also noted that a vertebral deformity does not always indicate a vertebral fracture but a vertebral fracture is always accompanied by vertebral deformity, and also that the combination of semi-quantitative visual and quantitative morphometric methods may be the best approach to the diagnosis of a vertebral fracture. Ribeiro et al. [19] proposed procedures for detection of VCFs in lateral radiographs of the lumbar spine using Gabor filters and an artificial neural network for extraction of the superior and the inferior plateaus of each vertebral body, and applied the method of Genant et al. [17] for classification using measures of height of the vertebral bodies. Their results indicated sensitivity up to 78% and specificity of 95%. Kasai et al. [20] developed an automatic computer-aided diagnosis (CAD) system for vertebral fractures based on chest X-ray images. Comparing with manual analysis performed by radiologists, they obtained accuracy ranging between 70.9% and 76.6% in the detection of vertebral fractures.

Al-Helo et al. [21] developed a CAD system for detecting vertebral body fractures in computed tomography (CT) images. Using active shape models and gradient vector flow active contours, they obtained 99% sensitivity and 87.5% specificity with the *k*-means method. Ghosh et al. [22] proposed a fully automated CAD system for detection of lumbar VCFs in CT images using three height deviation measures of vertebral bodies as features. They obtained an accuracy of 97.33%. While CT is the preferred modality for trauma patients, MRI is used in most of other clinical scenarios of spinal disease investigation [22].

The previous works reviewed above have in common the use of imaging modalities with ionizing radiation. Arevalo-Perez et al. [23] studied the use of dynamic contrast-enhanced MRI (DCE-MRI) to aid in noninvasive distinction between pathological and benign vertebral fractures. They reviewed cases of patients with vertebral fractures who underwent DCE-MRI and biopsy. The results indicated that pathological fractures had significantly higher