ELSEVIER

CrossMark

The Spine Journal 15 (2015) 1248–1254

THE SPINE JOURNAL

Clinical Study

Performance of statistical models of shape and appearance for semiautomatic segmentations of spinal vertebrae T4–L4 on digitized vertebral fracture assessment images

Robert van der Velde, MD[a,*], Takouhi Ozanian, PhD[b], Bianca Dumitrescu, MD, PhD[c,d], Jane Haslam, PhD[b], Joes Staal, PhD[b], Alan Brett, PhD[b], Joop van den Bergh, MD, PhD[a,e], Piet Geusens, MD, PhD[c]

[a]*Department of Internal Medicine, VieCuri MC Noord-Limburg, Tegelseweg 210, 5912 BL Venlo, The Netherlands*
[b]*Mellor House, 26 Mellor Rd, Cheadle Hulme, Cheadle, SK8 5AU, United Kingdom*
[c]*Internal Medicine, Department of Rheumatology, University Hospital, Maastricht University, Debeyelaan 25, 6229 HX Maastricht, The Netherlands*
[d]*University of Medicine and Pharmacy "Carol Davila" Bucharest, Romania Bulevardul Eroii Sanitari 8, Bucuresti 050474, Romania*
[e]*Department of Internal Medicine, Maastricht University Medical Centre/NUTRIM, Debeyelaan 25, 6229 HX Maastricht, The Netherlands*

Received 18 March 2014; revised 8 January 2015; accepted 6 February 2015

Abstract

BACKGROUND CONTEXT: Despite its clinical importance, accurate identification of vertebral fractures is problematic and time-consuming. There is a recognized need to improve the detection of vertebral fractures so that appropriate high-risk patients can be selected to initiate clinically beneficial therapeutic interventions.

PURPOSE: To develop and evaluate semiautomatic algorithms for detailed annotation of vertebral bodies from T4 to L4 in digitized lateral spinal dual-energy X-ray absorptiometry (DXA) vertebral fracture assessment (VFA) images.

STUDY DESIGN: Using lateral spinal DXA VFA images from subjects imaged at University Hospital fracture liaison service, image algorithms were developed for semiautomatic detailed annotation of vertebral bodies from T4 to L4.

PATIENT SAMPLE: Two hundred one women aged 50 years or older with nonvertebral fractures.

OUTCOME MEASURES: Algorithm accuracy and precision.

METHODS: Statistical models of vertebral shape and appearance from T4 to L4 were constructed using VFA images from 130 subjects. The resulting models form a part of an algorithm for performing semiautomatic detailed annotation of vertebral bodies from T4 to L4. Algorithm accuracy and precision were evaluated on a test-set of 71 independent images.

RESULTS: Overall accuracy was 0.72 mm (3.00% of vertebral height) and overall precision was 0.26 mm (1.11%) for point-to-line distance. Accuracy and precision were best on normal vertebrae (0.65 mm [2.67%] and 0.21 mm [0.90%], respectively) and mild fractures (0.78 mm [3.18%] and 0.32 mm [1.39%], respectively), but accuracy and precision errors were higher for moderate (1.07 mm [4.66%] and 0.48 mm [2.15%], respectively) and severe fractures (2.07 mm [9.65%] and 1.10 mm [5.09%], respectively). Accuracy and precision results for the algorithm were comparable with other reported results in the literature.

FDA device/drug status: Not applicable.

Author disclosures: ***RvdV:*** Nothing to disclose. ***TO:*** Nothing to disclose. ***BD:*** Nothing to disclose. ***JH:*** Other: Optasia Medical Ltd (Employee of Optasia Medical Ltd, who manufactures the SpineAnalyzer software described in the article); Patent: US8126249 (Issued). ***JS:*** Other: Optasia Medical Ltd (Employee of Optasia Medical). ***AB:*** Other: Optasia Medical Ltd (Salary and stock options); Patent: US8126249 (Issued). ***JvdB:*** Nothing to disclose. ***PG:*** Nothing to disclose.

The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

* Corresponding author. Department of Internal Medicine, VieCuri MC Noord-Limburg, Tegelseweg 210, 5912 BL Venlo, The Netherlands. Tel.: (31) 773-205-555.

E-mail address: robertvandervelde@planet.nl (R. van der Velde)

http://dx.doi.org/10.1016/j.spinee.2015.02.018

CONCLUSIONS: This semiautomatic image analysis had high overall accuracy and precision on normal vertebrae and mild fractures, but performed less well in moderate and severe fractures. It is, therefore, a useful tool to identify normality of vertebral shape and to identify mild fractures.

Keywords: Osteoporosis; Vertebral; Fractures; DXA; VFA; Morphometry

Introduction

Interpretation of vertebral deformities can be accomplished on lateral images of the spine obtained by dual-energy X-ray absorptiometry (DXA), X-ray, or computed tomography scanners. Several ways for characterizing osteoporotic deformities in lateral spine images can be found in the literature [1–5] There are two principal approaches: semiquantitative techniques for which (subjective) judgment by a trained radiologist is needed [2,6] and fully quantitative morphometric methods [3–5]. The fully quantitative methods rely on the (manual) delineation of at least six points on each vertebra from which height measurements are derived to determine the anterior, middle, and posterior vertebral body height reductions. The semiquantitative methods can include additional subtle shape information that cannot be captured by vertebral body height reduction measurements only [7]. The *de facto* standard for fracture assessment is Genant semiquantitative method [2], however, there can be issues of reproducibility [8], especially for mild fractures.

It is well-known that vertebral fractures are an important independent risk factor for future osteoporotic fractures [7,9–18]. However, a high percentage of patients with asymptomatic vertebral fractures will not be recognized (and will, therefore, not be eligible for treatment) if screening is based on bone mineral density evaluation only [19]. Even while using techniques to specifically screen for vertebral fractures, mild fractures (which can have serious consequences) are easily missed [8,9,11,13–15]. Furthermore, although objective measurements of vertebral deformity are extremely useful for grading fracture severity, they are time-consuming and readers need special training. The underdiagnosis and resulting undertreatment of vertebral fractures is a recognized problem worldwide [20]. Delmas et al. [20] reported that in the IMPACT trial, about 34% of vertebral fractures in 2,451 subjects were overlooked by trained radiologists.

To improve the detection and classification of vertebral deformities, it is necessary to supply clinicians and radiologists with tools that increase their accuracy and efficiency in these tasks, so that clinically beneficial therapeutic interventions can be initiated more easily. In this article, we describe the performance of a tool that can be used for semiautomatic segmentation of vertebral bodies after which morphometry points can be determined automatically. The technique for the initial segmentation task is based on the statistical models of shape and appearance [21–26].

The present study builds on our own previously published work [21] to develop and evaluate the performance of statistical model-based algorithms for semiautomatic comprehensive annotation of vertebrae T4–L4 in lateral spine radiographs. We aim to extend the algorithms to perform annotation of vertebrae T4–L4 in vertebral fracture assessment (VFA) images derived from DXA scanners.

Materials and methods

Data

To build the models, a set of 201 DXA VFA images from 201 subjects was used. The images were acquired at the Maastricht University Hospital fracture liaison service using a Hologic 4500A DXA scanner (Hologic, Bedford, MA, USA). Subjects were women aged 50 years or older with a nonvertebral fracture. The average body mass index of this group was calculated from the length and weight measures of the individual subjects. The original data set was narrowed for the presence of vertebral fractures by an initial triaging process, selecting subjects in whom at least one vertebral fracture was present according to semiquantitative analysis on VFA images. Image resolution was 360×362 μm per pixel. An example VFA image is shown in Fig. 1, Left.

Mark-up

Vertebrae from T4–L4 were annotated using a standardized land marking protocol, described in detail in our previous work [21]. Briefly, the protocol uses 95 points to represent the circumferential vertebral borders, including right/left/central endplate margins and anterior/posterior margins (Fig. 2). Vertebrae that were considered to be inadequately imaged for reliable image annotation were excluded from further analysis.

The image data set was annotated by an experienced rheumatologist (BD) who in addition to the 95-point mark-up, annotated each vertebral body with standard six-point morphometry points, allowing the fracture severity of each vertebra to be classified using quantitative morphometry, based on the method published by Black et al. [7], and using the thresholds proposed by Genant et al. [2]. The six-point marking was considered as the gold standard.

Training

Subsequently, the data set was split into independent training and test sets. Next, 13 statistical models of