Vertebral Fracture Identification using Dual-Energy X-ray Absorptiometry

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Outline

• An introduction to osteoporosis
• Osteoporosis and fragility fractures

• Dual-energy X-ray absorptiometry (DXA)
• Vertebral fracture assessment (VFA) by DXA
• VFA by DXA versus conventional radiography

• What is a vertebral fracture?
• Common non-fracture deformities

• Approaches used to identify osteoporotic vertebral fractures
Osteoporosis and Fragility Fractures
Osteoporosis – A Definition

The World Health Organization (WHO) defines osteoporosis as:

‘A disease characterized by low bone mass and microarchitectural deterioration of bone tissue leading to enhanced bone fragility and a consequent increase in fracture risk’

World Health Organization (WHO) 1994
Prevalence of Osteoporosis

- Osteoporosis affects 200 million women worldwide
  - 1/3 of women aged 60 to 70
  - 2/3 of women aged 80 or older
  - Nearly 1 in 2 women and 1 in 5 men will suffer an osteoporotic fracture

Hernlund et al., Arch Osteopor, 2013, 8: 136
Osteoporosis and Fragility Fractures

- Osteoporosis can lead to fragility fractures
- Fragility fractures can occur following a fall from standing height of less

Li et al. Journal of Orthopaedic Surgery and Research 2010 5:62
Osteoporotic Vertebral Fractures

• Vertebral fractures occur most frequently in older people
  o High frequency among postmenopausal women

• Difficult to diagnose and are often only discovered when the spine is imaged

• Can cause significant morbidity:
  o Back pain caused by collapsed vertebrae
  o Kyphosis (stooped posture) due to height loss
  o Impaired function and quality of life

Image courtesy of the National Osteoporosis Society, UK
Vertebral Fractures Substantially Increase the Risk of New Fragility Fractures

- Women with vertebral fractures have a 5-fold increased risk of a new vertebral fracture and a 2-fold increased risk of hip fracture
  
  *Black et al., J Bone Miner Res 1999*
  *Melton et al, Osteoporos Int 1999*

- One woman in five will suffer from another vertebral fracture within a year

  *Lindsay et al., JAMA, 2001*
Dual-Energy X-ray Absorptiometry and Vertebral Fracture Assessment
Dual-Energy X-ray Absorptiometry (DXA)

Discovery DXA scanner (Hologic Inc.)
Performing a Vertebral Fracture Assessment (VFA) using DXA

**Posteroanterior view**
(x-rays enter through the back and exit via the front)

**Lateral view**
(x-rays enter through one side and exit via the other side)
VFA by DXA

No Fracture

Fracture
Why use VFA by DXA?
Ionising Radiation Doses to the Patient

Natural Daily Background Radiation

- Thoracic spine - AP and lateral
- Lumbar spine - AP and lateral

= 6 microSv

VFA by DXA

- 24 microSv ≈ 4 days background radiation

Conventional Radiography

- 1700 microSv (1.7 milliSv) ≈ 9 months background radiation
Image Quantity

Conventional Radiography
4 images are required to capture the thoracic and lumbar spine (AP and lateral views)

VFA by DXA
Only 2 images are required to capture the thoracic and lumbar spine (PA and lateral views)
Image Resolution and Quality

**Conventional Radiography**
Resolution = 0.25 to 0.1 mm
Superior image quality
(compared to VFA by DXA)

**VFA by DXA**
Resolution = 1.0 to 0.35 mm
Good image quality
(but slightly poorer than conventional radiography)
What is an Osteoporotic Vertebral Fracture?
Identification of the Vertebral Ring and Endplate

Vertebral body

Vertebral ring (ring apophysis)

Vertebral endplate
Vertebral Endplates in a Normal Vertebra

Fig. 3 Appearance of vertebral endplates in a normal vertebra. R represents the vertebral ring line, C + R represent the central endplate within the vertebral ring overlapping the vertebral ring line

An Osteoporotic Vertebral Fracture

‘Evidence of depression of the central endplate with or without a fracture of the vertebral ring or the cortex of the vertebral body’

Typical Osteoporotic Vertebral Fractures: Endplate Fracture is an Essential Feature

**Concave**
- Collapse of the central upper endplate - Reduction of the mid vertebral height

**Wedge**
- Reduction of both the mid and anterior vertebral heights

**Crush**
- Collapse of the whole vertebral body
When is a Vertebral Fracture not an Osteoporotic Vertebral Fracture?

- Traumatic Fracture
  - Angulation of the endplate
  - Bone fragmentation
Common Non-fracture Deformities
Short Vertebral Height with Normal Endplates

Short vertebral height (SVH)
- Anterior height < posterior height
- No apparent fracture of the endplate
Schmorl’s Nodes

Schmorl’s node

An upward and downward protrusion (pushing into) of the soft tissue of an intervertebral disc into the bony tissue of the adjacent vertebrae


Artefacts – Overlying Structures

- Large osteophytes (bone spurs)
- Tip of the scapula (shoulder blade)
- Head of the humerus (shoulder joint)
Scheuermann's Disease

- Anterior wedging of the vertebrae
- Irregularities of the bone/disc interface
  - Kyphosis
Approaches used to Identify Osteoporotic Vertebral Fractures
Quantitative Morphometry (QM) – Measurement of Vertebral Dimensions

\[ \text{hp} = \text{posterior height} \]
\[ \text{hm} = \text{mid height} \]
\[ \text{ha} = \text{anterior height} \]

Classification of Vertebral Fractures by QM

Wedge deformity

Grade 1

\[4.0 \leq \frac{ha}{hp} < 3.0 \text{ SD}\]

A

Grade 2

\[\frac{ha}{hp} < 4.0 \text{ SD}\]

Biconcavity deformity

Grade 1

\[4.0 \leq \frac{hm}{hp} < 3.0 \text{ SD}\]

B

Grade 2

\[\frac{hm}{hp} < 4.0 \text{ SD}\]

Compression deformity

Grade 1

\[4.0 \leq \frac{hp}{hp} < 3.0 \text{ SD}\]

C

Grade 2

\[\frac{hp}{hp} < 4.0 \text{ SD}\]

Normal

Semi-Quantitative (SQ) Method – A Visual Assessment Tool Allowing Fracture Severity Grading

<table>
<thead>
<tr>
<th>Grade</th>
<th>Height Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 %</td>
</tr>
<tr>
<td>1</td>
<td>20 to 25 %</td>
</tr>
<tr>
<td>2</td>
<td>25 to 40 %</td>
</tr>
<tr>
<td>3</td>
<td>≥ 40 %</td>
</tr>
</tbody>
</table>

Genant HK and Jergas M, Osteoporos Int, 1993;14 (suppl 3):S43-55
Algorithm-Based Qualitative Method (ABQ) – A Visual Assessment Tool Requiring Endplate Involvement

Main advantages:
- Requires evidence of fracture of the vertebral endplate
- No minimum threshold for apparent reduction in vertebral height

The ABQ Diagnostic Algorithm

START

- Depression of endplate?
  - NO
  - YES: Close to centre of endplate?
    - NO
    - YES: Concave depression?
      - NO
      - YES: Whole endplate depressed within ring?
        - NO
        - YES: Trauma, tumor, metabolic disease?
          - NO
          - YES: Depression of endplate?

- Short vertebral height?
  - NO
  - YES: Scheuermann’s, childhood/young adult fracture, scoliosis, variants

- Variants: step-like endplate (thoracic vertebrae, anterior); Cupid’s bow or balloon disc (lumbar vertebrae, posterior)

- Check for oblique projection or scoliosis

- Focused area: Schmorl’s node
  - YES
  - NO: Trauma, tumor, metabolic disease?

- Non-fracture deformity, developmental variant, non-osteoporotic fracture, other metabolic condition

- Normal

Computation Methods for the Identification of Vertebral Fractures

Currently, standard VFA image evaluation methods rely on the visual identification of fractures.

It would be an advance if these approaches could be automated.

Several computational methods have been developed.

- Some are commercially available (e.g. SpineAnalyzer).

Typically, these fracture identification tools:

- Do not examine the vertebral endplates for deformities.
- Are based on 2D image computation approaches.

SpineAnalyzer™ (Optasia Medical, Cheadle, UK)
Summary (1)

- VFA by DXA and spine radiographs are complimentary techniques for identifying vertebral fractures

- The identification of vertebral fractures represents a challenge

- Several approaches have been developed, but in practice we have found that the ABQ algorithm is the most reliable
Summary (2)

- **Vertebral fractures:**
  - Often remain unreported
  - Are frequently inadequately characterized

- **Automation of the vertebral fracture identification process could:**
  - Ensure that a standardized approach is adopted
  - Allow those fractures which are often missed (mild fractures) to be identified and reported

- **Several computational methods have been developed**
  - Do not examine the vertebral endplates for deformities

- **More sophisticated approaches need to be developed**
  - Examination of the 3D structure of the vertebrae
Thank you!