Imperial College London

BIOMECHANICS GROUP
EST 1965

Digital Volume Correlation based on MRI: A non-invasive methodology enabling measurements of internal strains in human intervertebral discs

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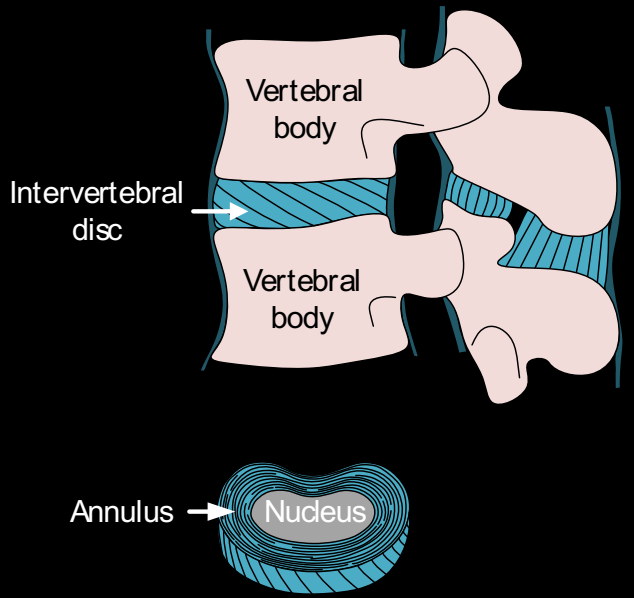
YSA competition
Belfast, Irleand
September 2019

Low back pain is the leading cause of disability

- Lifetime risk is 75% [1]
- Costs the NHS £500 million annually [2]
- Link between low back pain and disc degeneration [3]



1. Hoy et al. 2014

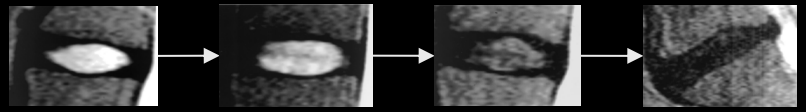
2. Maniadakis and Gray. 2000

3. Luoma et al. 2000

Why are we interested in disc strains?

- Understanding mechanical effects of disc degeneration
- Designing/evaluating surgical techniques and implants
- Identifying failure mechanisms and evaluating the risk spinal fractures
- Disc strains can serve as a predictor for a range of spinal diseases

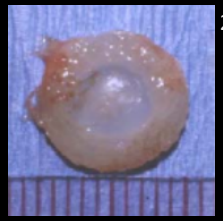
1



2

Nucore®

PDN®



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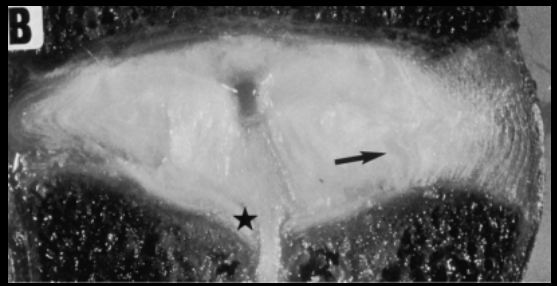


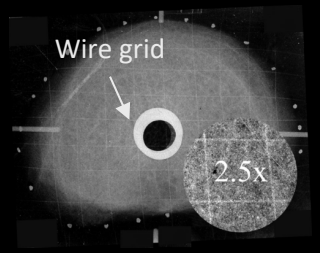
1. Pfirrmann et al. 2001

2. Mizuno et al. 2006

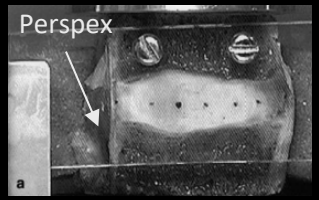
3. Adams et al. 2000

What do we already know?

- Internal behaviour has been quantified using:
  - Wires through discs[1]
  - Cut in half pushed up against Perspex[2]
  - Pressure sensors pushed through disc[3]
  - Finite Element models[4]
  - DIC (2D)[5-7]



1



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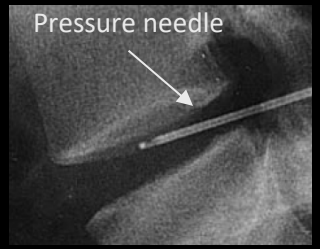

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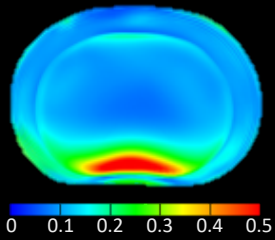

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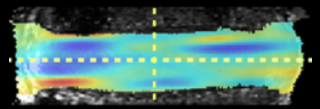
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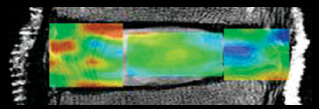

6,7

1. Tsantrizos et al. 2005 *2. Meakin et al. 2001* *3. Sato et al. 1999* *4. Yang et al. 2019* *5. Yoder et al. 2014* *6. O'Connell et al. 2007* *7. O'Connell et al. 2011*

What do we not know?

- How does the 3D internal strains of the disc change with degeneration
- Is there any relationship between strain distribution within the disc and failure mechanism of spine

Aims

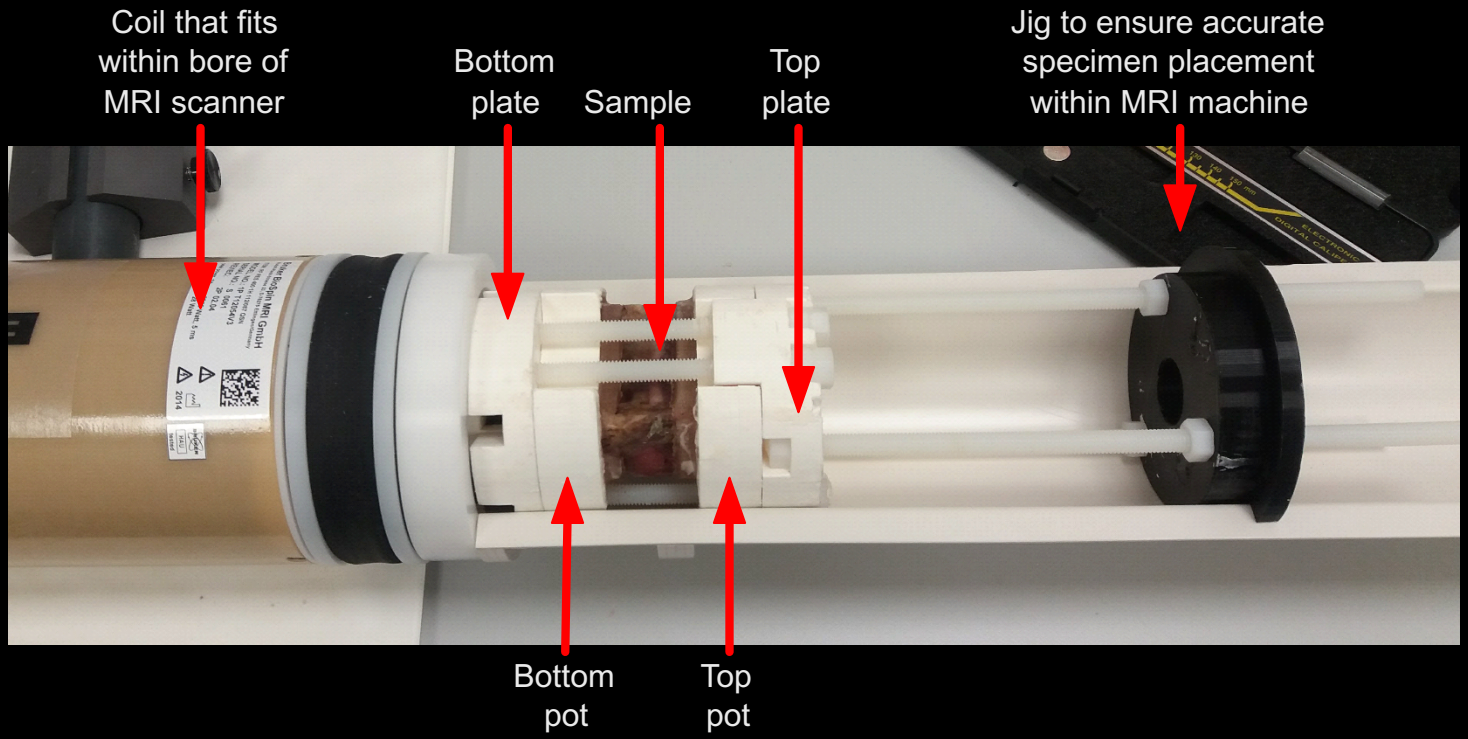
- Determining the reliability of using DVC based on MRI for measuring internal 3D strains in human discs
- Identify differences in internal strains between degenerate and non-degenerate discs
- Perform failure tests to determine whether there is a correlation between locations of high strain and failure location

Samples and Scans

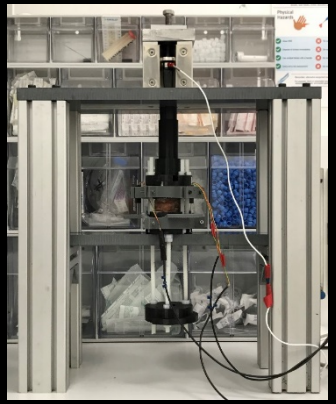
- 10 human lumbar discs
  - 5 degenerate (Pfirrmann grade ≥ 3)
  - 5 non-degenerate (Pfirrmann grade ≤ 2)
- 9.4T MRI scans
  - Unloaded
  - Unloaded repeat
  - 1kN of load
  - After axial compression to failure

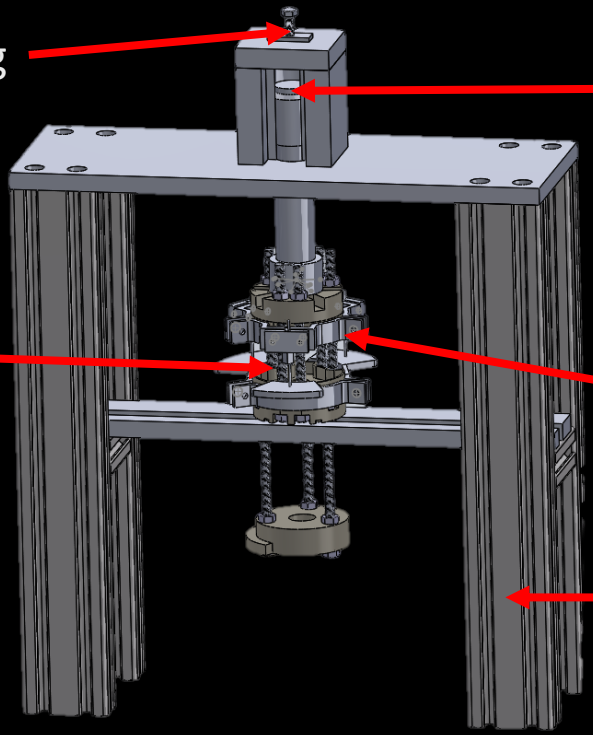
T2 weighted
90 x 90 x 800 um voxels
Scan time = 17 mins

MRI Compatible Loading Rig

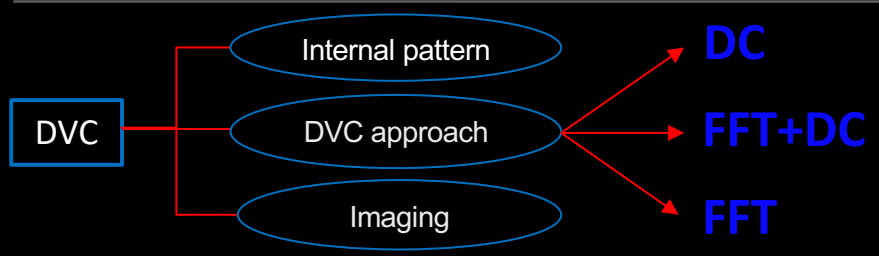


Benchtop Loading Device





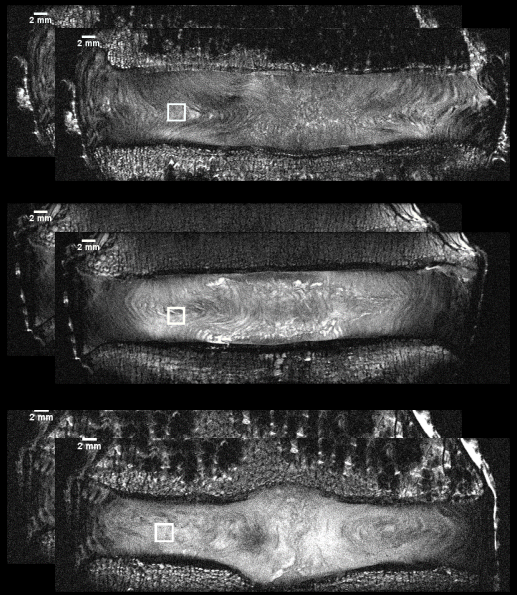
Digital Volume Correlation (DVC)-Zero Strain Study

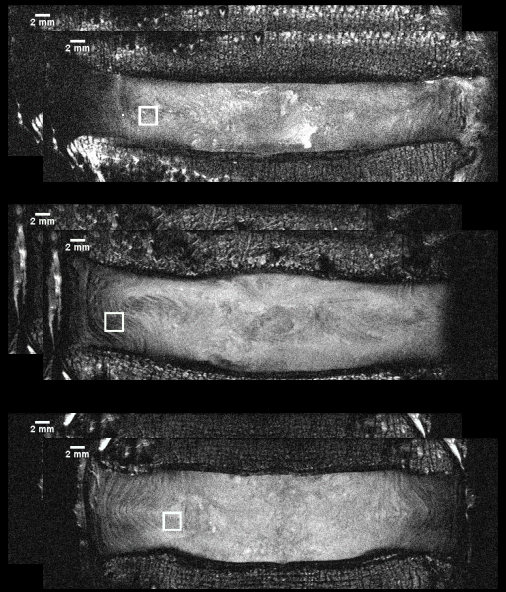


12.2%

2.9%

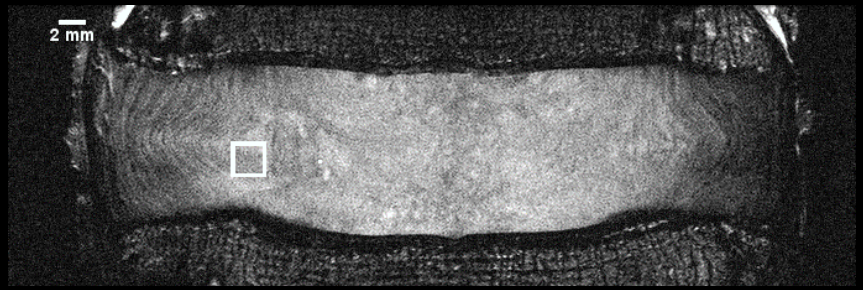
4.3%

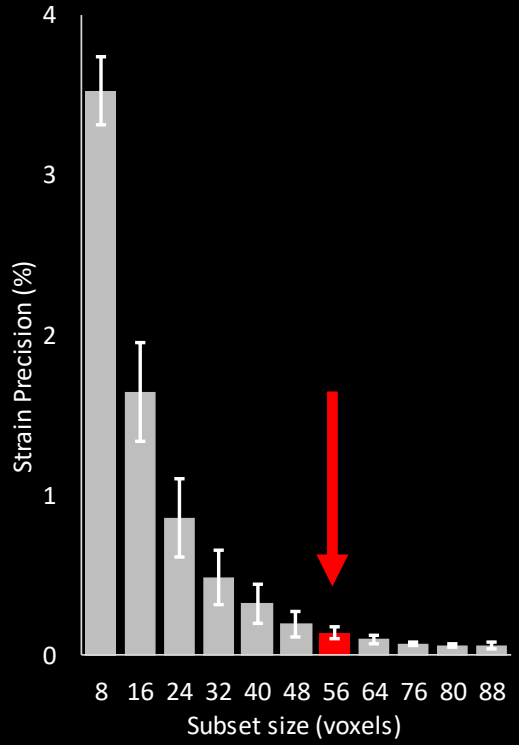




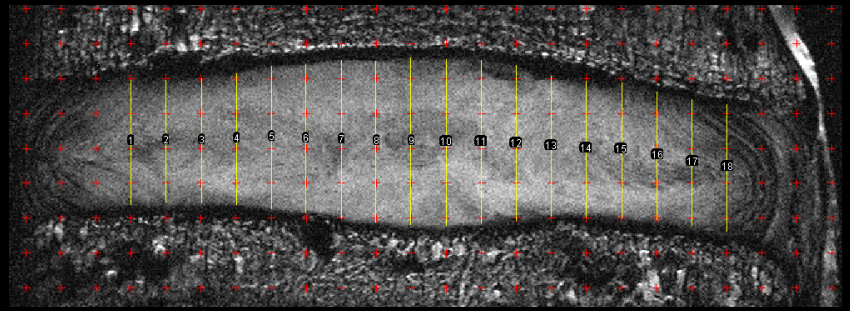
Digital Volume Correlation (DVC)

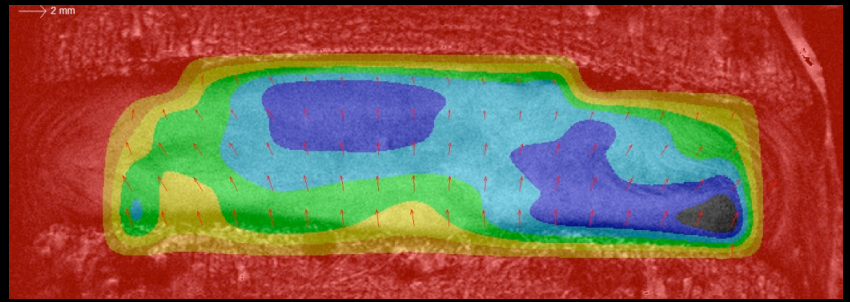
- Accuracy & precision study to find optimum subset size
  - 56 voxels
  - 2.52mm edge length
  - >1000 subsets per disc

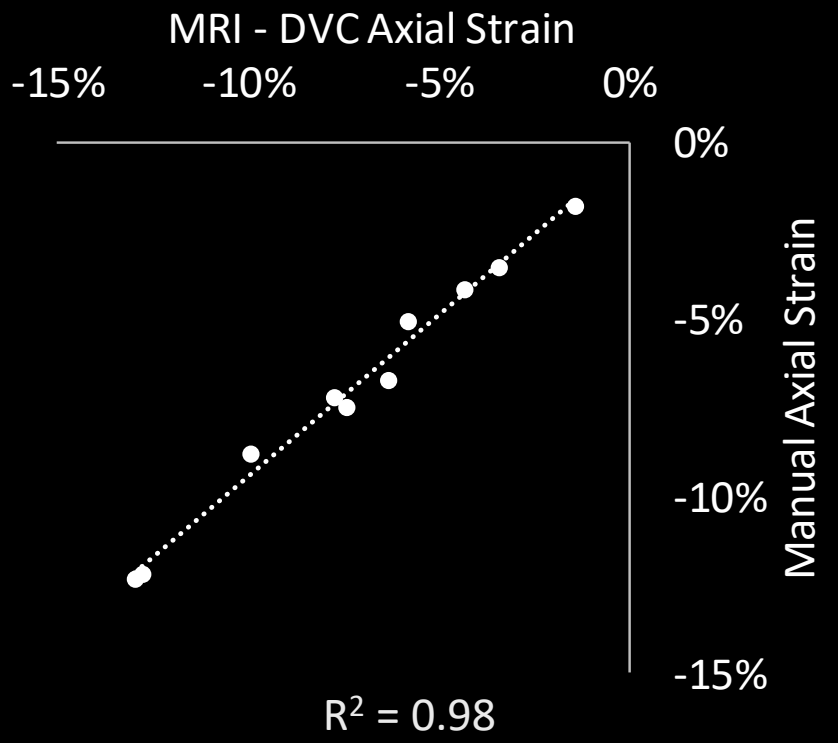




DVC matched well with manual measures





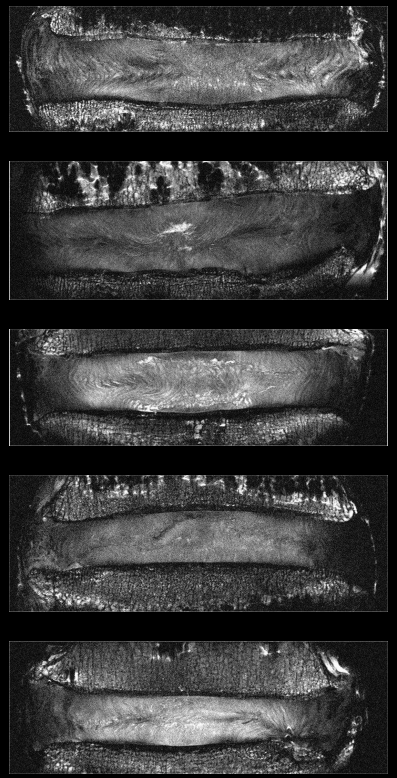


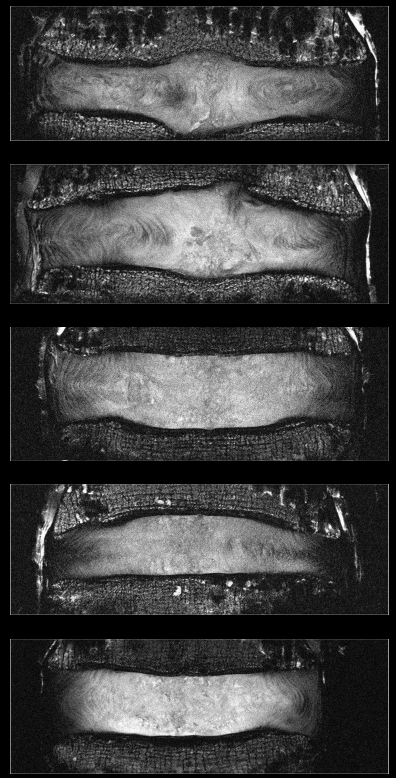
Unloaded and Loaded MRIs

Degenerate

1KN axial load

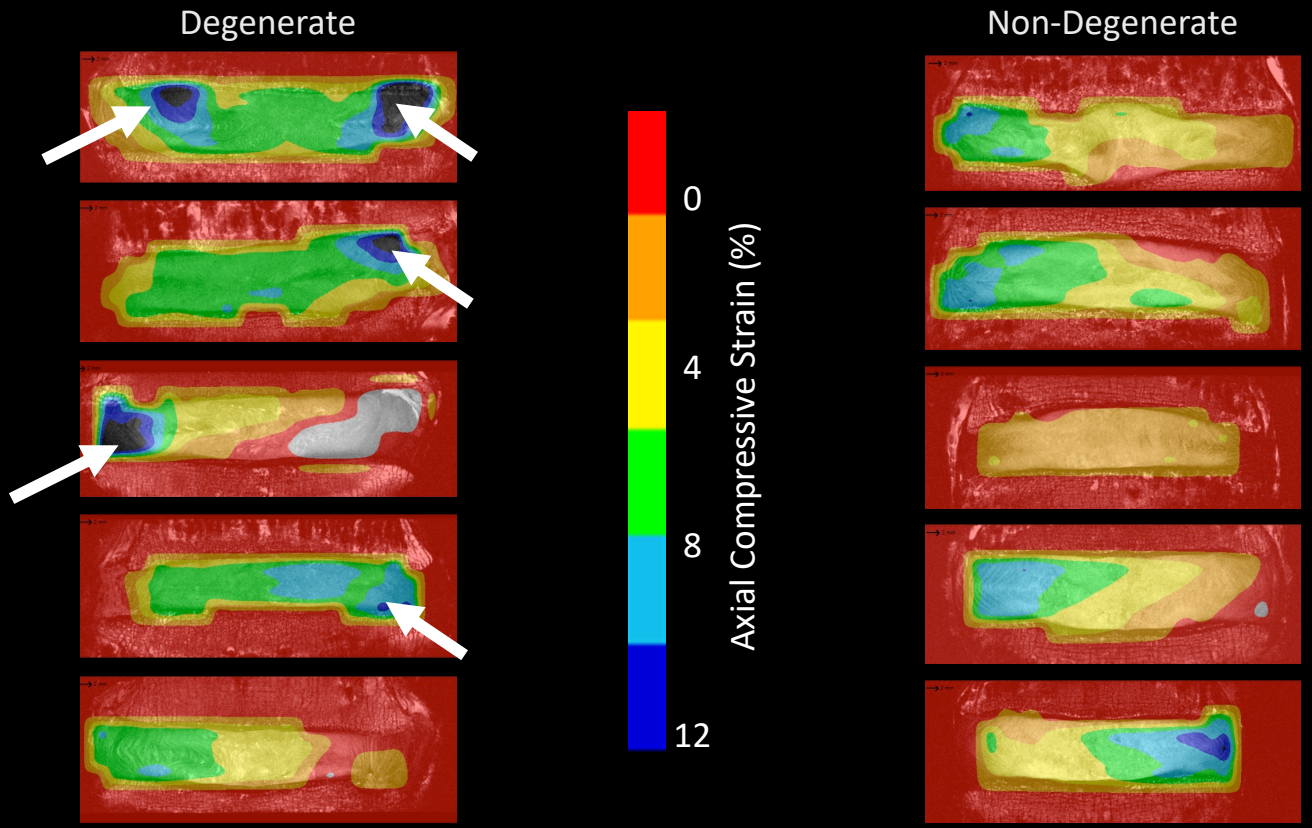
Non-Degenerate



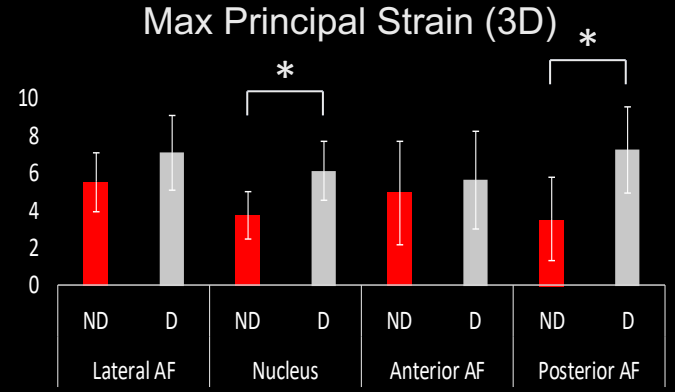


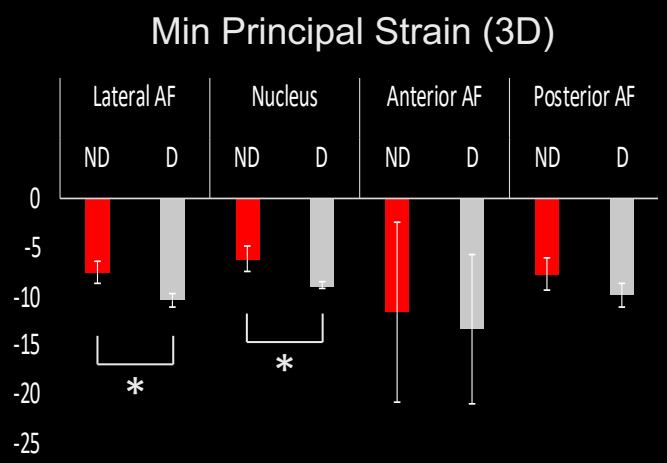
Axial Strains

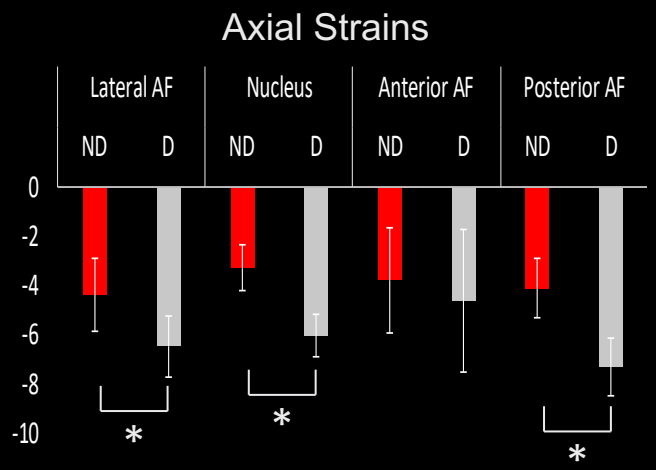
- ↑ Peak Strain in Degenerate
- Particularly in AF



Average of the axial and Max/Min Principal Strain (3D) within the whole disc





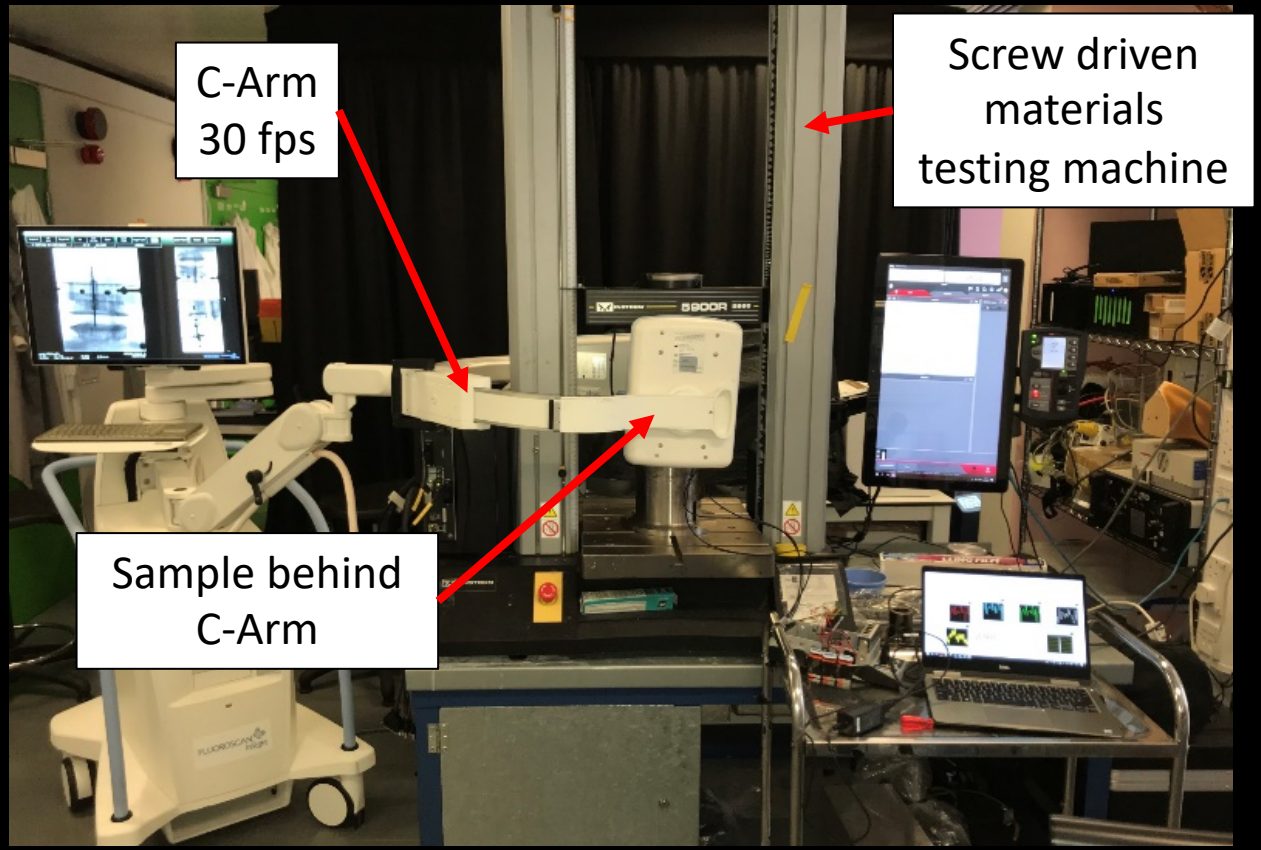


Non-degenerate

Degenerate

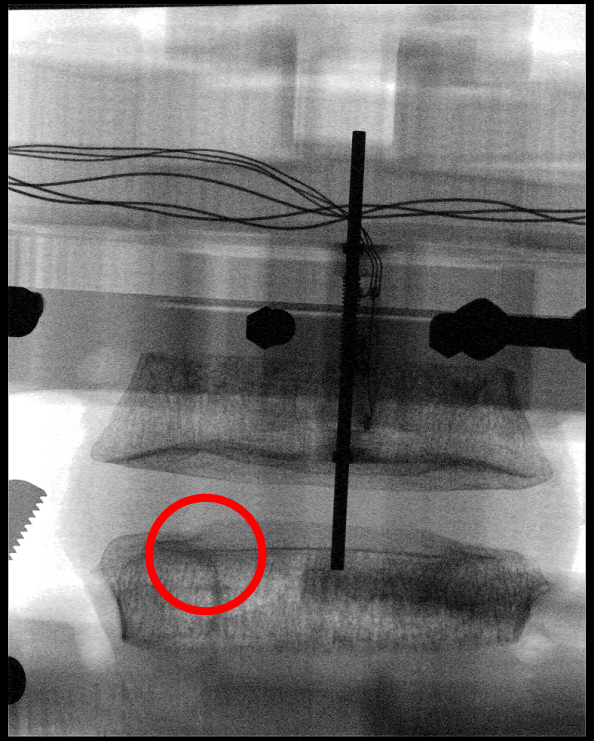
* Significant difference ($p \leq 0.05$)

Axial Compression to Failure

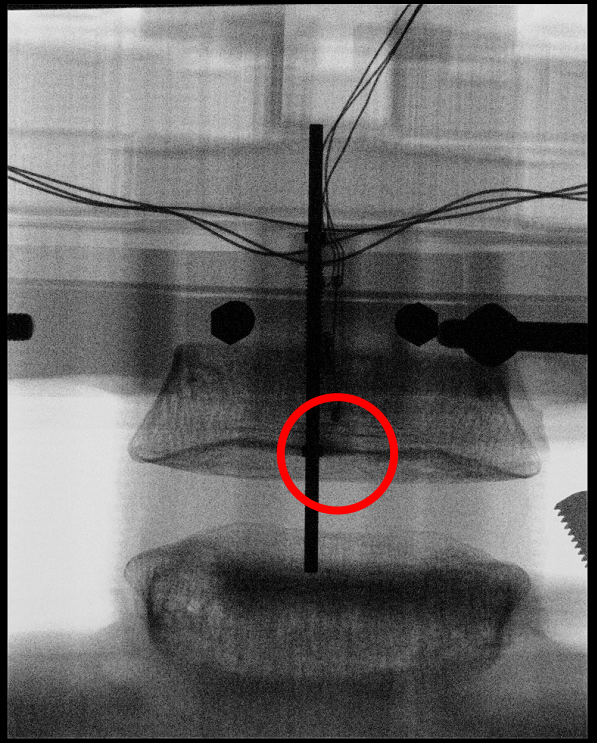


Failure Fluoroscope Images

Degenerate

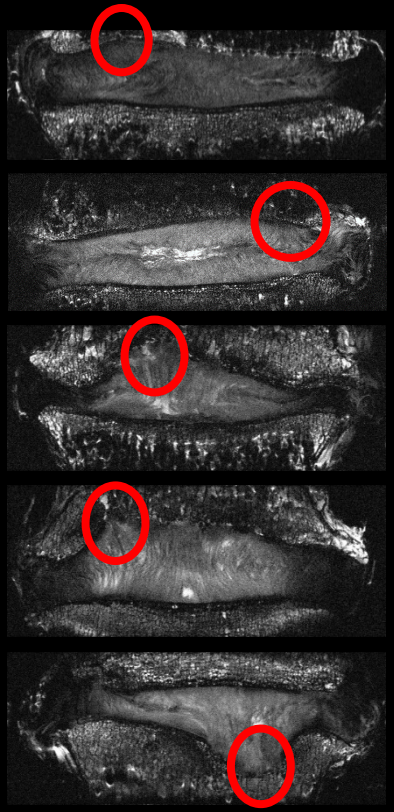


Non-Degenerate

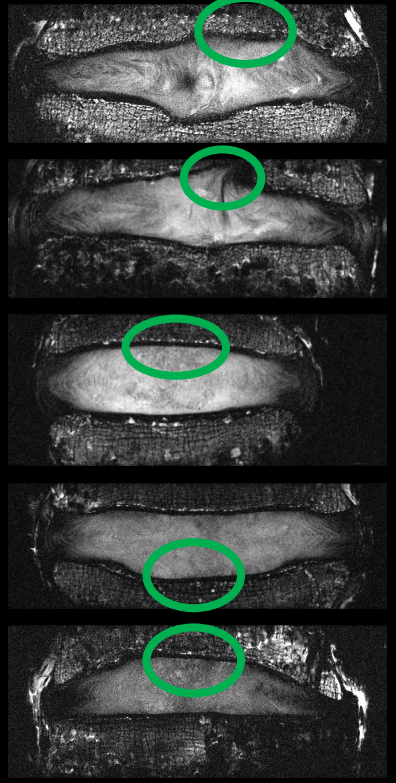


Failure MRIs

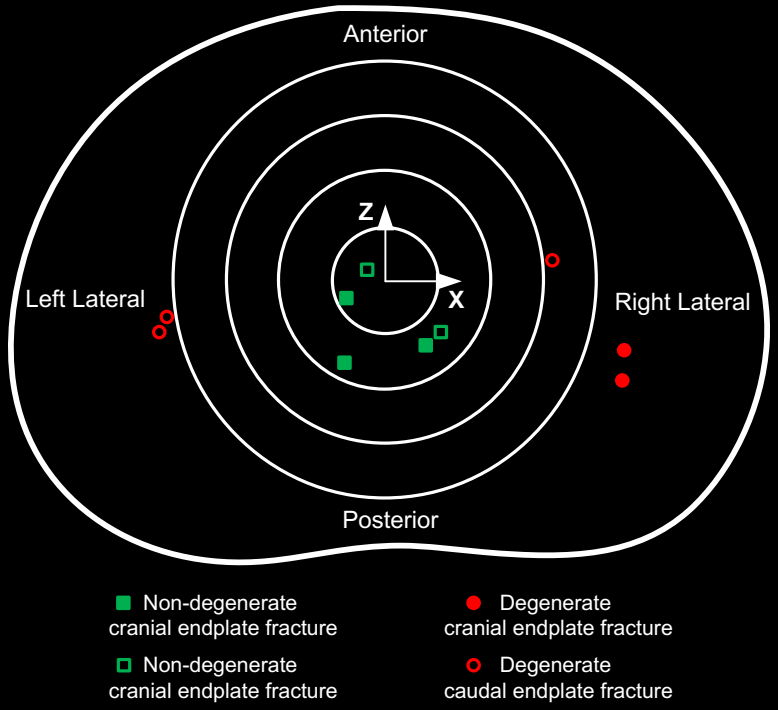
Degenerate



Non-Degenerate

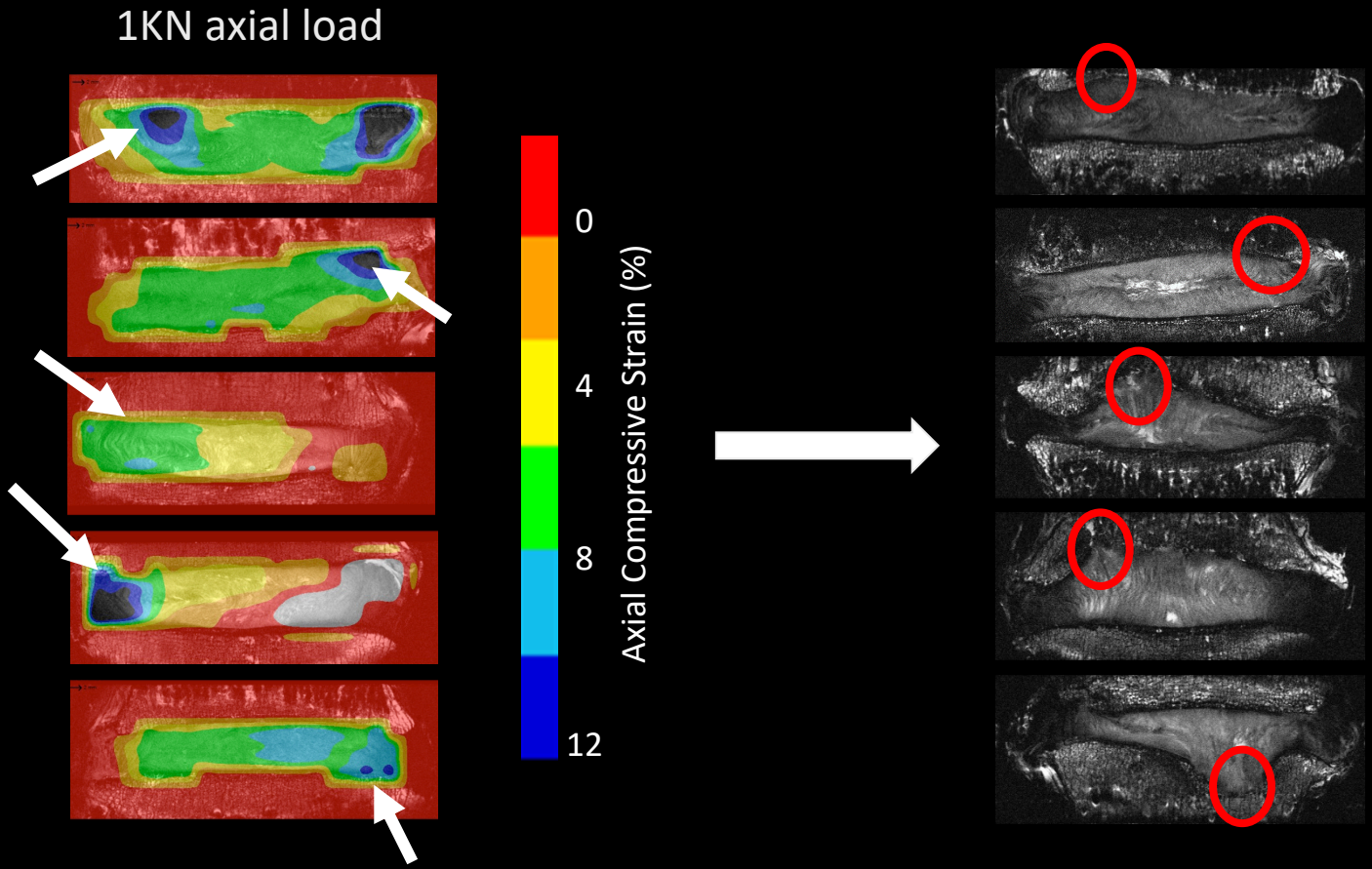


Endplate Failure Locations



- Location of fracture in degenerate sample going toward edges

Prediction of failure location with DVC results



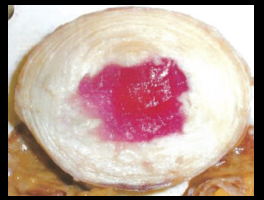
Conclusions

- Developed a method of measuring 3D strains in human discs using MR images (DVC based on MRI)
- DVC has a potential to show mechanical changes in human discs after degeneration
- DVC has the potential to predict fracture locations through analysing strain distributions within discs under physiological loads (1KN)

Future Work

- Using the method in-vivo
- Investigate other parameters that may influence failure location
- Other modes of loading
- Interactions between nucleus replacements and surrounding tissues
- Use strain maps to validate finite element models

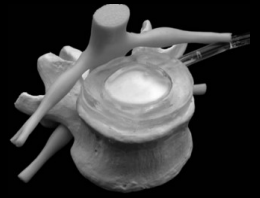
Nucleus replacement devices



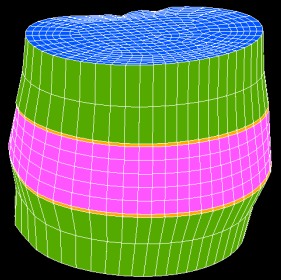
Nucore®

PDN®

Regain®



DASCOR®



Thanks to the rest of the team!

- Jeff Clark
- Nicoleta Baxan
- Spyros Masouros
- Brett Freedman
- Nicolas Newell
- Ulrich Hansen