Imaging the porcine vertebral endplate with desktop micro-computed tomography

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Background

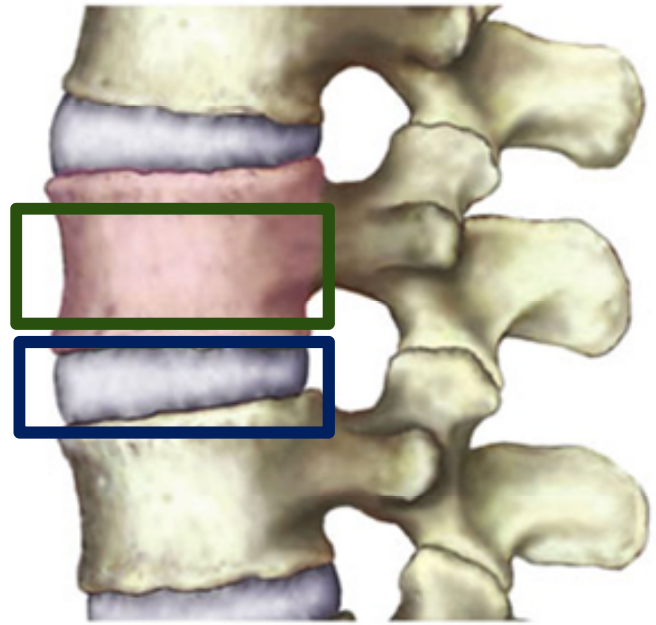
- Low back pain (LBP) is one of the most prevalent and debilitating musculoskeletal (MSK) disorders in Canadian rural workforce[1,2]
- Prevalence of LBP and neck pain is associated with exposure to high levels of WBV and mechanical shocks[3]
- Daily exposure to high levels of whole body vibration (WBV) and mechanical shocks often exceeds ISO recommended daily vibration dose values (VDV)[4]

[5]

[1] McMillan, J Agromed, 2015; [2] Essien, J Occup Environ Med, 2016; [3] Milosavljevic, Ann Occup Hyg, 2012; [4] Milosavljevic, Int J Indus Ergon, 2012; [5] Kociolek, Int J Indus Ergon, 2018.

Background

- Pain is a complex condition which includes biological, structural, and psycho-social factors
  - Associations between LBP and structural spine damage[1,2]
- Literature evaluating spinal damage related to WBV exposure has focused on the intervertebral disc[3-6]
- Literature evaluating structural properties of the vertebra have focused on the vertebral body[7,8]

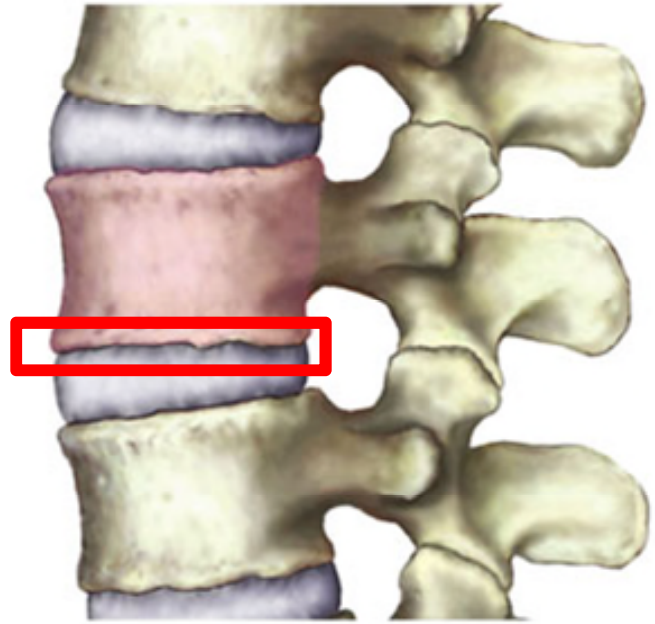


- What about the vertebral endplate?

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

Background

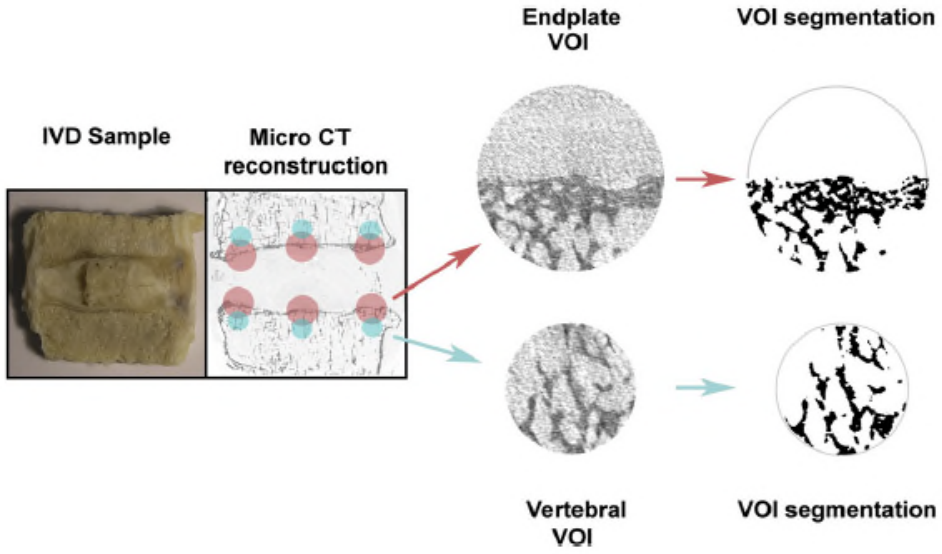
- Proposition that endplate damage is a major initiating factor for disc degeneration[1] and subsequent LBP[2,3]
  - Important as the intervertebral disc is immune-privileged[4], avascular[5], and aneural[6]
  - Disturbance in the vertebral endplate environment could precede intervertebral disc degeneration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



[1] Rade, Spine, 2018; [2] Dudil, Eur Spine J, 2016; [3] Herlin, PLOS One, 2019; [4] Wang, Int J Clin Exp Pathol, 2014; [5] Grunhagen, J Bone Joint Surg, 2006; [6] Urban, Arth Res Therap, 2003.

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

[1] Rutges, Osteoarth Cartil, 2011; [2]

Objective

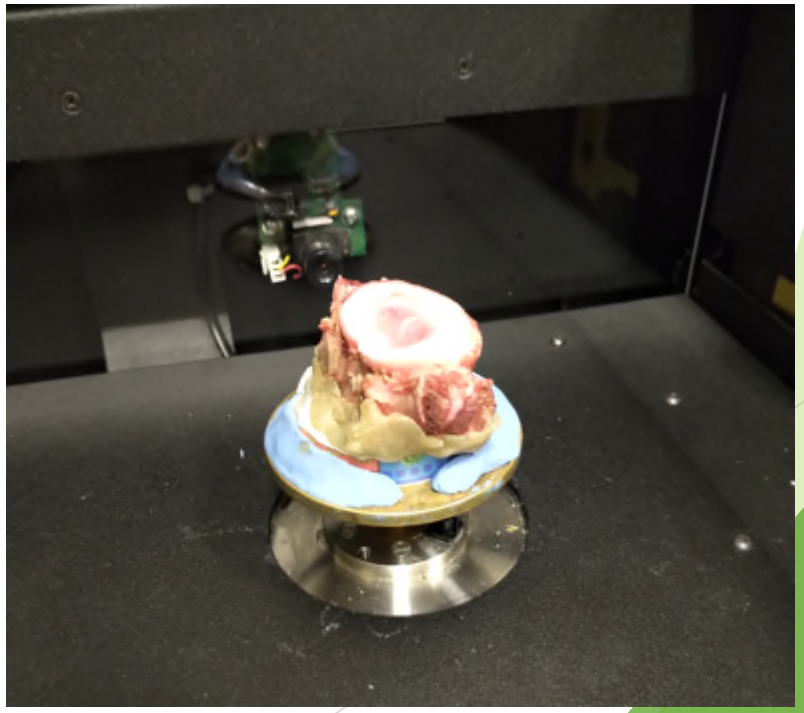
- Use micro-computed tomography to develop reliable image-based outcomes to evaluate bone structural properties at the vertebral endplate

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, 100uA, 180^{o} rotation with steps of 0.3^{o}, ~55min scan time, 4-frame averaging, 0.5mm Al filter, 26.6μm isotropic resolution



[1] Abramoff, Biophotonics, 2004; [2] Rasband, US National Institutes of Health, 1997.

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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)

[1] Abramoff, Biophotonics, 2004; [2] Rasband, US National Institutes of Health, 1997.

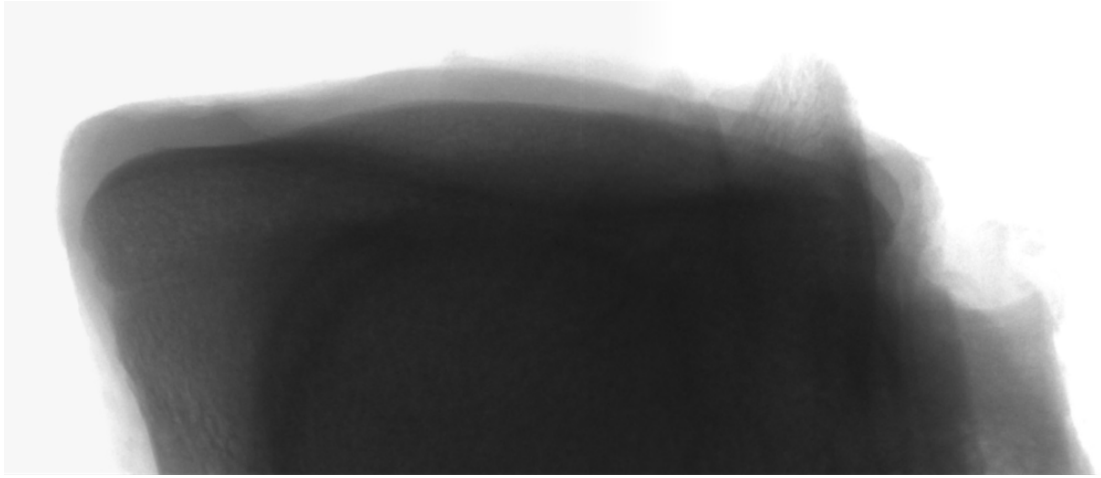
Methods

- 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)

[1] Gluer, Osteoporos Int, 1995; [2] Burnett, Osteoporos Int, 2014

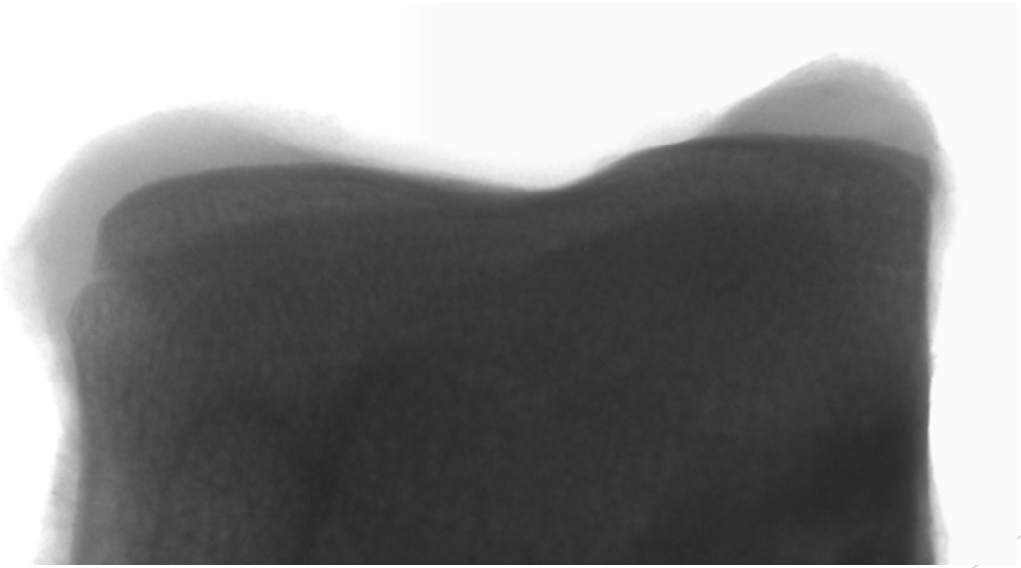
Preliminary Imaging Results

Inferior Surface (C5)



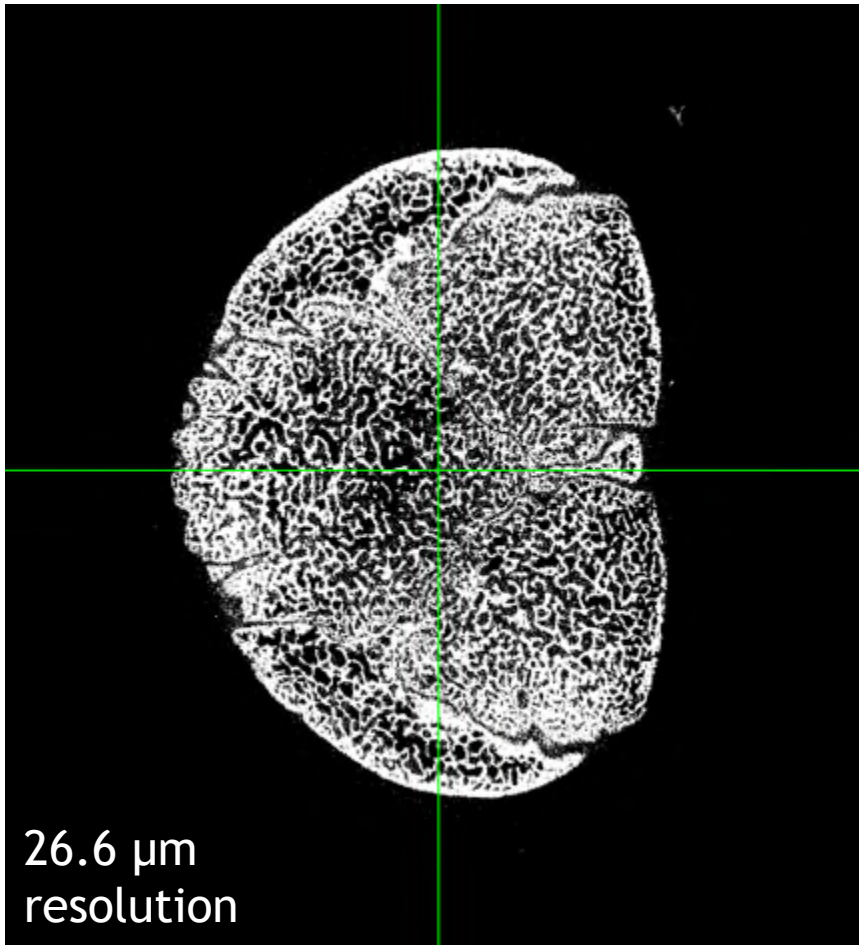
Anterior

Posterior

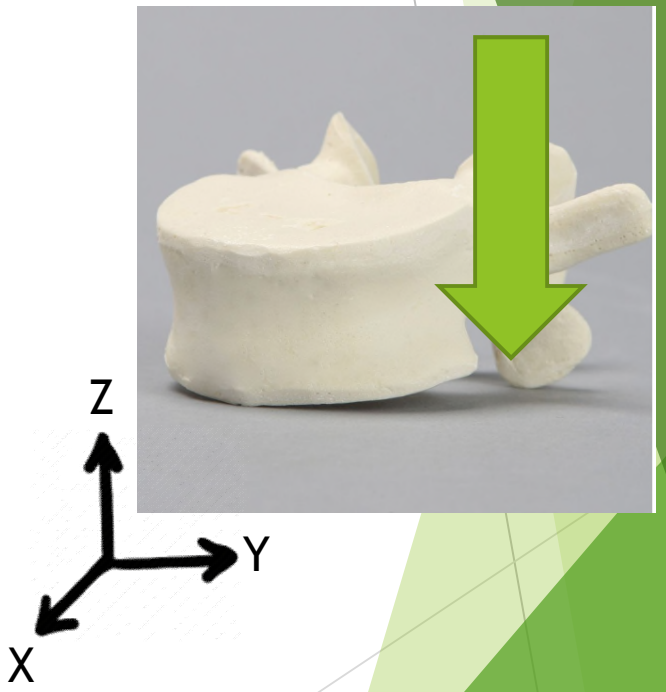


Superior Surface (C6)

Preliminary Imaging Results



View in transverse plane (along z-axis)



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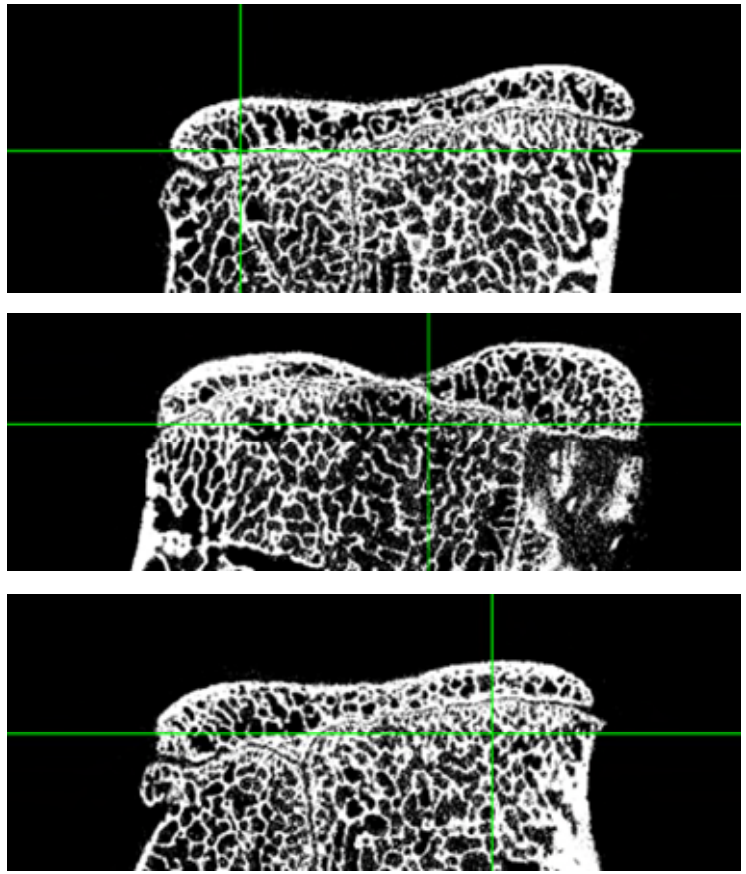


Anterior

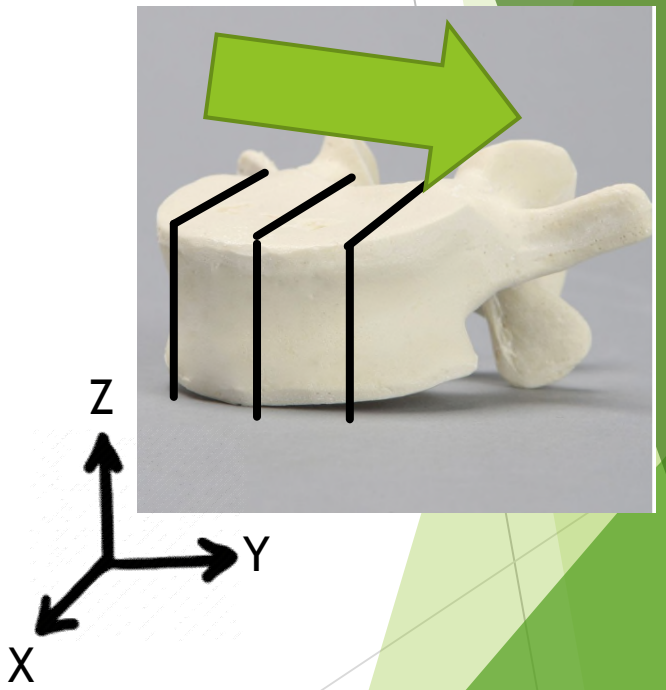
Posterior

33%

50%

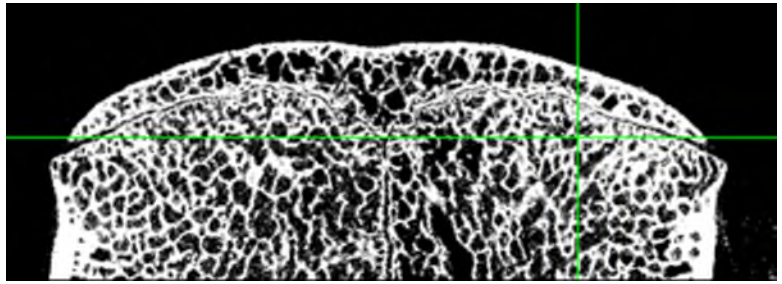
66%

26.6 µm resolution

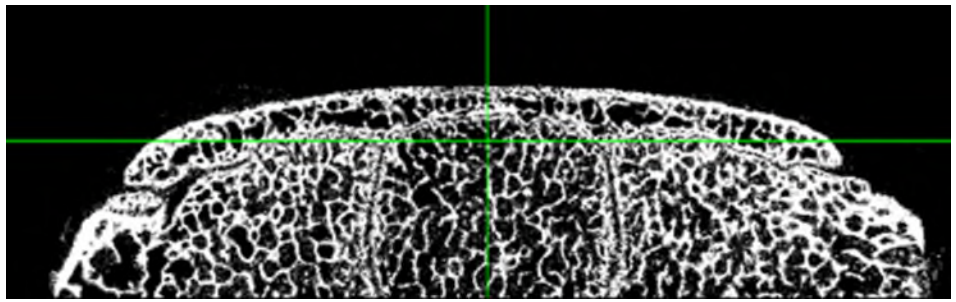


View in sagittal plane (along y-axis)

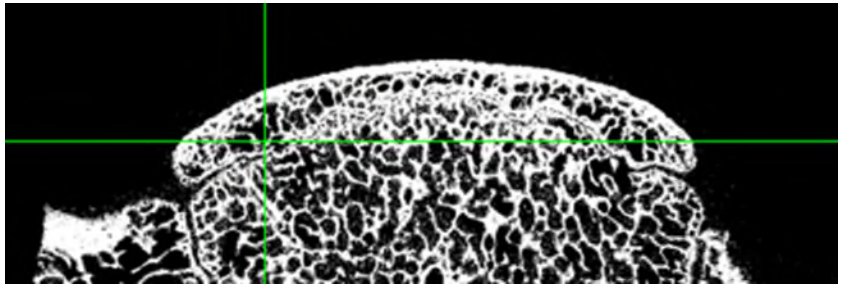
Preliminary Imaging Results



33%

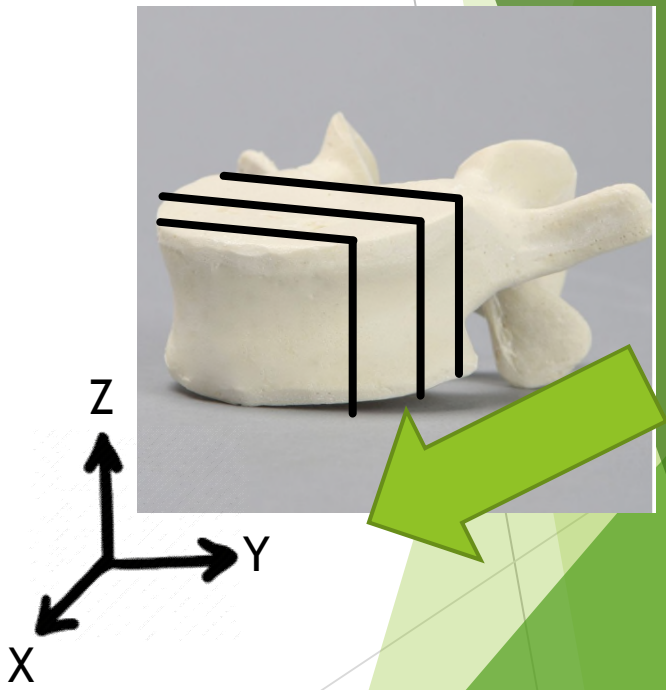


50%



66%

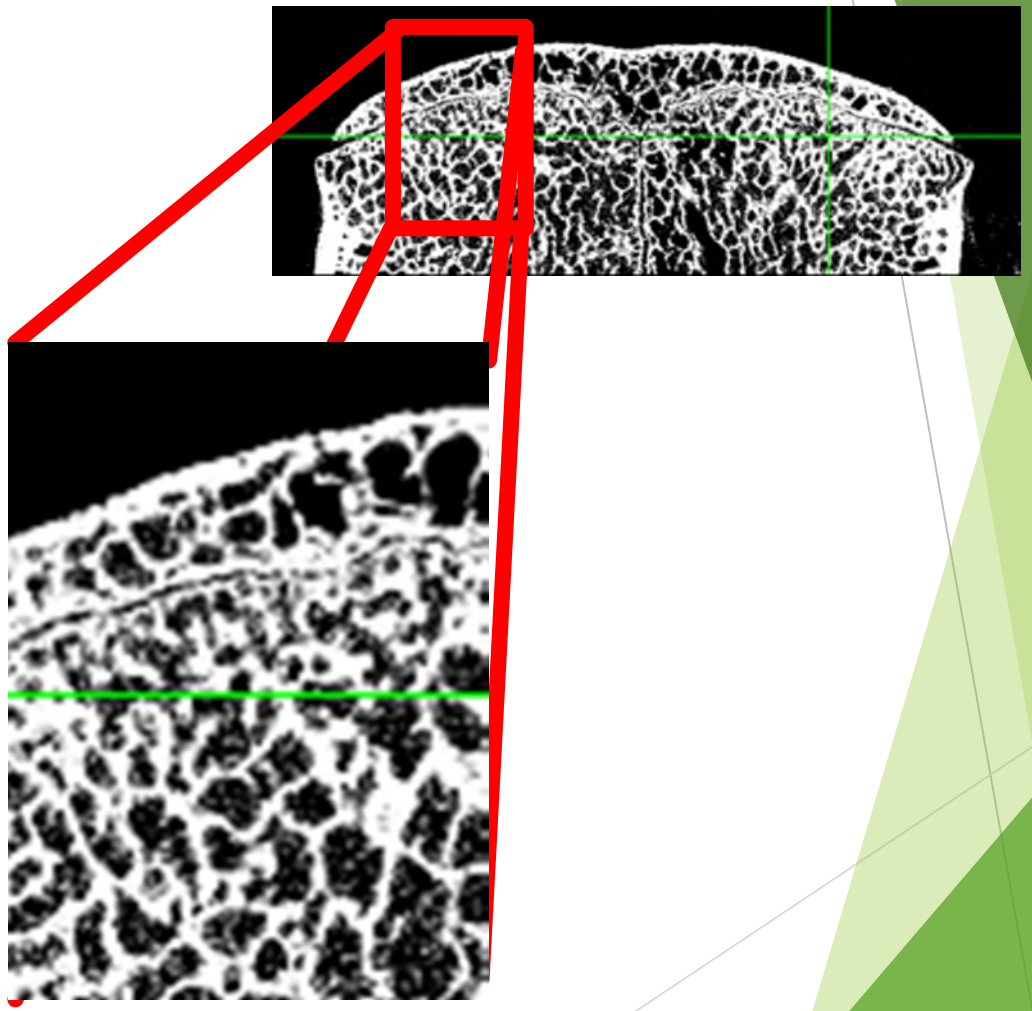
26.6 μm resolution



View in coronal plane (along x-axis)

Anticipated Structural Outcomes[1]

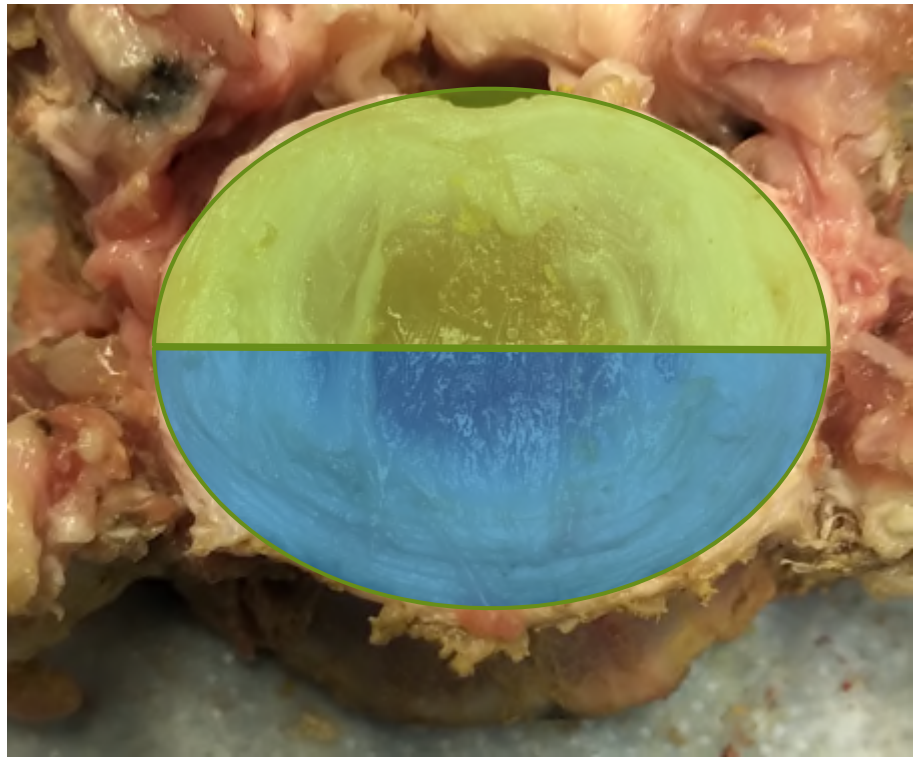
- Bone volume fraction (BV/TV)
- Cortical porosity
- Cortical porosity distribution
- Endplate thickness and area
- Trabecular porosity
- Trabecular thickness
- Trabecular number
- Degree of anisotropy

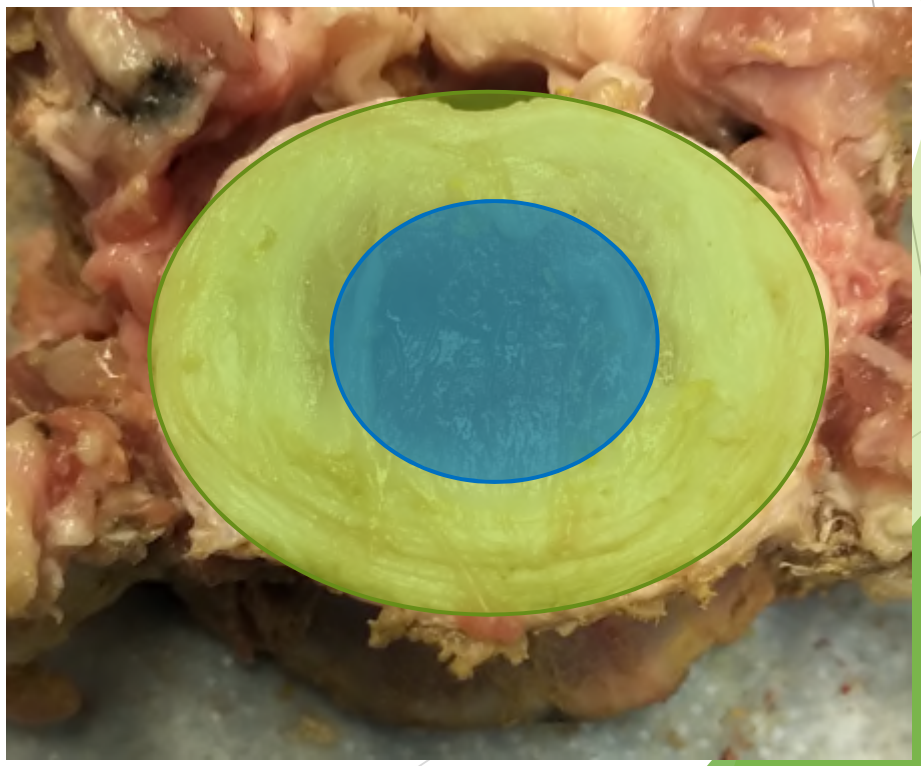


[1] Parfitt, J Bone Mineral Res, 1987

Anticipated Regional Outcomes

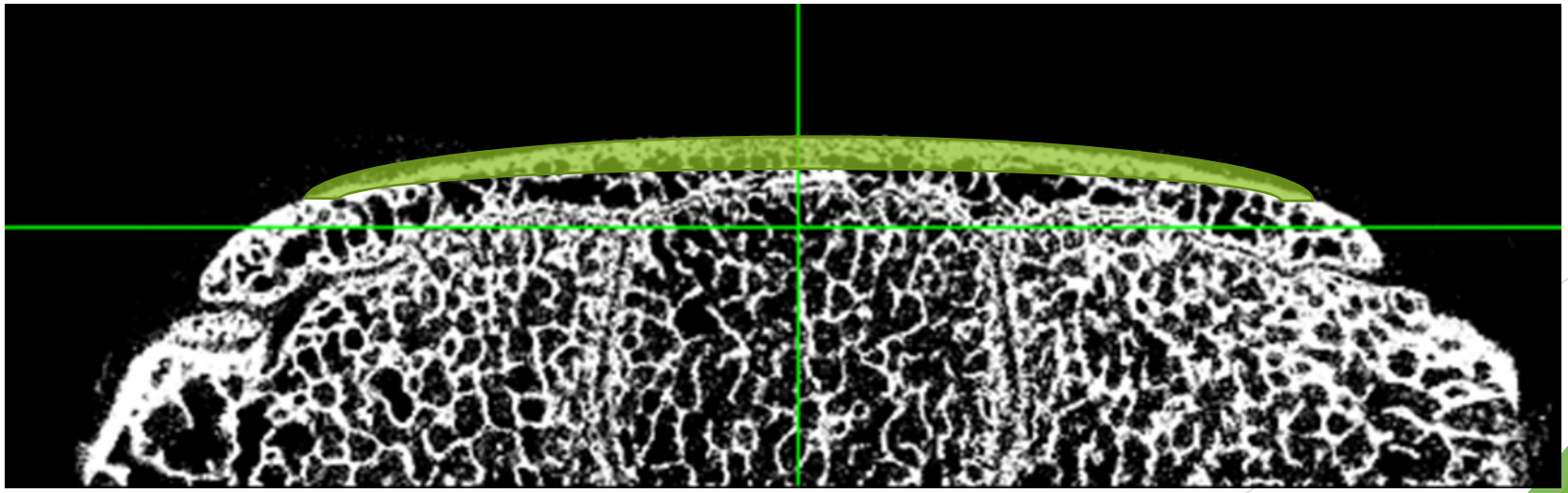
- Anterior and posterior
- Sub-nucleus and sub-annulus





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)



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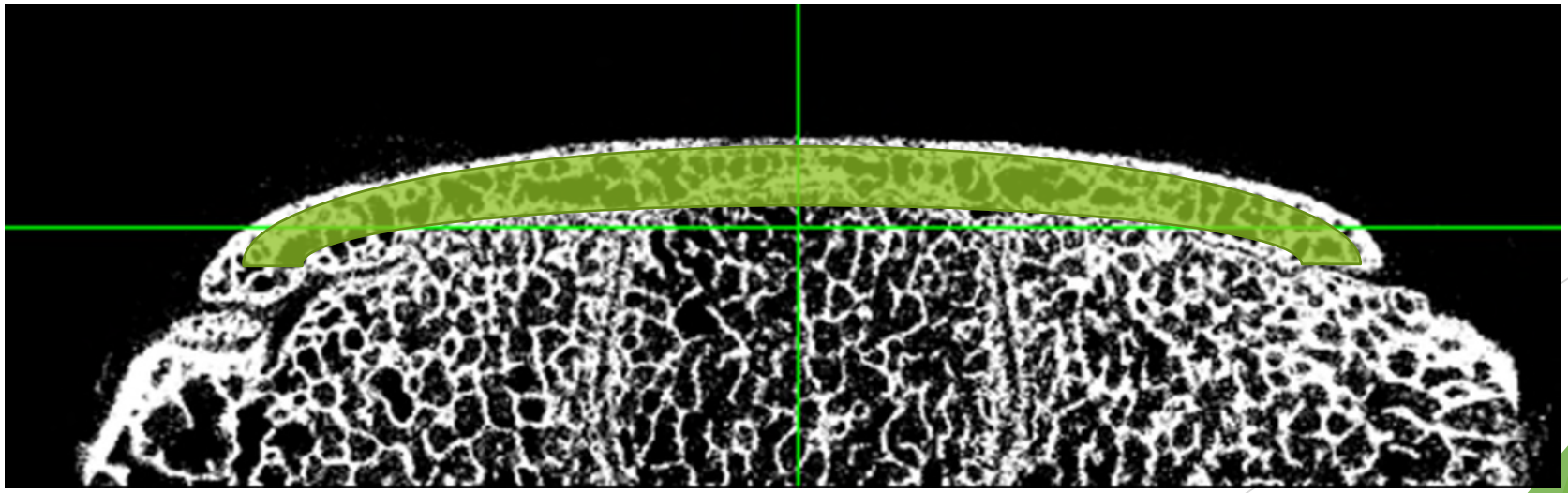

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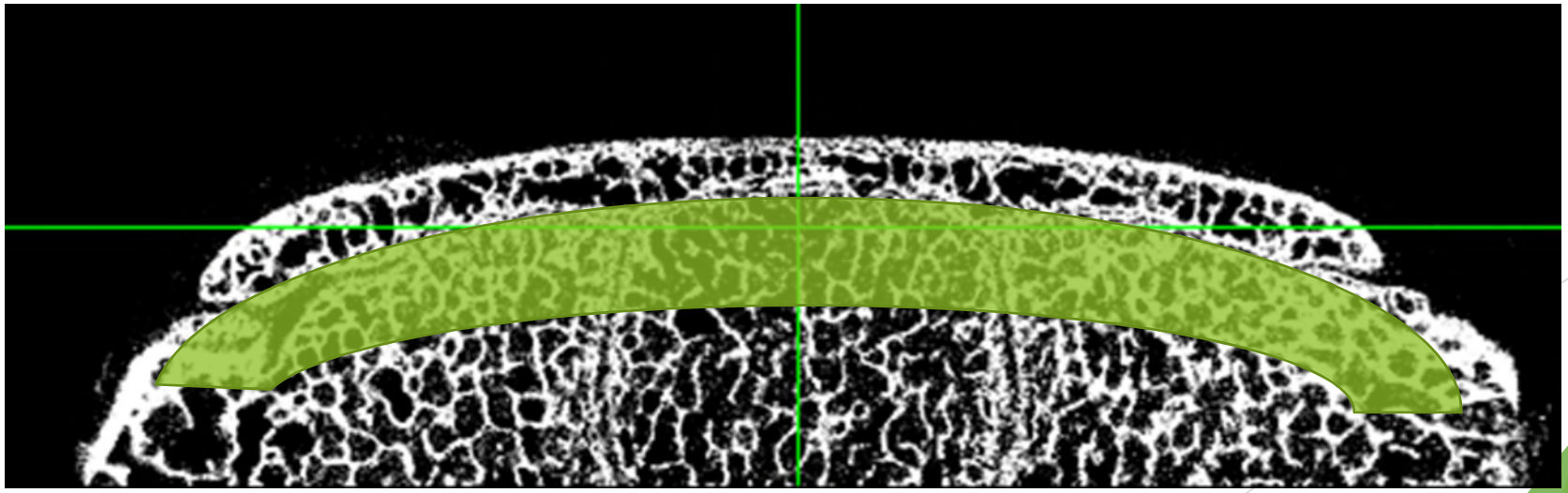


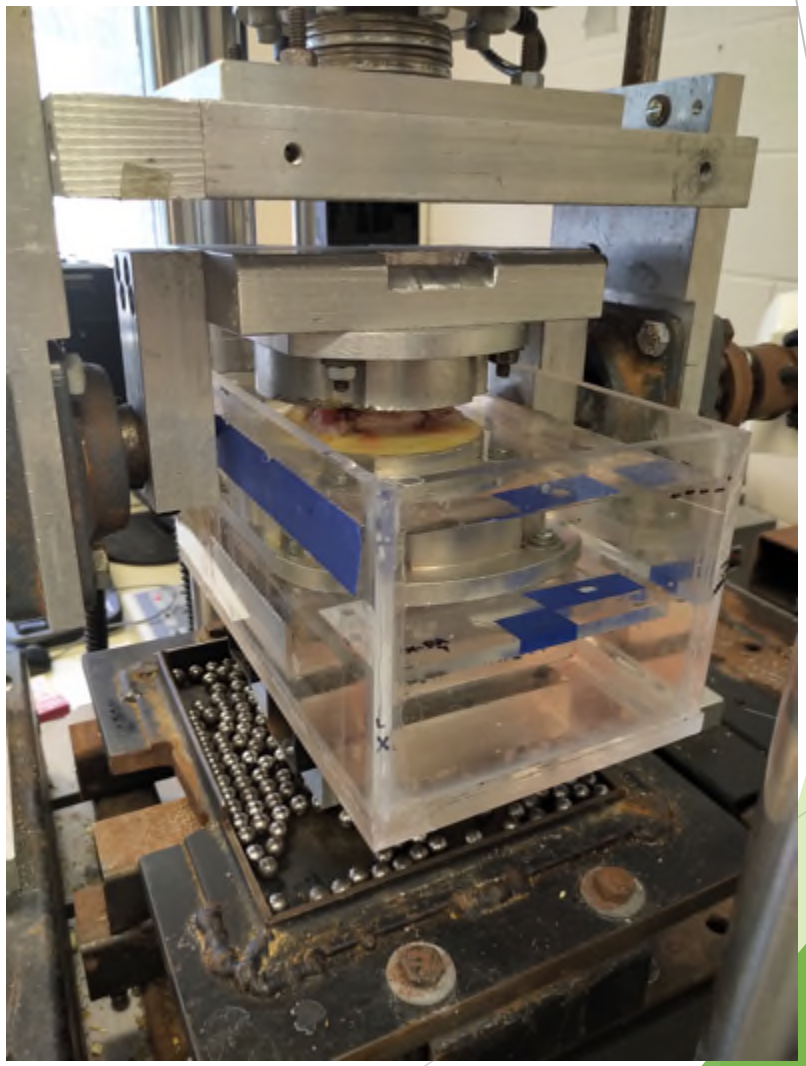
Next Steps

- Post-processing[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

[1] Johnston, Osteoarth Cartil, 2009; [2] Burnett, Osteoporos Int, 2014.

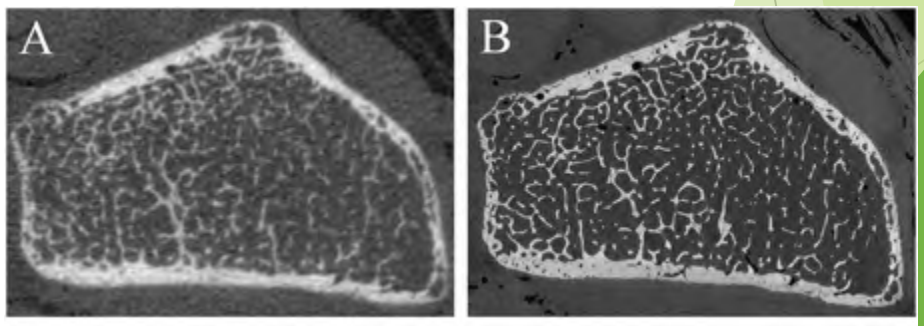
Anticipated Applications

- 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



[1]

82 µm isotropic resolution HR-pQCT

17.7 µm isotropic resolution SR-µCT (BMIT)

[1] Soltan, Bone, 2018.

Thank-you

- Dr. Stephan Milosavljevic
- Dr. David Cooper and CooperLab
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[1] McMillan, J Agromed, 2015; [2] Essien, J Occup Environ Med, 2016; [3] Milosavljevic, Ann Occup Hyg, 2012; [4] Milosavljevic, Int J Indus Ergon, 2012; [5] Kociolek, Int J Indus Ergon, 2018.