In this project, "3-D Visualization and Prediction of Spine Fractures", we have developed a method of measuring the deformations that occur throughout a human vertebra (one of the bones in the spine) as we compress (crush) the vertebra to failure in our laboratory. This method, which is performed on segments of spines obtained from cadavers, involves first imaging the vertebra with a high-resolution CT ("CAT") scanner at multiple points during the process of applying successively greater amounts of compression, thus producing a time-lapse series of images. Figure 1 A-F and G-L each show a portion of two different time-lapse series. The images in A-L are 2-D projections of the CT scans (these projections look like standard x-ray images). The 3-D view of half of the middle vertebra of the three-vertebra segment that is crushed is shown in the row right below the 2-D projections. Only half of the vertebra is shown so that one can appreciate the internal structure. In each of these 3-D renderings, the gray rendering is from the first CT scan, which was performed before the compression commenced, and the blue rendering is from one of the subsequent CT scans. That is all the first step of the method.

The second step of the process uses a computer-vision technique, digital volume correlation (DVC), to analyze the gray/blue pairs of images to quantify the deformations that are occurring in small regions throughout the vertebra. The DVC process is shown schematically in Figure 2. The DVC results for the images shown in the top two rows of Figure 1i and ii are in the bottom row of panels i and ii. (One quadrant of the vertebra is removed for visualization purposes.) These DVC results are, to my knowledge, the first measurements of the 3-D deformations that occur in a vertebra during failure. That is, they are the first robust and detailed measurements of how a human vertebra fails.

Prior studies that sought to study failure of human vertebrae use numerical simulation. The common simulation method is finite element (FE) analysis. Researchers can build an FE model from the CT scan performed on a hospital patient (note that this CT scan is lower resolution than the CT scans we do in our laboratory), represent the bone tissue within the model according to how bright the tissue appears in the CT scan, and then simulate the application of compression to the vertebra. Importantly, these FE models *have never been assessed* for how accurately they predict how the vertebra fails. We aim to perform this assessment by comparing the FE predictions of deformations to the aforementioned measurements of deformation.

Figure 3A and 3B show the experimental result for one vertebra, and Figure 3C-J show FE predictions *for the same vertebra*, for eight different types of simulations. (We have 27 additional specimens, i.e. we could make 27 more figures like Figure 3.) Our overarching questions are: (1) how similar is each of 3C through 3J to 3B? (2) Are some of the eight simulations more similar than other to the experimental measurement? What I would like to do to answer these questions is to make a quantitative comparison of prediction to measurement. Both the prediction and the measurement consist of matching 3-D grids of data, so we could for example compute the difference between experiment and prediction at each point. But I don't know if this is the best way…

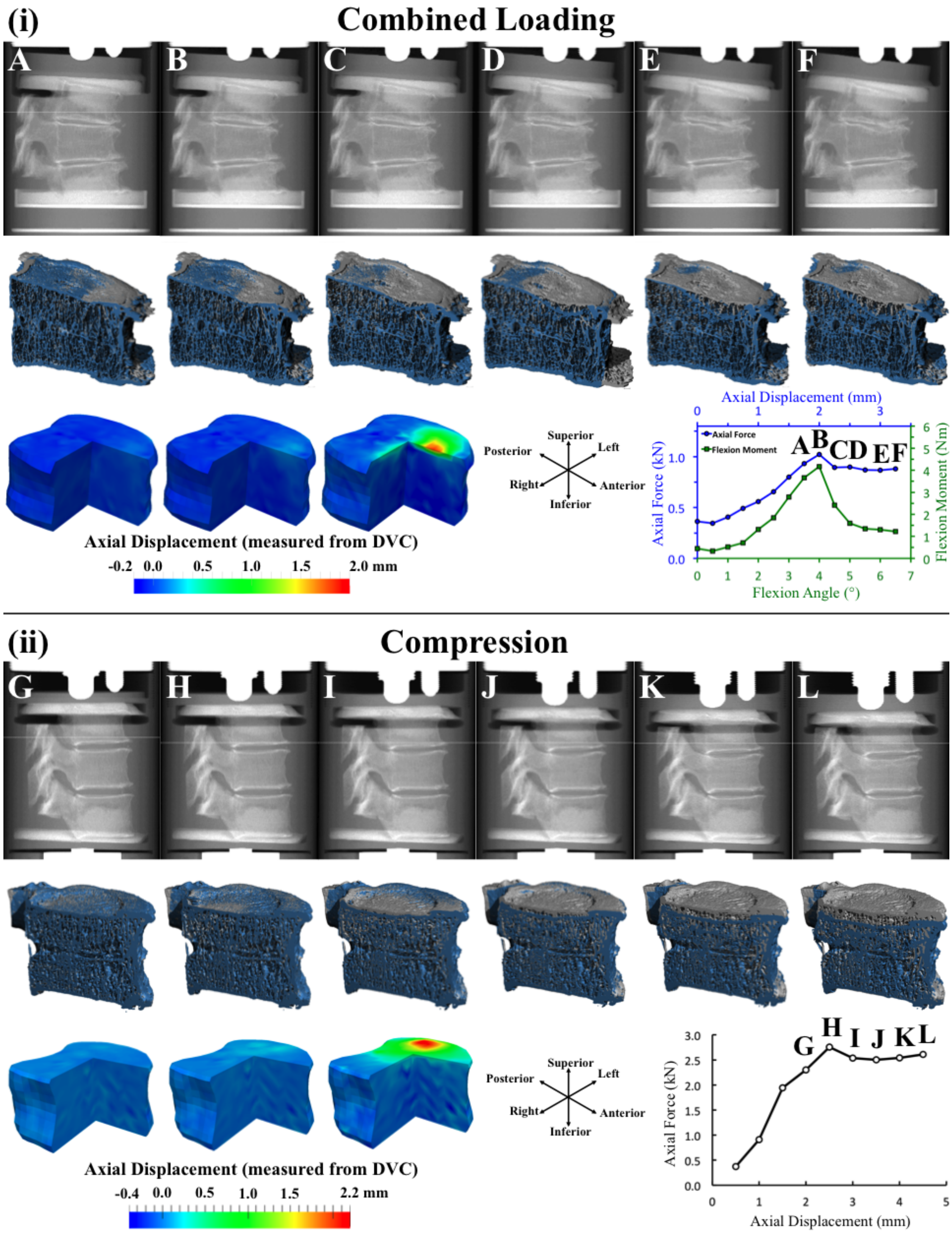
(i)
Combined Loading
A
B
C
D
E
F
Superior
Posterior
Left
Right
Anterior
Inferior
Axial Displacement (measured from DVC)
-0.2 0.0 0.5 1.0 1.5 2.0 mm
Axial Displacement (mm)
Axial Force
Flexion Moment
Axial Force (kN)
Flexion Moment (Nm)
Flexion Angle (°)
(ii)
Compression
G
H
I
J
K
L
Superior
Posterior
Left
Right
Anterior
Inferior
Axial Displacement (measured from DVC)
-0.4 0.0 0.5 1.0 1.5 2.2 mm
Axial Force (kN)
Axial Displacement (mm)

Figure 1.

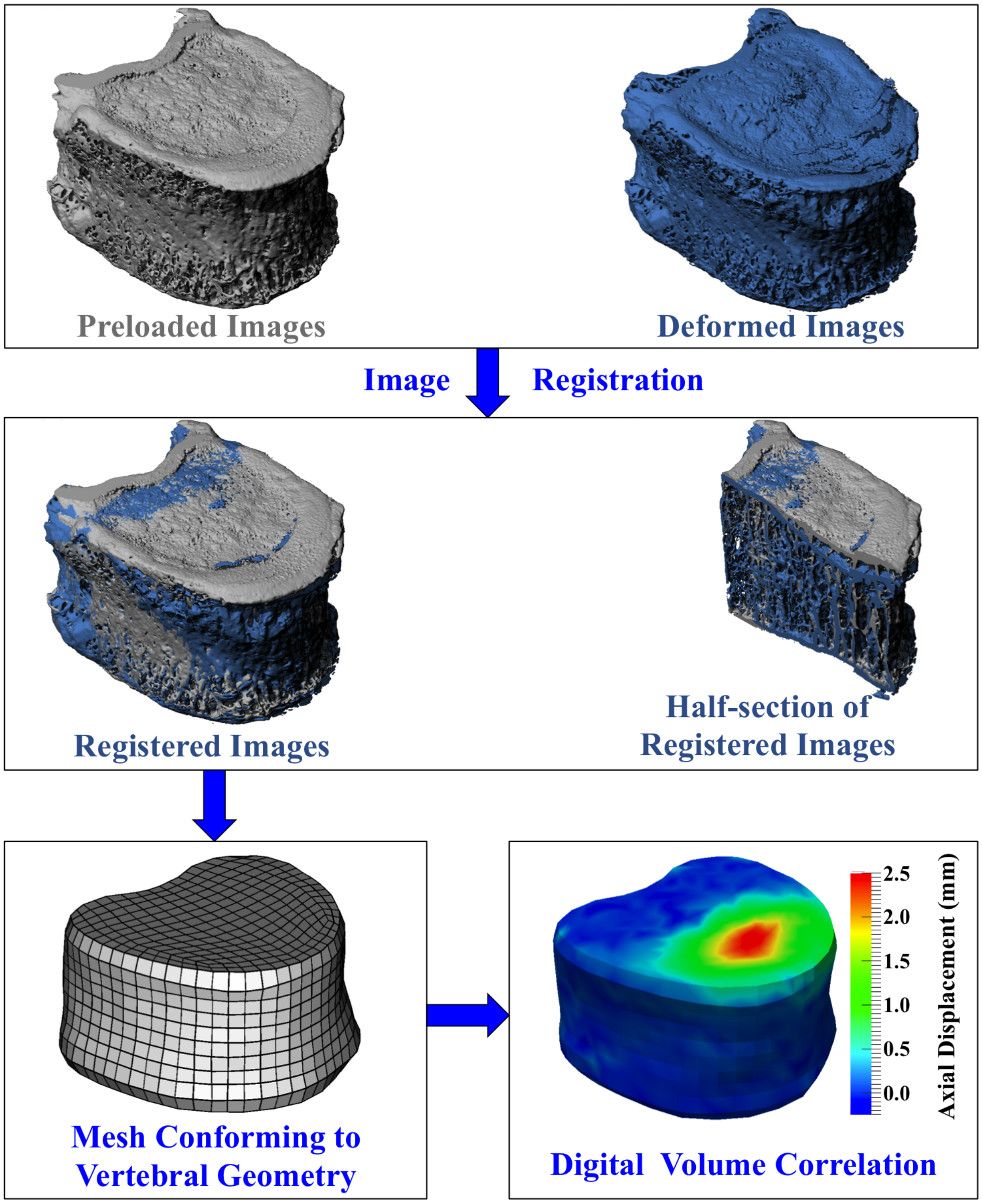

Figure 2. Schematic for the digital volume correlation (DVC) process: images of the T8 vertebral body acquired prior to and at each load increment were aligned via image registration, and the vertebral body was subdivided into a "mesh" consisting of hexahedral regions with 1.9mm side lengths. The displacement of each corner of each region was estimated using digital volume correlation.[34] The image at the bottom right shows these displacements interpolated throughout the entire vertebral body. Note: The pedicle and posterior elements are not pictured because any deformations occurring in these regions were not analyzed.

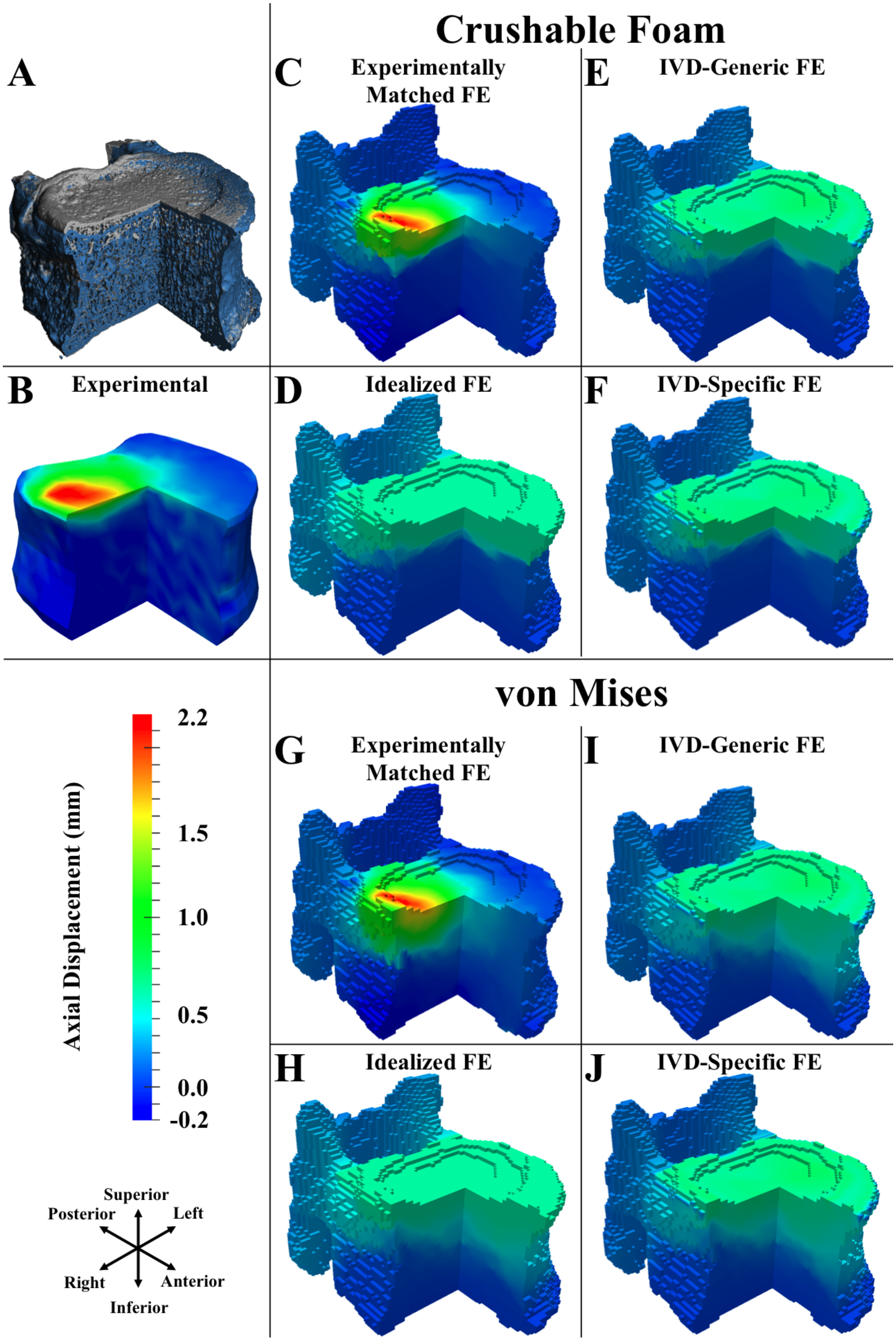
Crushable Foam
A
B
Experimental
C
Experimentally Matched FE
D
Idealized FE
E
IVD-Generic FE
F
IVD-Specific FE
von Mises
G
Experimentally Matched FE
H
Idealized FE
I
IVD-Generic FE
J
IVD-Specific FE
Axial Displacement (mm)
2.2
1.5
1.0
0.5
0.0
-0.2
Superior
Posterior
Left
Right
Anterior
Inferior

Figure 3.