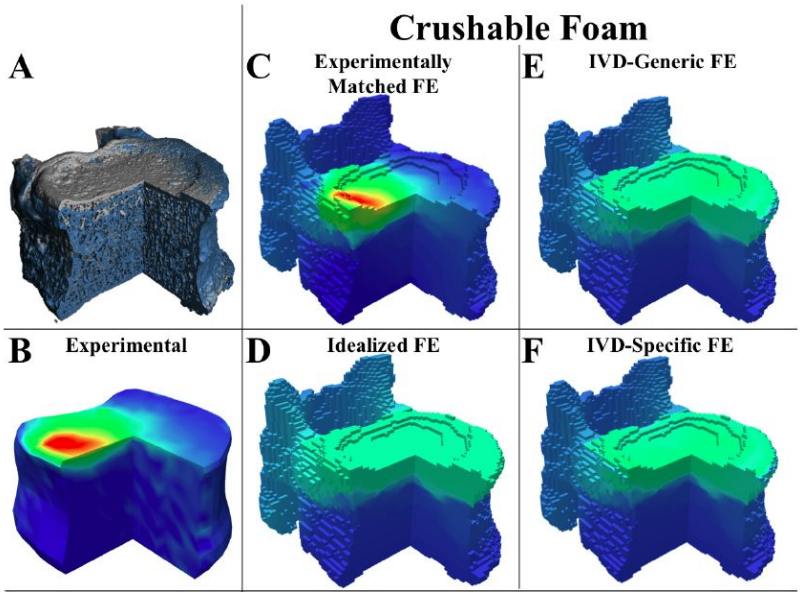
3D Visualization and Prediction of Spine Fractures
Progress Report #1

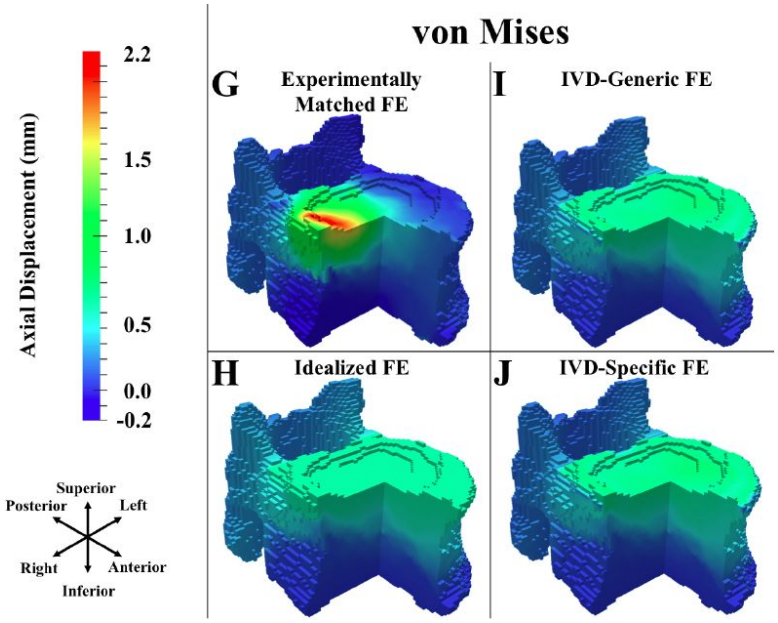
Jiayuan Shi, Jing Liu,
Qianyun Zou, Su Yang

Background

In the project "3-D Visualization and Prediction of Spine Fractures", Professor Morgan and her group conduct three steps to measure the deformations that occur throughout a human vertebra (one of the bones in the spine) as they compress the vertebra to failure in the laboratory. The first step is to use high-resolution CT("CAT") scanner at multiple points during the process of applying successively greater amounts of compressions to produce a time-lapse series of images, in both 2-D and 3-D projections. In the 3-D rendering, the gray rendering is from the first scan performed before the compression commenced, and the blue rendering is from one of the subsequent CT scans. The second step 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 results are the first robust and detailed measurements of how a human vertebra fails. For the third step, the group use the common simulation method, finite element(FE) analysis. Researchers build an FE model from the CT scan performed on a hospital patient, 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.

The below Figure A and B show the experimental result for one vertebra, specifically, Figure A shows the 3-D rendering of the CT scan, and Figure B shows the DVC result. Figure C-J show FE predictions for the same vertebra, for eight different types of simulations.





However, these FE simulation models have never been assessed for how accurately they predict how the vertebra fails. So in this report, we perform this assessment by doing statistical analysis about the dataset of vertebra displacement, and comparing the FE predictions of deformations to the experimental aforementioned measurements of deformation.

Dataset

The dataset Professor Morgan gave us contained two worksheets, one for Flexion, which meant a combination of flexion and compression applied, and one for Union, which meant only compression applied. The Flexion sheet had two specimens' worth of data(Flexion 513 and Flexion 528) whereas the Union sheet had only one specimen's worth of data(Union 581). For each specimen, there were eight groups of three columns, corresponding to eight simulations. The first of the three columns was the grid point ID number. The second and third columns are data for displacement measured in experiment and predicted by simulations, respectively.

Since all the data contained in the worksheets were one-dimension, we decided to first start a global comparison by looking at the distribution of differences between simulation and experiment results, which helped us better understand the overall performance of each simulation. And then we conducted a KS-test to see if the distribution of simulations significantly differed from the experimental distribution.

Analysis

- Distribution

For global comparison, we started by looking into distributions based on differences between simulation and experimental results. Firstly, we plotted the distribution and in histograms and boxplots for Flexion groups. Results in Flexion 513 and Flexion 528 showed that distributions are not normal, instead they are either left-skewness or right skewness and there seems no patterns between. It also showed that in most cases, simulation results have higher value than experimental results. Although it results appear quite random, one

interesting fact we have found is that, the 2nd and the 6th simulation results are closer to experimental results in both two flexion groups.

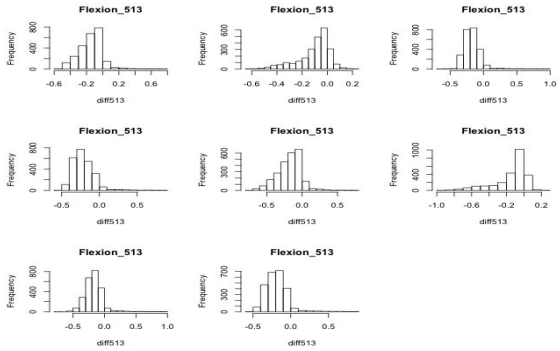


Figure K. Histograms of Vertebra Sample 513

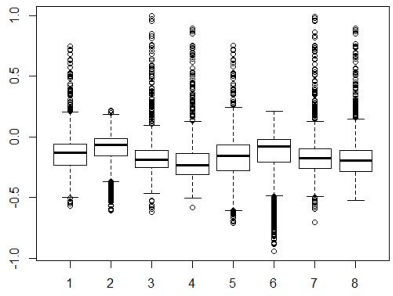


Figure L. Boxplots of Vertebra Sample 513

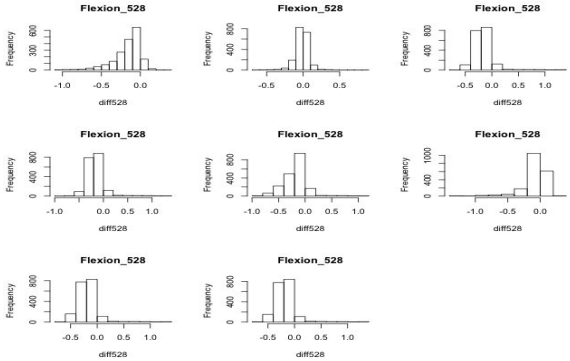


Figure M. Histograms of Vertebra Sample 528

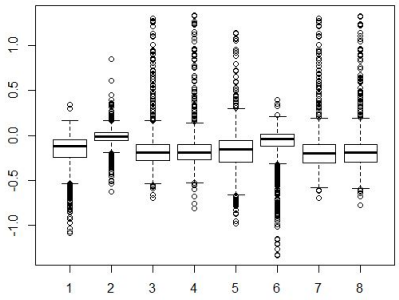


Figure N. Boxplots of Vertebra Sample 528

Secondly, we plotted the distribution and in histograms and boxplots for Union group. For here, distributions are quite normal and differences are uniform. So we assume that when only compression is applied, simulations for models work better. But since human body is a complex system, we would not draw a conclusion before we confirm our assumption with Professor Morgan.

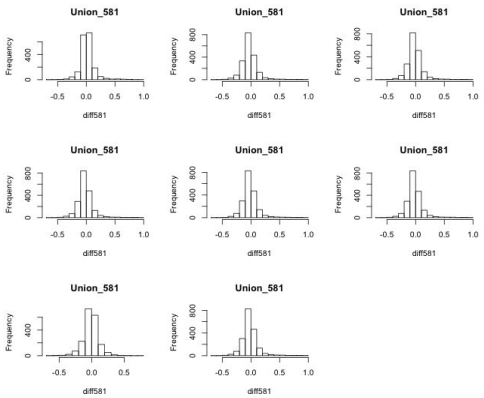


Figure O. Histograms of Vertebra Sample 581

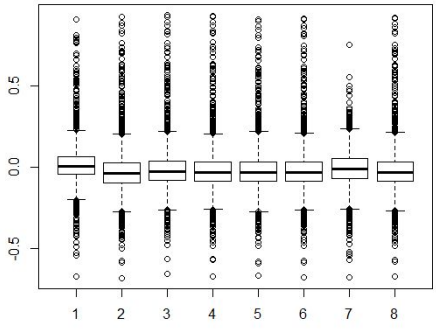


Figure P. Boxplots of Vertebra Sample 581

- KS-test

We ran a two-sample KS-test for each of the eight simulations versus experiment. All of these tests gave a p-value less than 0.001, indicating a significant difference in the distribution of simulations and experiment. However, the displacement on a vertebra was spatially dependent, meaning that the displacement of one grid is highly correlated with the displacement of other grids around it. So the data were not independent, which conflicted with the fundamental assumption of KS-test. Therefore, although we found all differences were significant, the conclusion was not solid. However, as we only had one-dimension data, it was the most appropriate test we came up with.

Future Research

We obtained the (x,y,z) coordinates data of sample 528. The sample vertebra was separated into 384 regions with each region projected into a 3-D coordinate. We visualized the vertebra by using one point representing each region (Figure Q). Furthermore, we split x, y, z dimensions of each region so that we can compare the distance on each coordinate (Figure R). As we only have experimental data of sample 528, there is no contrast group yet. In the coming stage, we are looking forward to acquiring simulated data of sample 528, then we would be able to draw another distribution of the simulated data by dimensions on the same coordinate. The result may reveal the degree of displacement of the deformed vertebra. Besides of sample 528, this method could be applied to other samples as well.

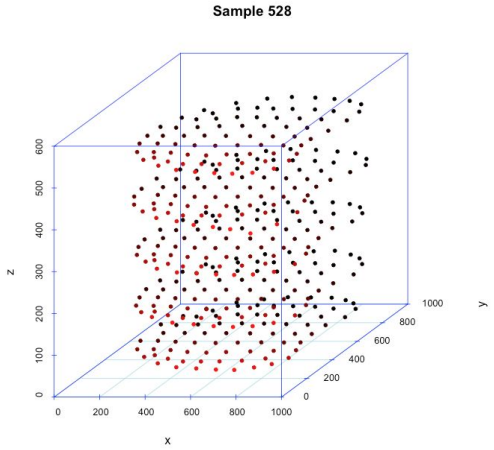


Figure Q. 3D plot of Vertebra Sample 528

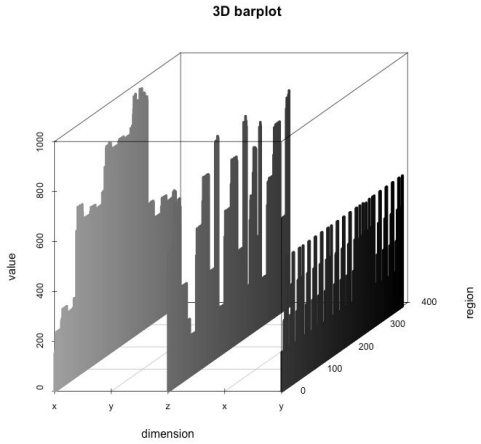


Figure R. Split-Dimension Plot of Sample 528

Appedex

```
Flexion_513 <- read.csv("Flexion_513.csv",header=T)
Flexion_528 <- read.csv("Flexion_528.csv",header=T)
Union_581 <- read.csv("Union_581.csv",header=T)

# Flexion_513
matrix.diff513 <- matrix(rep(0,19944), nrow=2493)
i <- 1
k <- 0
while(i < 24){
  diff513 <- Flexion_513[,i+1] - Flexion_513[,i+2]
  k <- k+1
  matrix.diff513[,k] <- diff513
  hist(diff513, main = "Flexion_513")
  i <- i+3
}
df513 <- data.frame(matrix.diff513)

mean(df513[,1])
median(df513[,2])
mean(df513[,3])
mean(df513[,4])
mean(df513[,5])
median(df513[,6])
mean(df513[,7])
mean(df513[,8])
# the 2nd is closest to 0 one

boxplot(df513[,1], df513[,2], df513[,3], df513[,4], df513[,5], df513[,6], df513[,7], df513[,8])

# Flexion_528
matrix.diff528 <- matrix(rep(0,15600), nrow=1950)
i <- 1
k <- 0
while(i < 24){
  diff528 <- Flexion_528[,i+1] - Flexion_528[,i+2]
  k <- k+1
  matrix.diff528[,k] <- diff528
  hist(diff528, main = "Flexion_528")
  i <- i+3
```

```
}
df528 <- data.frame(matrix.diff528[1:1897,])

median(df528[,1])
mean(df528[,2])
mean(df528[,3])
mean(df528[,4])
mean(df528[,5])
median(df528[,6])
mean(df528[,7])
mean(df528[,8])
# the 2nd is the closest to 0 one

boxplot(df528[,1], df528[,2], df528[,3], df528[,4], df528[,5], df528[,6], df528[,7], df528[,8])

# Union_581
matrix.diff581 <- matrix(rep(0,15512), nrow=1939)
i <- 1
k <- 0
while(i < 24){
  diff581 <- Union_581[,i+1] - Union_581[,i+2]
  k <- k+1
  matrix.diff581[,k] <- diff581
  hist(diff581, main = "Union_581")
  i <- i+3
}
df581 <- data.frame(matrix.diff581)

mean(df581[,1])
mean(df581[,2])
mean(df581[,3])
mean(df581[,4])
mean(df581[,5])
mean(df581[,6])
mean(df581[,7])
mean(df581[,8])
# all of them are quite close to each other, the 2nd and 7th one seems to be even better

boxplot(df581[,1], df581[,2], df581[,3], df581[,4], df581[,5], df581[,6], df581[,7], df581[,8])

# 3D data plot
# Read in data
data<-read.csv(file.choose())
```

```
x<-data[,2]
y<-data[,3]
z<-data[,4]
colnames(data)<-c("number","x","y","z")
data3<-data[,2:4]
str(data)

# Data plot
library("scatterplot3d")

scatterplot3d(x,y,z, highlight.3d = TRUE, col.axis = "blue",
          col.grid = "lightblue", main = "Sample 528", pch = 20)

data3<-as.matrix(data3)
data3d<-data.frame(dimension=c(col(data3)),region=c(row(data3)),value=c(data3))
scatterplot3d(data3d, type = "h", lwd = 5, pch = " ",
          x.ticklabs = (colnames(data3)), y.ticklabs = rownames(data3),
          color = grey(1152:1 / 1843), main = "3D barplot")
```