Imaging the porcine vertebral endplate with desktop micro-computed tomography

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Background

- Low back pain (LBP) is one of the most prevalent and debilitating musculoskeletal (MSK) disorders in Canadian rural workforce\[1,2\]

- Prevalence of LBP and neck pain is associated with exposure to high levels of WBV and mechanical shocks\[3\]

- Daily exposure to high levels of whole body vibration (WBV) and mechanical shocks often exceeds ISO recommended daily vibration dose values (VDV)\[4\]

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Background

- Pain is a complex condition which includes biological, structural, and psycho-social factors
  - Associations between LBP and structural spine damage\cite{1,2}

- Literature evaluating spinal damage related to WBV exposure has focused on the intervertebral disc\cite{3-6}

- Literature evaluating structural properties of the vertebra have focused on the vertebral body\cite{7,8}

- What about the vertebral endplate?

\cite{1} Wahlström, Int Arch Occup Environ Health, 2018; \cite{2} Dudil, Eur Spine J, 2016; \cite{3} Bovenzi, Med Lav, 2017; \cite{4} Gregory, Spine, 2011; \cite{5} Yates, Spine, 2011; \cite{6} Adams, Spine, 2000; \cite{7} Jackman, J Orthop Res, 2014; \cite{8} Kummari, Calcif Tissue Int, 2009.
Background

- Proposition that endplate damage is a major initiating factor for disc degeneration\(^1\) and subsequent LBP\(^2,3\)
  - Important as the intervertebral disc is immune-privileged\(^4\), avascular\(^5\), and aneural\(^6\)
  - Disturbance in the vertebral endplate environment could precede intervertebral disc degeneration

- Existence of damage to the vertebral endplate during WBV and mechanical shock exposure is currently unknown, thus the minimum exposure needed to induce endplate damage is also unknown

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Background

Possible to use micro-computed tomography (micro CT) to evaluate the structural properties of the vertebral endplate[1]

But...there is a need for a reliable, robust technique to evaluate the entire endplate surface and underlying trabecular bone to determine likely sites for damage initiation under WBV

Objective

- Use micro-computed tomography to develop reliable image-based outcomes to evaluate bone structural properties at the vertebral endplate
Methods

- Acquired 4 porcine cervical spines from a common source
- Divided the spine into functional spinal units (FSU) comprised of either C3-4 or C5-6 then removed surrounding muscle tissue, neural arch and spinal processes
- Further dissected each FSU into individual vertebrae (C3 through C5) leaving the annulus intact on the imaged vertebral endplate surface
Methods

- Individual vertebrae were imaged with desktop micro-CT (SkyScan 1172; Bruker; Konich, Belgium)
  - 100kVp, 100μA, 180° rotation with steps of 0.3°, ~55min scan time, 4-frame averaging, 0.5mm Al filter, 26.6μm isotropic resolution

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- Raw images were reconstructed with NRecon 1.6.4
  (SkyScan) and visualized using ImageJ[1,2] with post-
  processing and analysis using MatLab (MathWorks; Natick,
  USA) and Analyze 10.0 (Mayo Foundation; Rochester, USA)

Methods

- Precision Errors
  - 14 specimens, 3 repeated scans after repositioning (42 total scans, 28 DOF)[1]
  - Root mean square coefficient of variation (CV%)[1,2] and intraclass correlation coefficient (ICC)

- Inferior endplates of C3 and C5 (n=7 samples, 21 total scans)
- Superior endplates of C4 and C6 (n=7 samples, 21 total scans)

Preliminary Imaging Results

Inferior Surface (C5)

Superior Surface (C6)
Preliminary Imaging Results

View in transverse plane (along z-axis)

26.6 µm resolution
Preliminary Imaging Results

View in sagittal plane (along y-axis)

26.6 µm resolution

33%

50%

66%
Preliminary Imaging Results

26.6 µm resolution

View in coronal plane (along x-axis)
Anticipated Structural Outcomes

- Bone volume fraction (BV/TV)
- Cortical porosity
- Cortical porosity distribution
- Endplate thickness and area
- Trabecular porosity
- Trabecular thickness
- Trabecular number
- Degree of anisotropy

Anticipated Regional Outcomes

- Anterior and posterior
- Sub-nucleus and sub-annulus
Anticipated Depth Analysis

- Endplate cortical thickness
- Vertebral endplate (1.5mm depth from the endplate surface)
- Vertebral trabecular bone (1.5mm to 5mm depth from endplate surface)
Anticipated Depth Analysis

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Next Steps

- Post-processing\textsuperscript{[1,2]}
  - Data reduction and image cropping
  - Filtering
  - Thresholding endplate surface, cortical bone, and trabecular bone
  - Masking and fitting splines to endplate surface
  - Isolate depths and regions at endplate surface
  - Structural property analysis

\textsuperscript{[1]} Johnston, Osteoarth Cartil, 2009; \textsuperscript{[2]} Burnett, Osteoporos Int, 2014.
Anticipated Applications

- Outcomes will provide image-based targets to quantify structural damage of vertebral endplate in cadaveric mechanical WBV and impact shock testing.
Anticipated Applications

- Outcomes will provide guidance in determining additional image analysis including using contrast agents and Synchrotron-CT

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