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Research article

CT-scout based, semi-automated vertebral morphometry after digital image enhancement

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ABSTRACT

Introduction: Radiographic diagnosis of osteoporotic vertebral fracture is necessary to reduce its substantial associated morbidity. Computed tomography (CT) scout has recently been demonstrated as a reliable technique for vertebral fracture diagnosis. Software assistance may help to overcome some limitations of that diagnostics. We aimed to evaluate whether digital image enhancement improved the capacity of one of the existing software to detect fractures semi-automatically.
Methods: CT scanograms of patients suffering from osteoporosis, with or without vertebral fractures were analyzed. The original set of CT scanograms were triplicated and digitally modified to improve edge detection using three different techniques: SHARPENING, UNSHARP MASKING, and CONVOLUTION.
Results: The manual morphometric analysis identified 1485 vertebrae, 200 of which were classified as fractured. Unadjusted morphometry (AUTOMATED with no digital enhancement) found 63 fractures, 33 of which were true positive (i.e., it correctly identified 52% of the fractures); SHARPENING detected 57 fractures (30 true positives, 53%); UNSHARP MASKING yielded 30 (13 true positives, 43%); and CONVOLUTION found 24 fractures (9 true positives, 38%). The intra-reader reliability for height ratios did not significantly improve with image enhancement (kappa ranged 0.22–0.41 for adjusted measurements and 0.16–0.38 for unadjusted). Similarly, the inter-reader agreement for prevalent fractures did not significantly improve with image enhancement (kappa 0.29–0.56 and −0.01 to 0.23 for adjusted and unadjusted measurements, respectively).
Conclusions: Our results suggest that digital image enhancement does not improve software-assisted vertebral fracture detection by CT scout.

1. Introduction

Osteoporotic vertebral fractures occur in ~20% of postmenopausal women, and of these, 75% elude clinical attention, resulting in substantial morbidity [1–3]. Moreover, 34% of all vertebral fractures remain undiagnosed, even when assessed by trained radiologists [2]. When these fractures are undetected and untreated, they can lead to height loss, kyphosis, chronic back pain, and subsequent fractures [1–5].

Although lateral radiograph of the spine is currently considered the gold standard for vertebral fracture diagnosis, there are new modalities available [2,6]. The International Society for Clinical Densitometry recommends dual-energy X-ray absorptiometry for vertebral fracture diagnosis [7]. However, the use of computed tomography (CT) is gaining attention [8–11].

Three terms usually describe image quality in radiography: (i) contrast (the difference in the image greyscale between adjacent points); spatial resolution (the ability to distinguish between two small objects); and noise (a limitation to differentiate objects from their background) [12]. Inferior spatial resolution with CT scout compared with lateral radiography is often implied as for its main disadvantage. However, unlike CT scout, conventional radiographs suffer from projection parallax effects produced by the divergent X-ray beam [13]. Moreover, since CT examinations are performed due to various indications, not necessarily vertebral fracture assessment, obtained data could be utilized without the need to expose the patient to additional radiation [8,11]. Emerging low-dose CT protocols provide an even more sensible approach [14–16]. Therefore, CT scout is an attractive

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alternative for the detection of vertebral fractures over lateral radiography.

There are three techniques to identify vertebral fractures from lateral spine views, regardless of the modality used: (1) Genant's semi-quantitative (SQ) visual scale [17], (2) the algorithm-based (AB) qualitative approach [18], and (3) quantitative six-point morphometry (QM) [13]. All methods require a trained reader, are time-consuming, and have limited reproducibility among readers. The highest level of expertise is needed in SQ, and AB approaches, which serve as the gold standard in identifying vertebral fractures, while QM suffers from high point placement variability, rendering it most prone to a low agreement among observers. Therefore, we hypothesized that a combination of SQ and QM would enhance vertebral fracture assessment while minimizing their individual constraints.

Software assistance, such as the SpineAnalyzer software, can substantially reduce the time commitment (e.g., from ~15 min for manual six-point placement to an average of 5 min with the SpineAnalyzer), as well as the necessary reader training [9]. Typically, image analysis begins by placing single points in the center of each vertebra, and then automatic vertebral boundaries are drawn. Most of the time, the contours are adequately placed, and no manual intervention from the reader is needed. However, sometimes these contours must be adjusted to reflect the real vertebral dimensions, and vertebral fracture is overlooked. Since the shape detection algorithm of the software program relies on edge detection, we speculated that manipulating the image (i.e., enhancing its contrast) could facilitate detection of the vertebral margins.

Therefore, the aim of this study was to establish if the inter- and intra-reader reliability of CT scout detection of vertebral fractures improves with digital modification. We also examined whether different methods of image modification changed the automated vertebral fracture detection if there were no manual adjustment of the point placement.

2. Methods

A total of 250 CT scanograms of patients suffering from osteoporosis admitted to the Orthopedic Trauma Department, with or without prevalent vertebral fractures, were analyzed.

2.1. Semi-automated quantitative vertebral morphometry

Semi-automated quantitative vertebral morphometry was performed using a model-based shape recognition algorithm. This technique uses a standard six-point morphometry enriched with detailed 95-point landmark annotation to capture the shape of each vertebra (SpineAnalyzer, Optasia Medical, Cheadle, UK) (Fig. 1). The program computes the vertebral heights (anterior, middle, and posterior in normalized pixels), height ratios (wedge, biconcave, crush), and deformity (wedge, biconcave, crush) percentage, which are indicative of a vertebral fracture. The relevant equations are shown in Fig. 2. Pixel coordinates of the six points were saved, and all data were exported to a worksheet file for further statistical analysis.

Fig. 1. The result of semi-automated quantitative vertebral morphometry of Th12 to L4 vertebra (SpineAnalyzer, Optasia Medical, Cheadle, UK).

$$\text{Wedge ratio (RW)} = h_A/h_P$$
$$\text{Biconvave ratio (RB)} = h_M/h_P$$
$$\text{Crush ratio (RC)} = \min[\max(h_{Pi}/h_{Pi-1}, h_{Ai}/h_{Ai-1}), \max(h_{Pi}/h_{Pi+1}, h_{Ai}/h_{Ai+1})]$$
$$\text{Wedge deformity (DW)} = 100 \times [1 - RW]$$
$$\text{Biconcave deformity (DB)} = 100 \times [1 - RB]$$
$$\text{Crush deformity (DC)} = 100 \times [1 - RC]$$

Fig. 2. Equations for ratios and deformity percentages, where h_A, h_m, and h_P indicate the anterior, middle, and posterior vertebral heights at the current level, "−1" and "+1" subscripts indicate a level below or above the current level, based on Black et al., [26].

2.2. Software-assisted contour placement

The shape recognition algorithm used in our study utilizes Active Shape Models described by Cootes et al. [19] Active Shape Models and Active Appearance Models are based on a statistical model from a set of annotated training images [20]. Since statistical shape models are meant to describe the characteristics of a particular population, the choice of the training set is critical; otherwise, the results will depict unreliable and defective shapes [19]. As naturally occurring variability of vertebral fracture morphology are insufficiently well understood to allow a theoretical model of deformability to be proposed, the software must "learn" fracture patterns from the representative training set. Each shape is annotated manually by three types of points during training: (1) points of particular significance (application-dependent, e.g., vertebral body corners); (2) points that are significant (application-independent, e.g., curvature extrema); and (3) points that can be interpolated from points of previous types. The positions of the points are subsequently examined, and averages are derived to form a statistical model of the given shape.

In this study, the complete (with manual point adjustment) analysis was made to determine the number of fractured vertebrae. Afterward, the procedure was repeated, but without manual adjustment of the morphometry points (Fig. 3).

2.3. Digital image enhancement

We used ImageJ 1.46r (Wayne Rasband, NIH, USA), an open-source Java-based image processing application, to perform digital image enhancement. The original set of images was triplicated and digitally modified using three different techniques. Obtained data were based on analysis of the same scans, not repeat acquisitions, to limit image variability due to data acquisition. All techniques utilized kernels (local operators).

SHARPENING (i.e., the contrast was intensified, and detail in the image accentuated) was performed on the first set using weighting factors in a kernel of the 3 × 3 neighborhood. Sharpening kernels