Femoral Component Insertion Monitoring Using Human Cadaveric Specimens

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Purpose

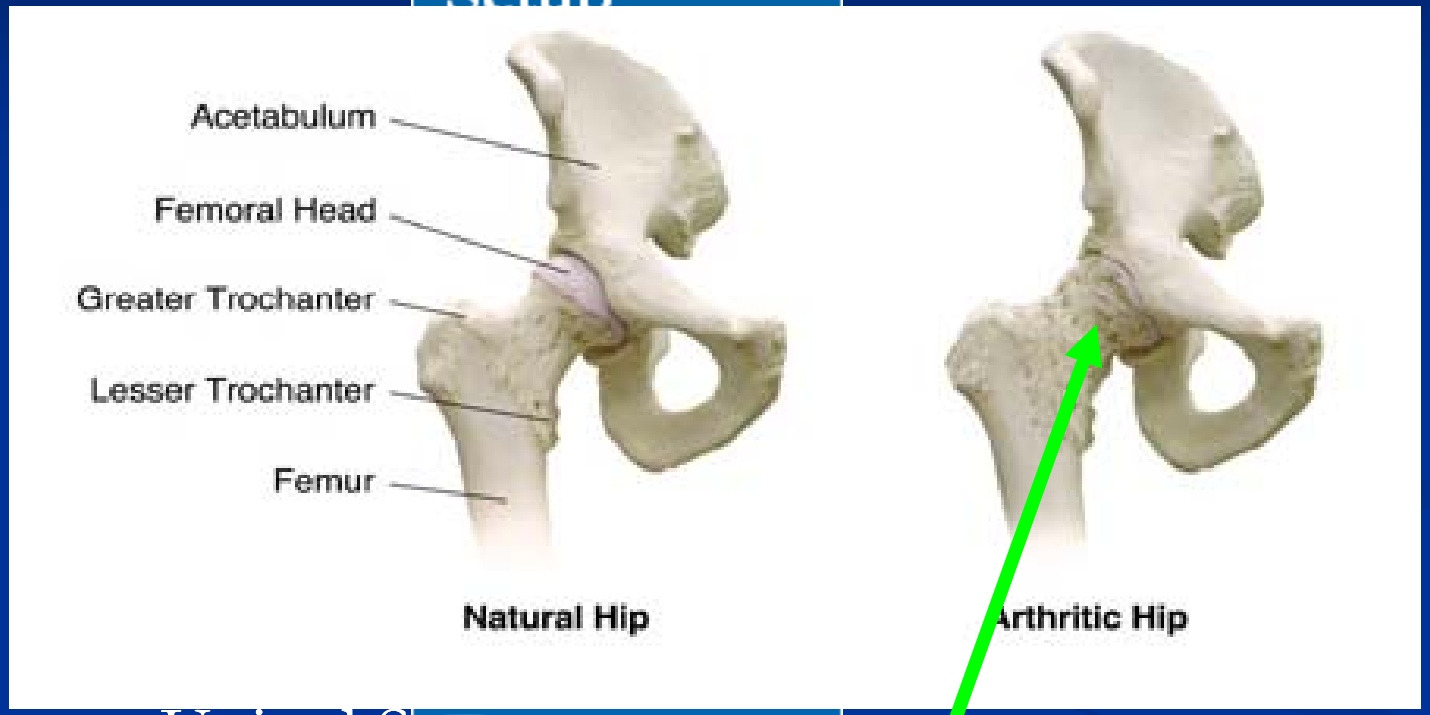
Setup

Data

Analysis

Conclusions

Osteoarthritis is a common debilitating disease of the hip joint.



United States (Arthritis Foundation, http://www.arthritis.org)

- Osteoarthritis is a degenerative joint disease; the cartilage that covers the ends of bones deteriorates

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This research investigates one type of total hip arthroplasty.

- Investigating seating of femoral component
- Cemented vs. Uncemented
- Traditional (>15 cm) vs. minimally invasive (<10 cm)

Minimally invasive surgery has costs and benefits.

Smaller incision

Costs → Decreased field of view → Risk of fracture

Benefits → Less tissue trauma → Quicker recovery

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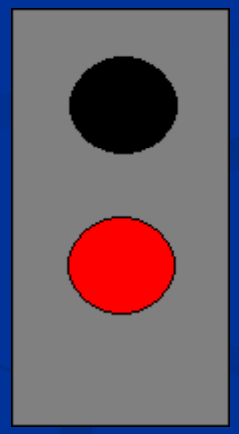
We are attempting to determine optimal seating.

Prevent femoral fracture

Ensure sufficient impaction

Determine seating quantitatively



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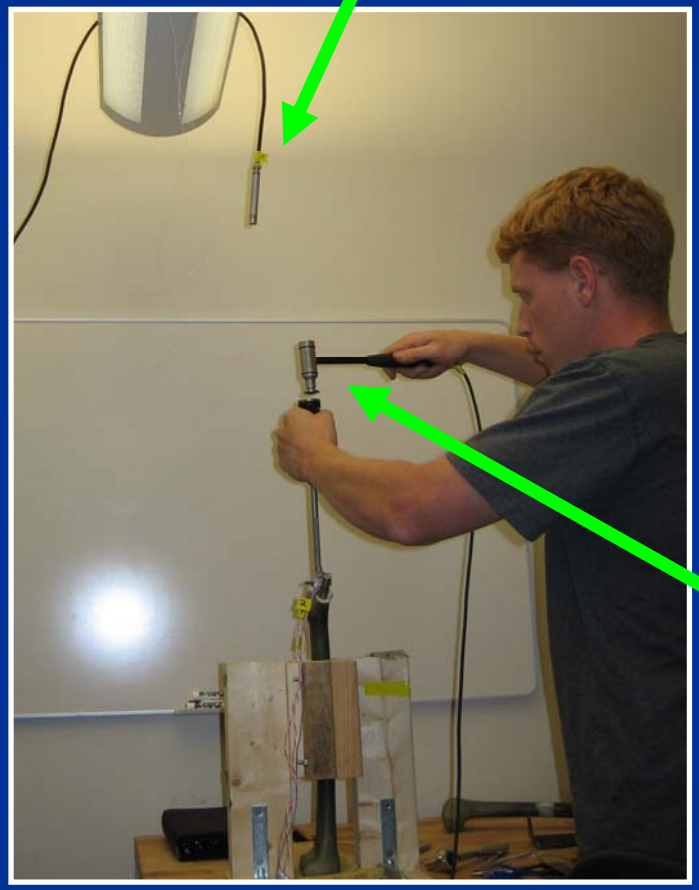
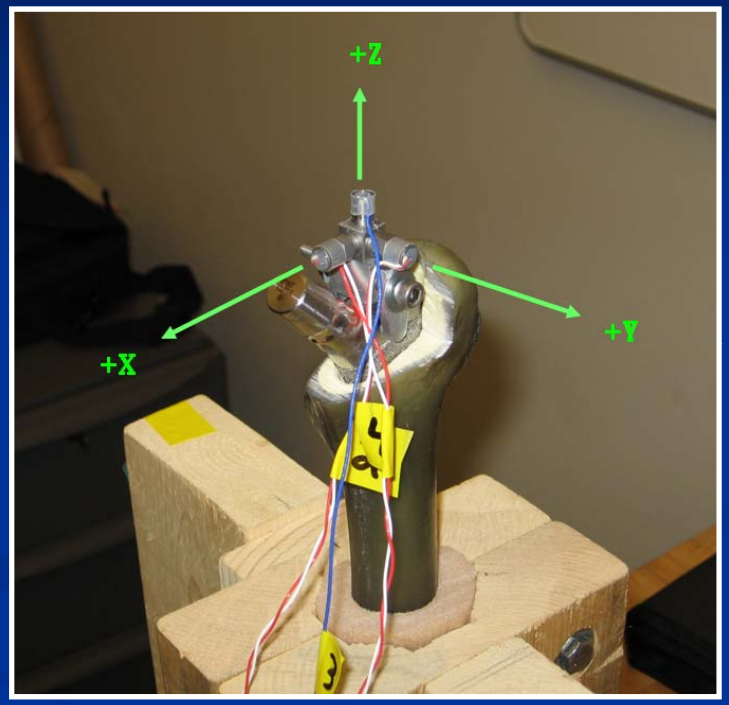
Replicate composite femurs were used to finalize data acquisition procedure.

Acoustic response



Force measurements



Accelerations

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Cadaveric Specimen tests were conducted at UCSD.

- 8 femoral prostheses were implanted
- Testing stopped due to failure of epoxy

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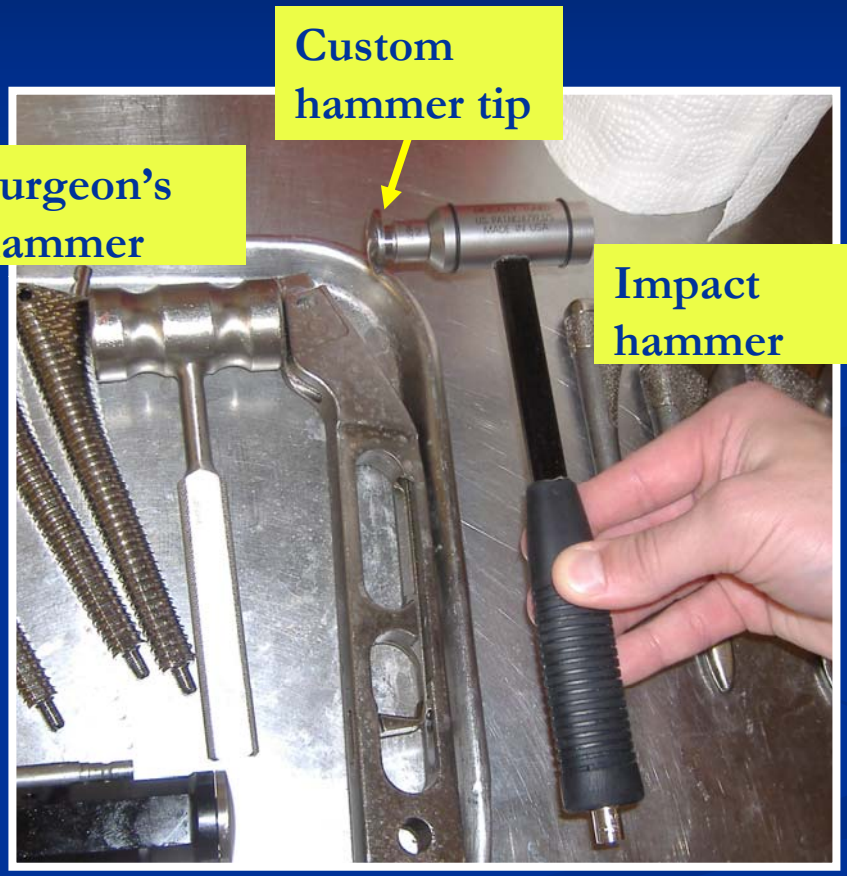
A hammer with a force transducer was used instead of the surgeon's hammer.



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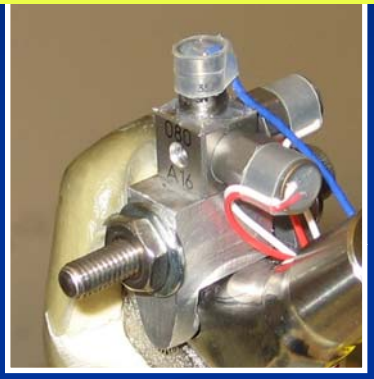
Various sizes of femoral implants were used with a fixture mounted on top.

Removable accel fixture



Varying sizes of femoral implants

Removable accel fixtures attach to prosthesis hole

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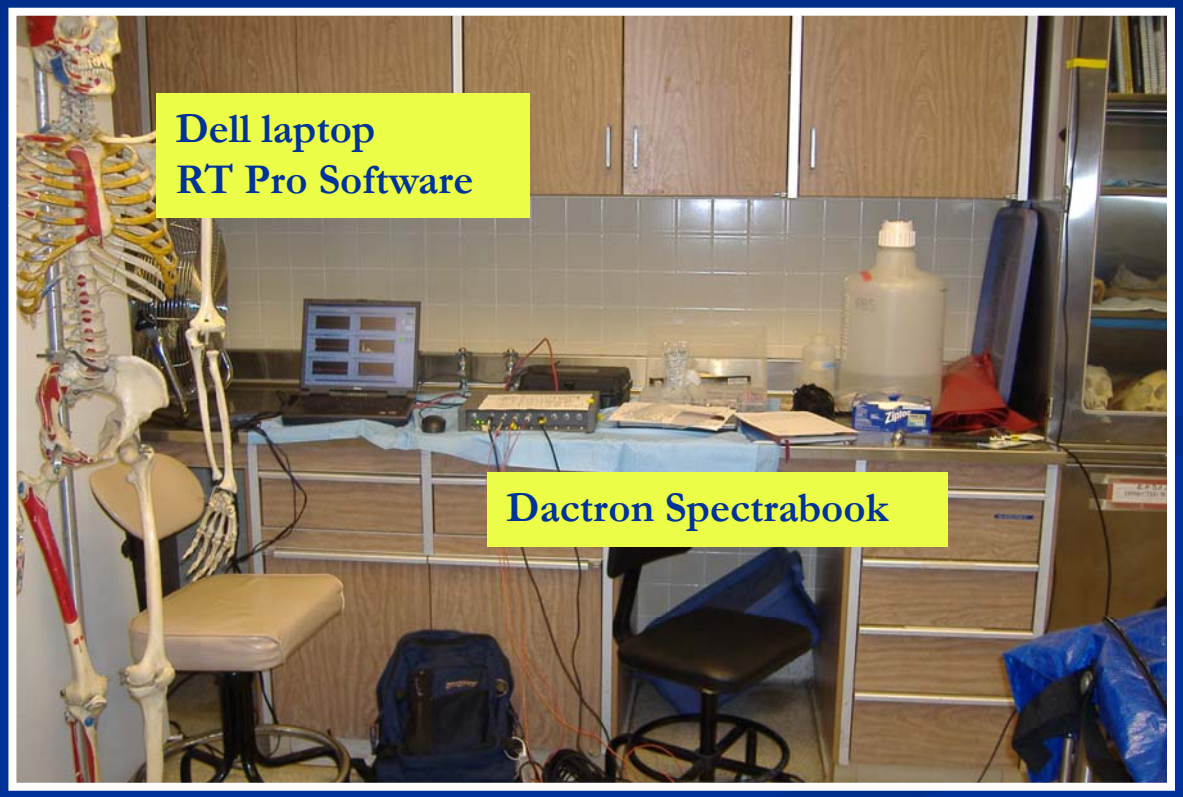
The data acquisition team was setup away from the surgery.



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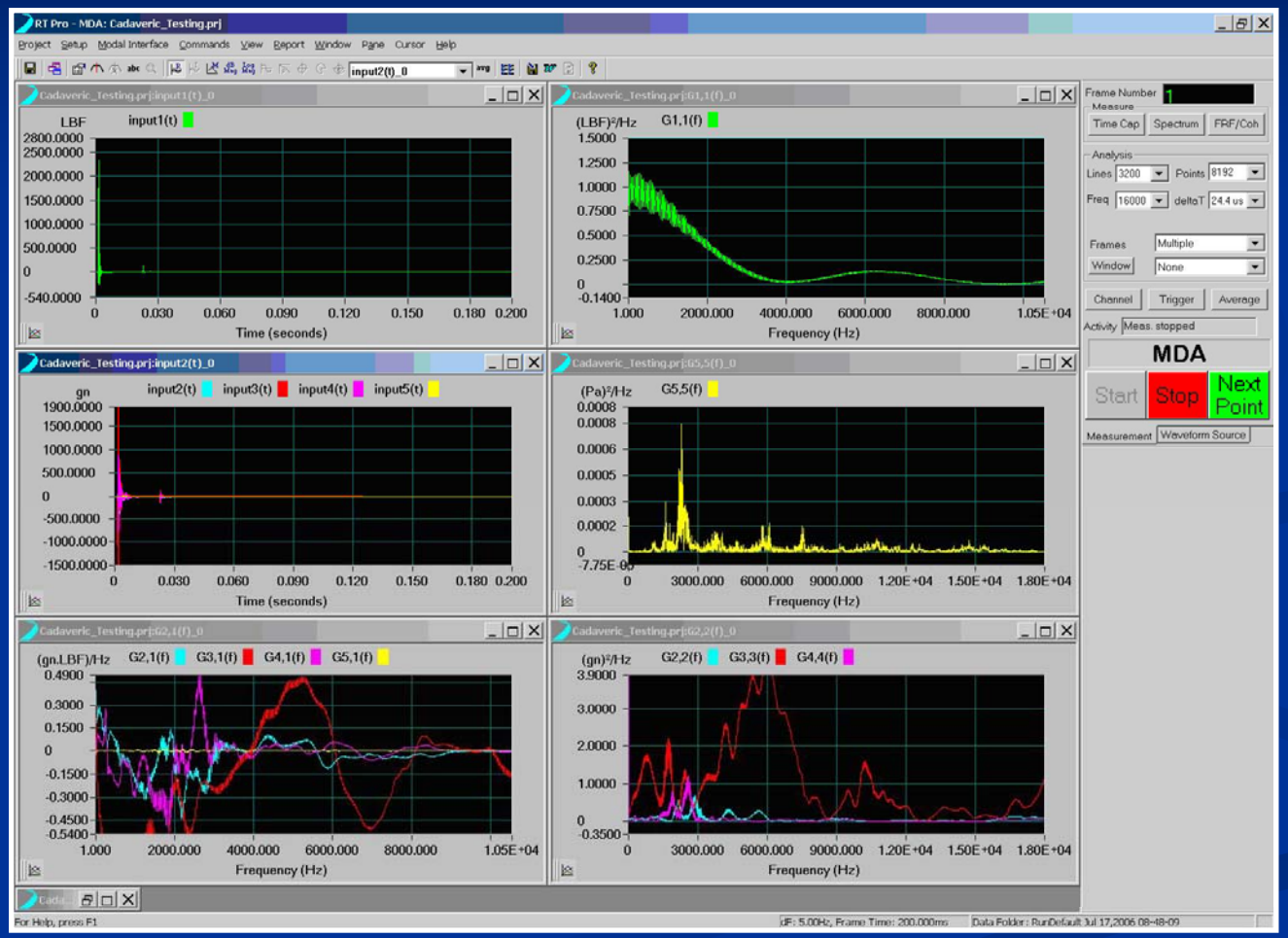
Screenshots were collected during data acquisition.



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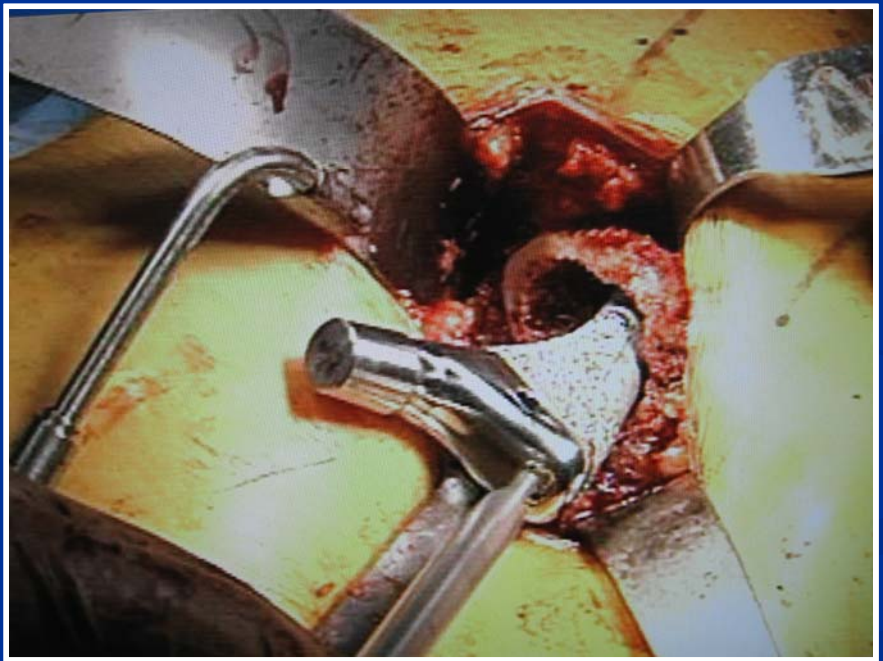
The procedure was followed on 5 different cadaveric specimens (8 total hips).

General Procedure:

1. Prepare proximal femur
2. Press implant into femur by hand



Femoral canal broached to proper size.

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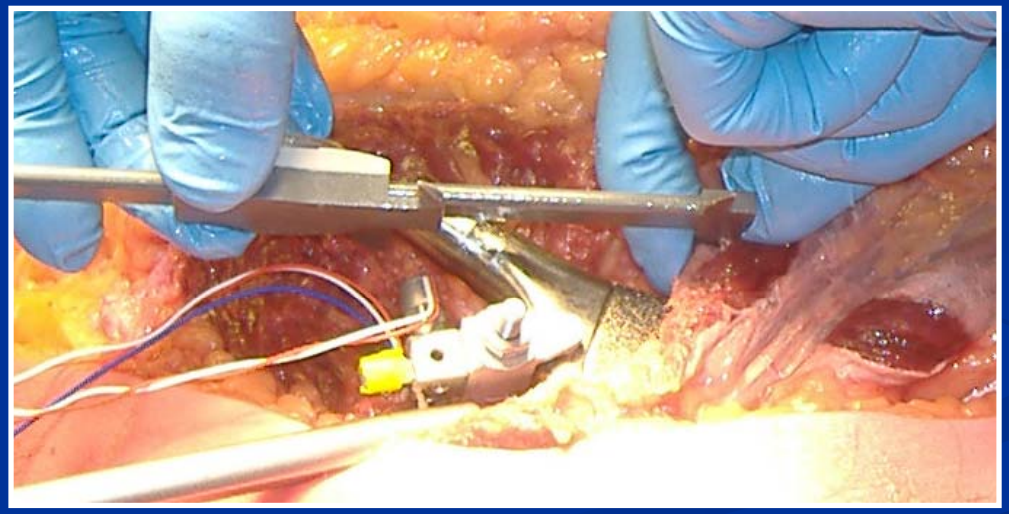
The procedure was followed on 5 different cadaveric specimens (8 total hips).

General Procedure:

1. Prepare proximal femur
2. Press implant into femur by hand
3. Take depth measurement



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General Procedure:

1. Prepare proximal femur
2. Press implant into femur by hand
3. Take depth measurement
4. Impact once with instrumented hammer and punch
   - Record force, acceleration, and acoustic data
5. Repeat 3,4 u[illegible] then until fracture

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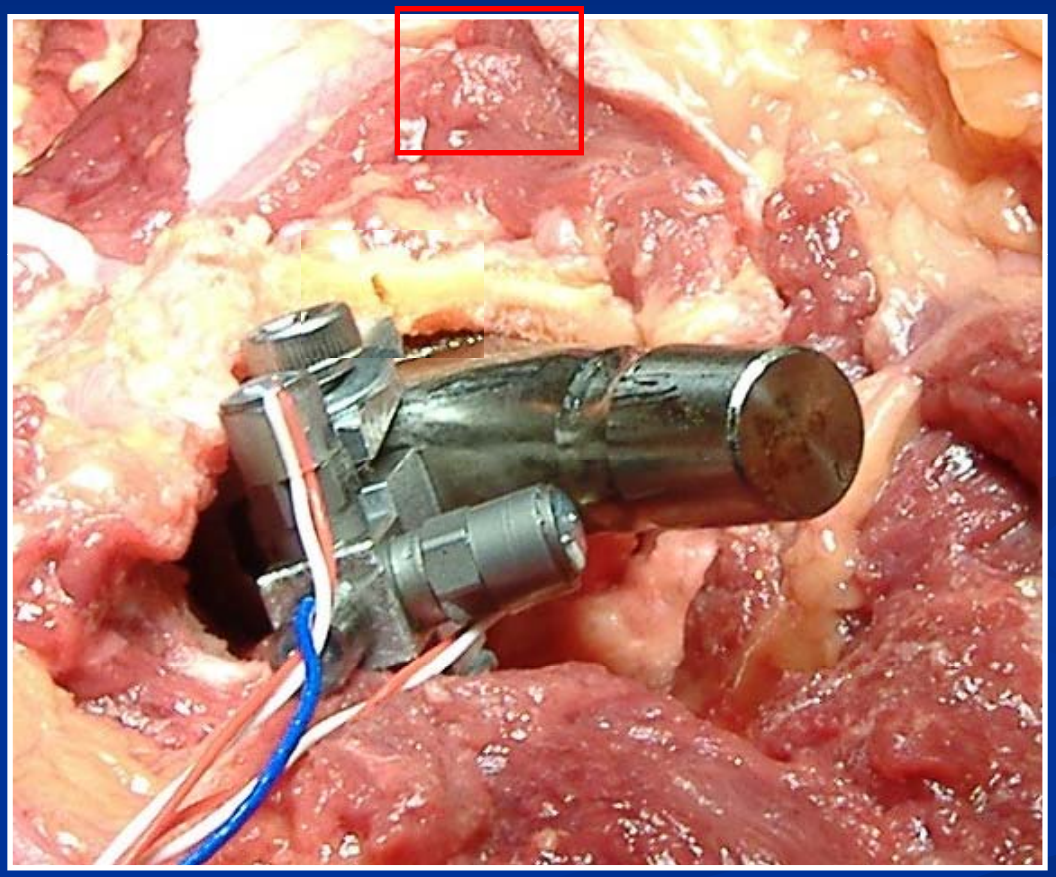
The point of seating and fracture was determined by the surgeon.



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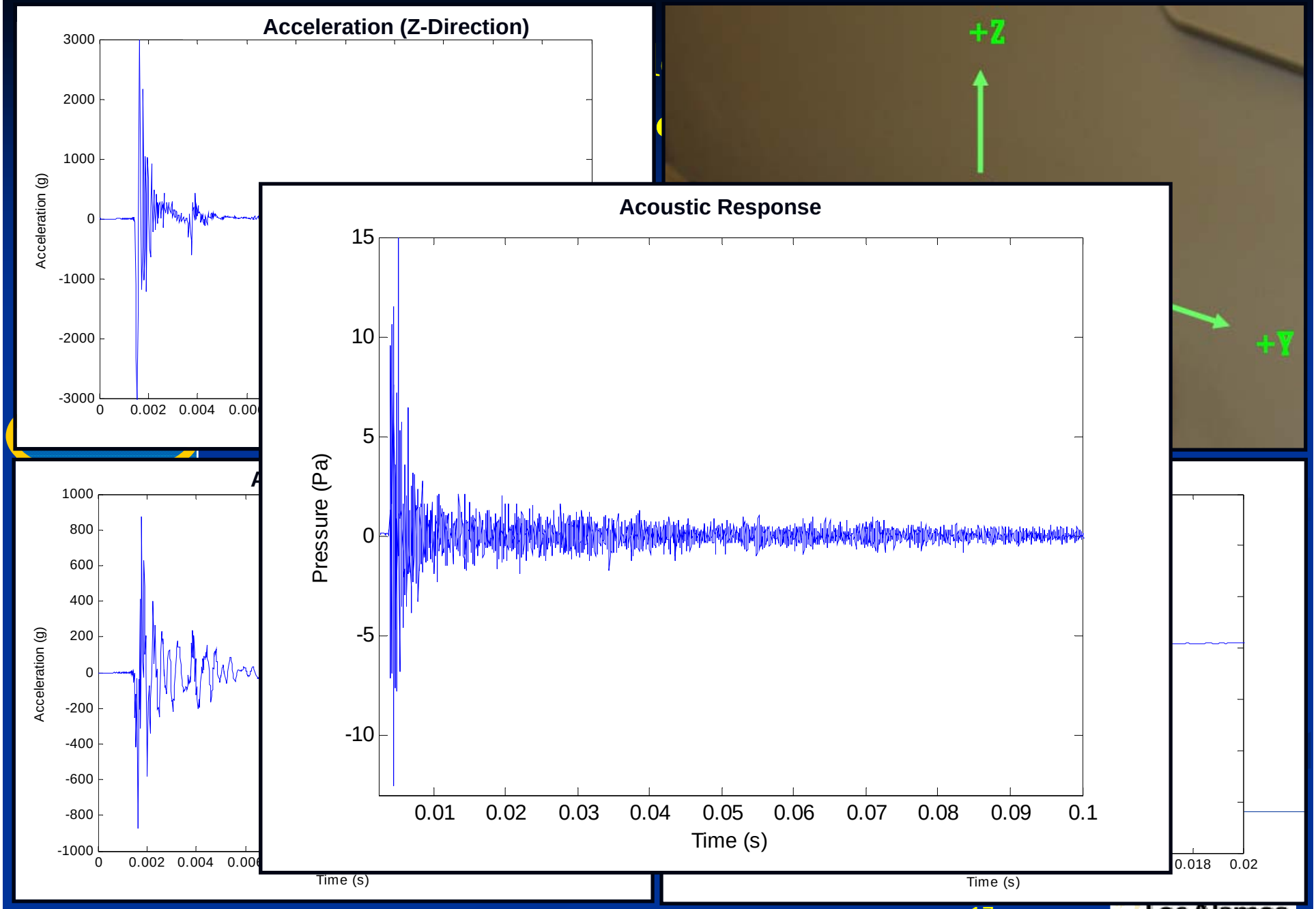
A variety of cadaveric specimens were tested.

Specimen	Sex	Age	Height (m)	Weight (kg)	BMD	Outcome
#1 Right	Female	87	Not Given	Not Given	TBD	Fractured
#1 Left	Female	87	Existing Hip Implant			Fractured
#2 Right	Female	84	1.65	57.61	TBD	Incomplete
#2 Left	Female	84	1.65	57.61	TBD	Fractured
#3 Right	Male	97	1.68	72.57	TBD	Unable to Fracture
#3 Left	Male	97	1.68	72.57	TBD	Unable to Fracture
#4 Right	Male	75	1.57	63.5	TBD	Incomplete
#4 Left	Male	Fractured During Reaming				Fractured
#5 Right	Female	59	1.7	Epoxy Failure	TBD	Incomplete
#5 Left	Female	59	1.73	68.04	TBD	Incomplete

Los Alamos



Acoustic Response

Purpose

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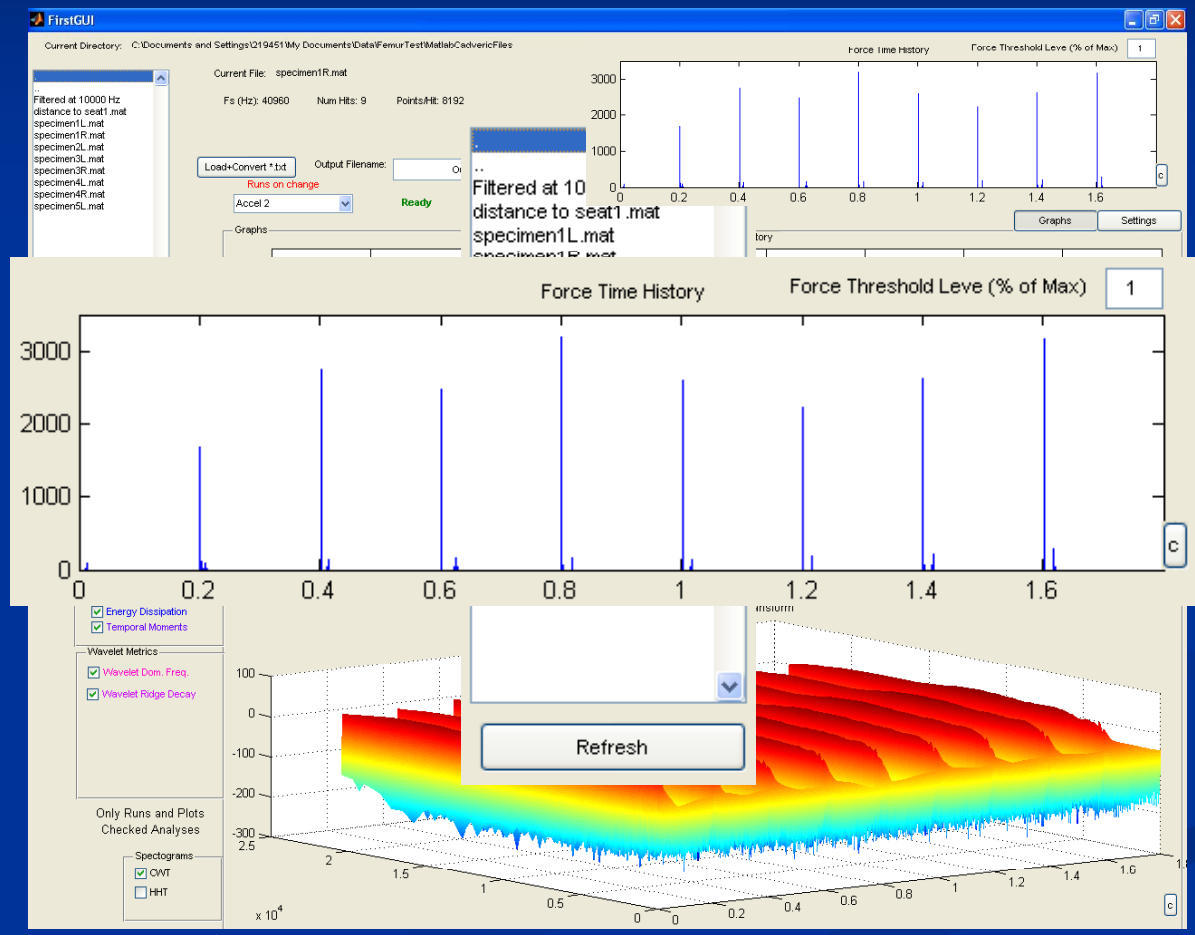
Data analysis was conducted using a custom Matlab GUI.



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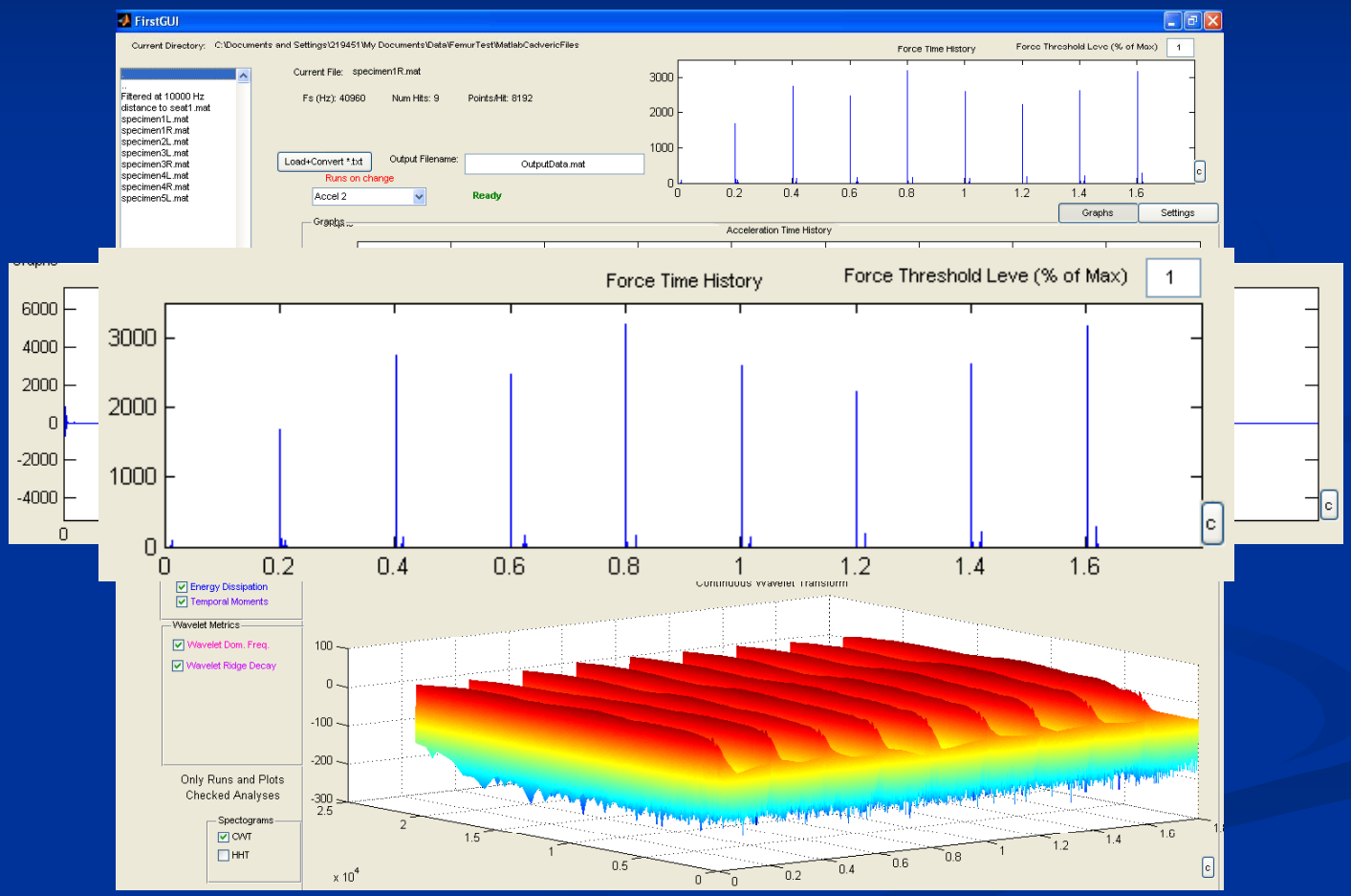

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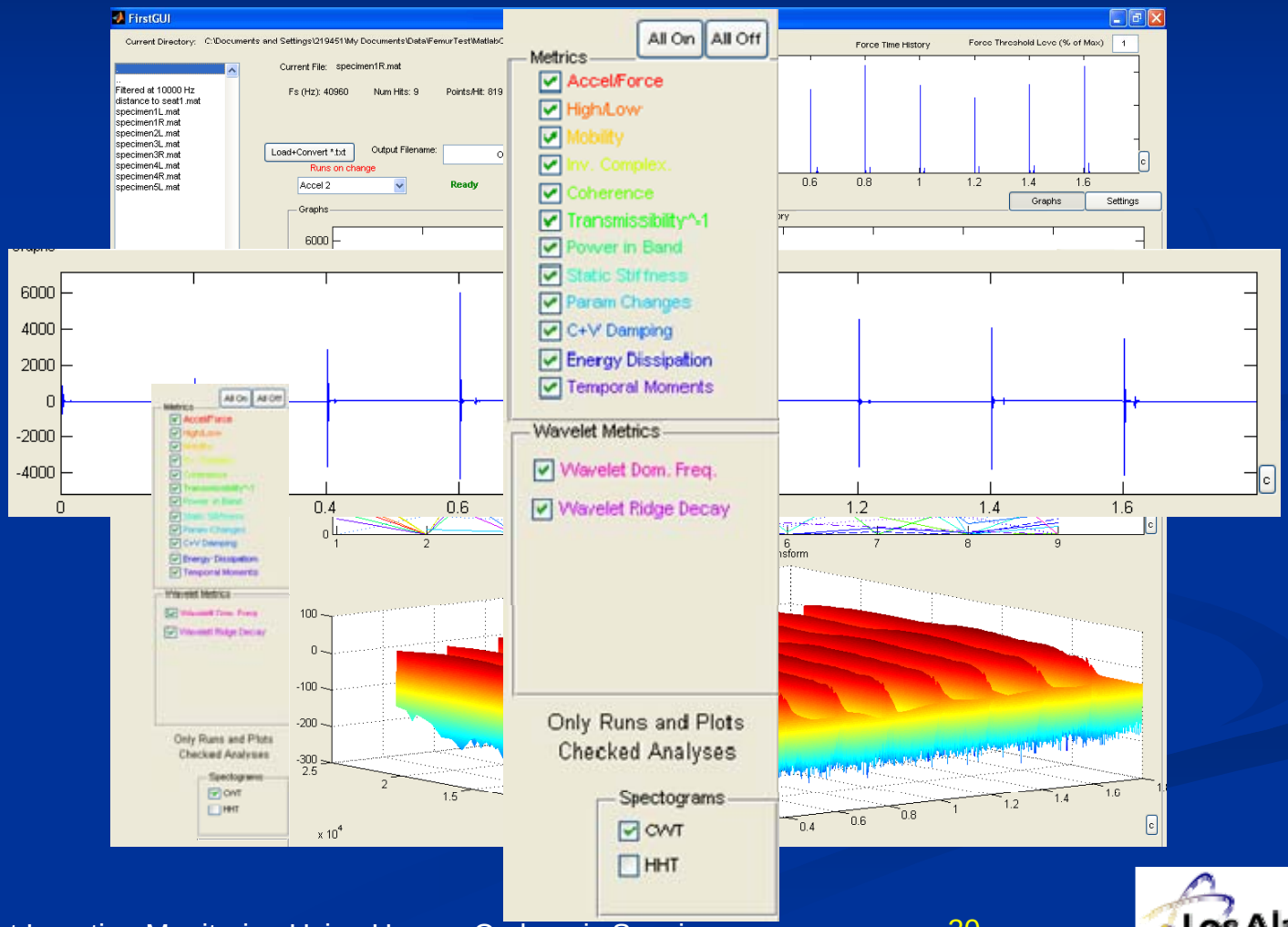
Feature Extraction

Time History



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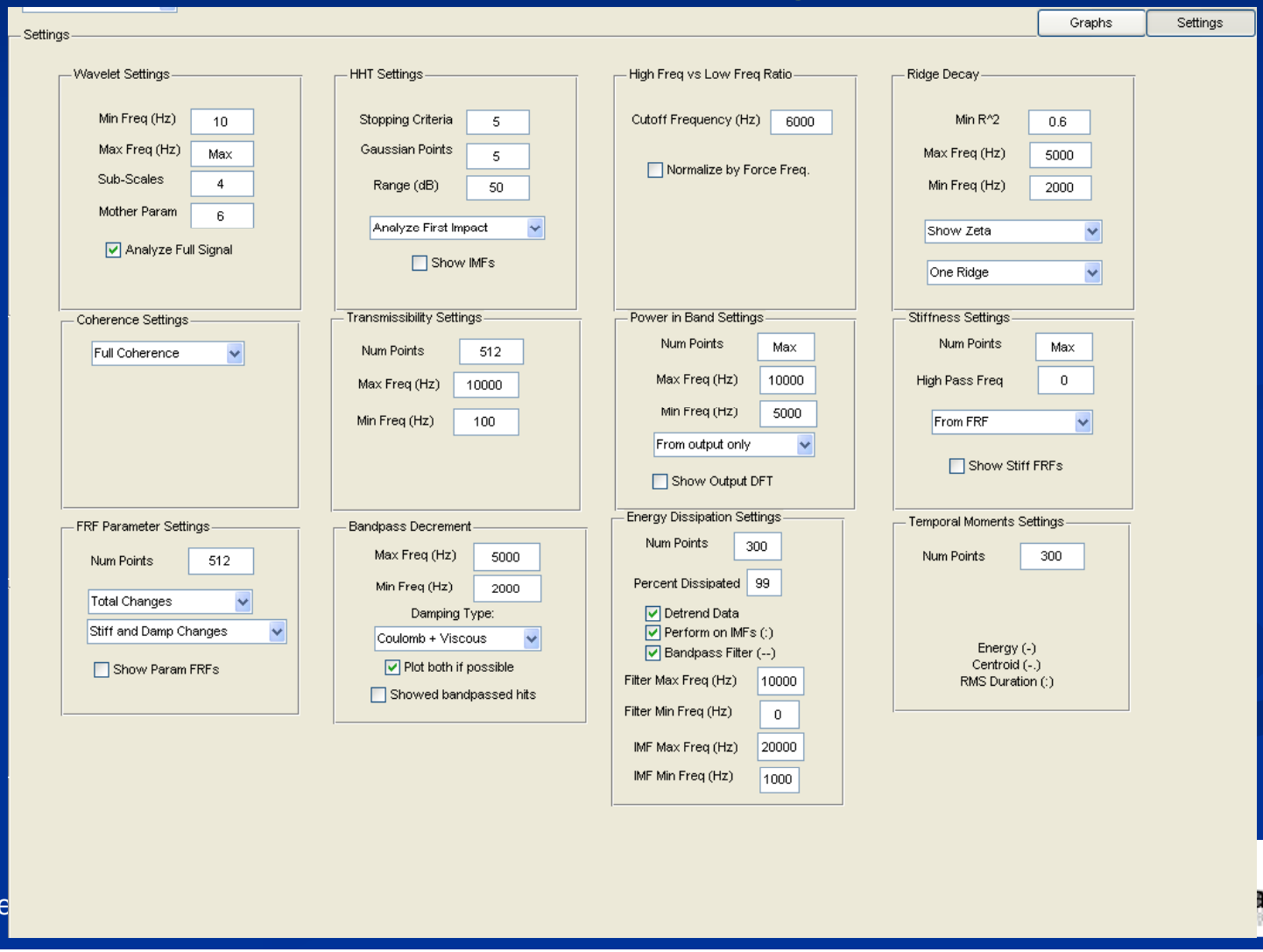
Analyses Settings



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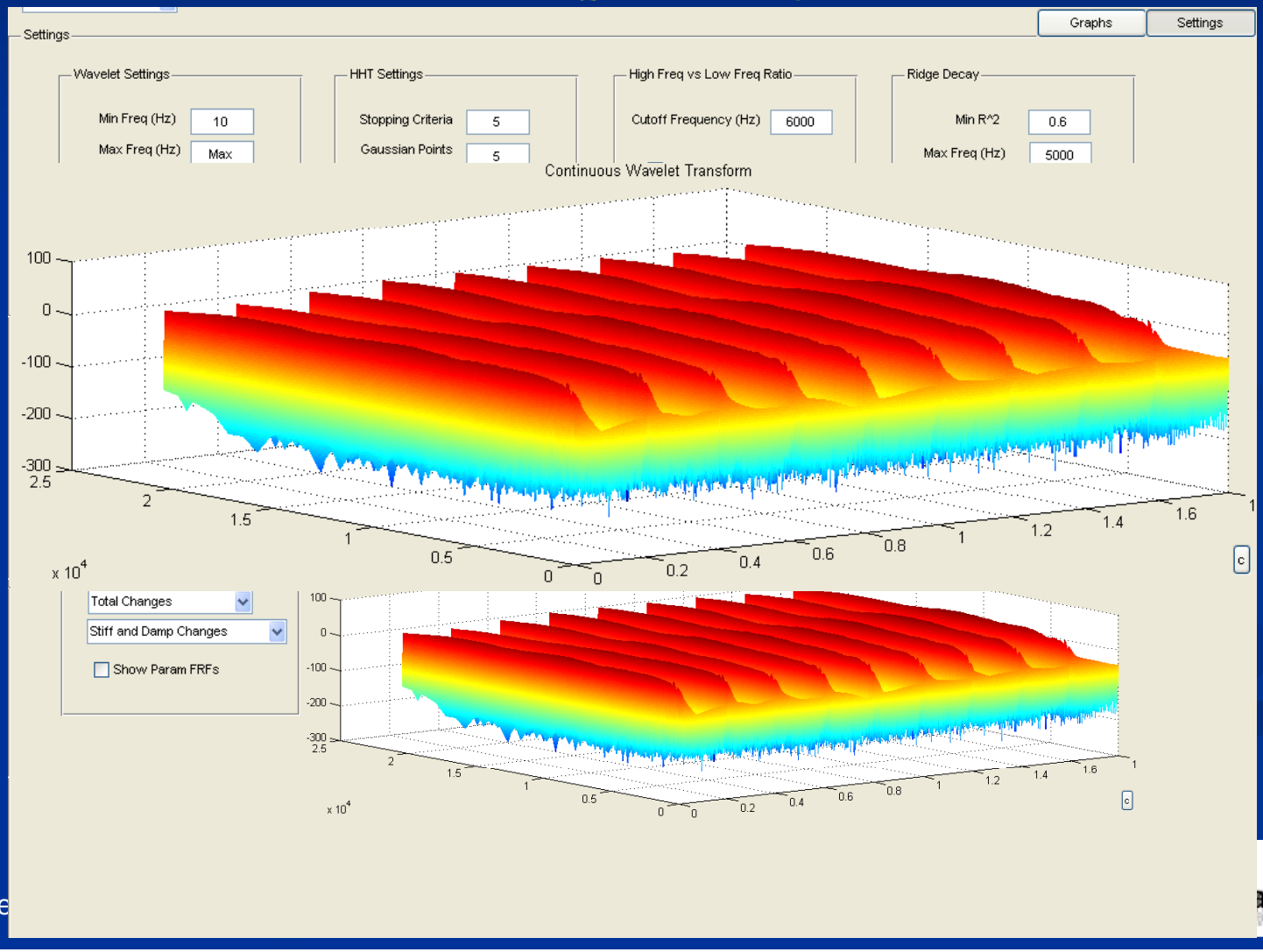
Time-Frequency Results



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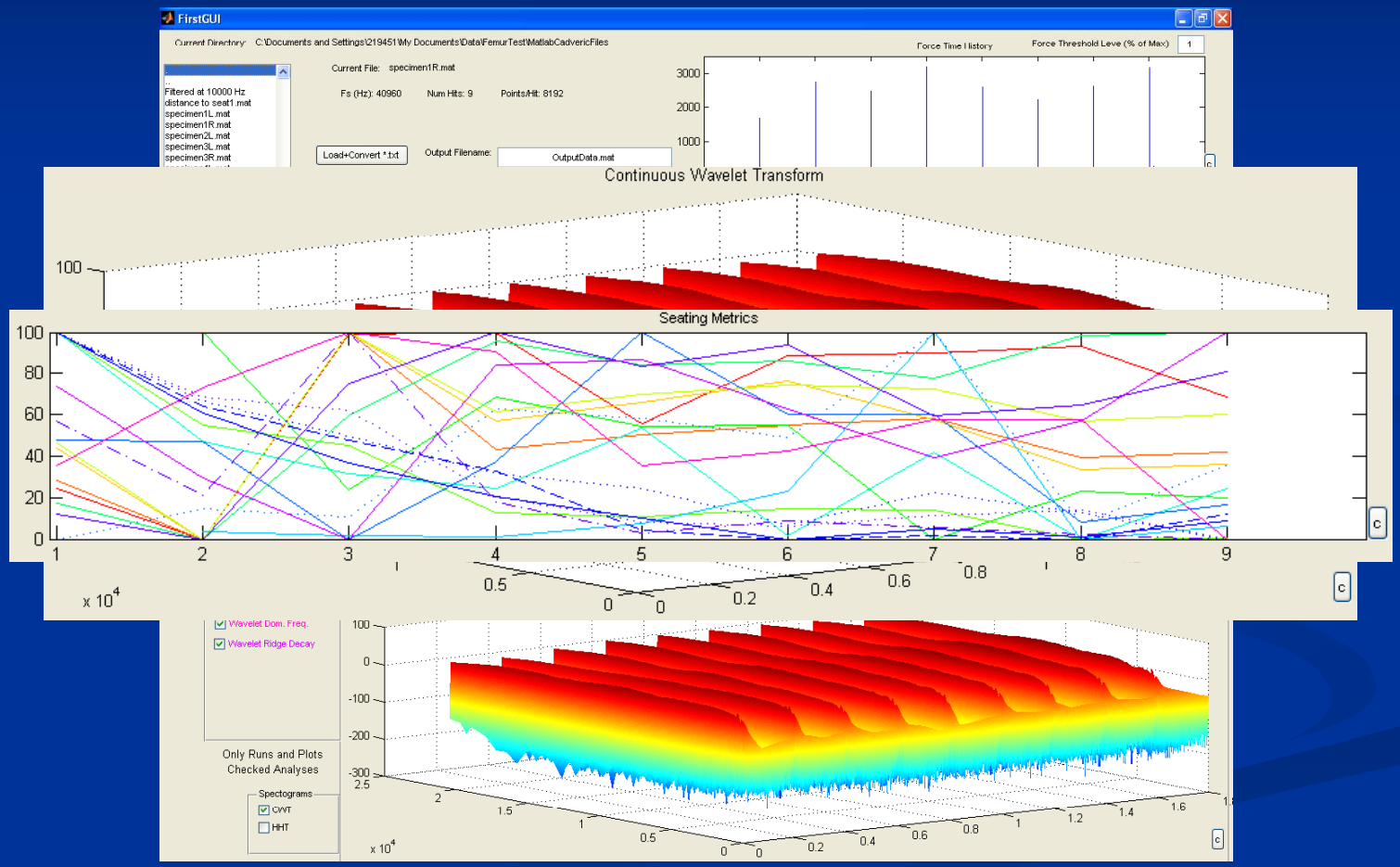
Time-Frequency Results

Extracted Features



Time to 99% of total norm was calculated using z-direction accelerations.

$$Norm_j = \frac{\sqrt{\sum_{i=1}^{j} a_i^2}}{Norm_{Total}} \qquad Norm_{Total} = \sqrt{\sum_{i=1}^{N} a_i^2}$$

$Norm_j$=Norm feature at j^{th} point

$Norm_{Total}$=Norm of entire signal interval

N=Number of points examined

a_i=Signal value at i^{th} point

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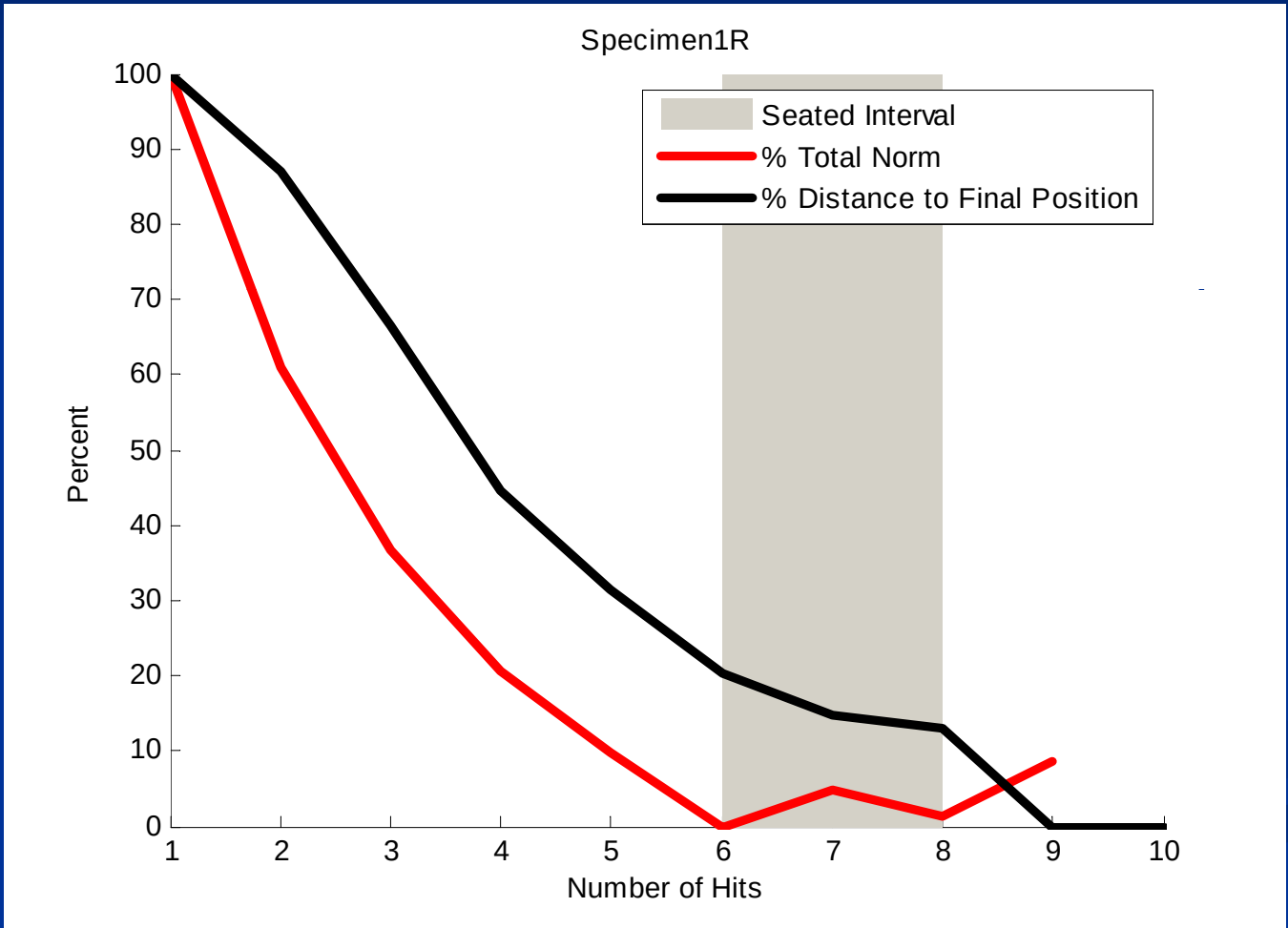
Total norm technique followed depth measurements.



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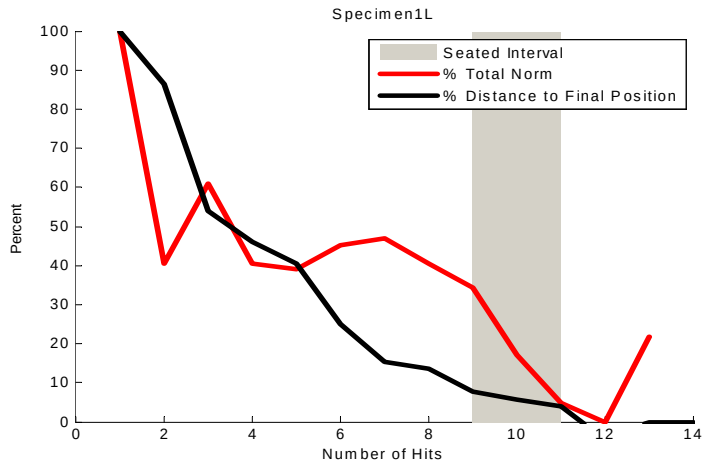

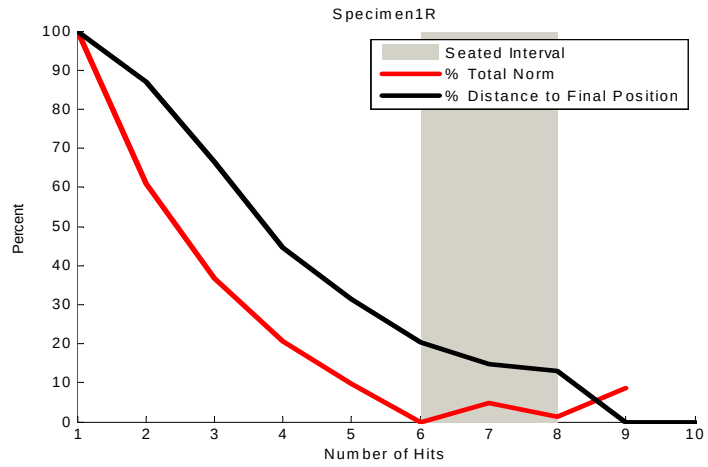

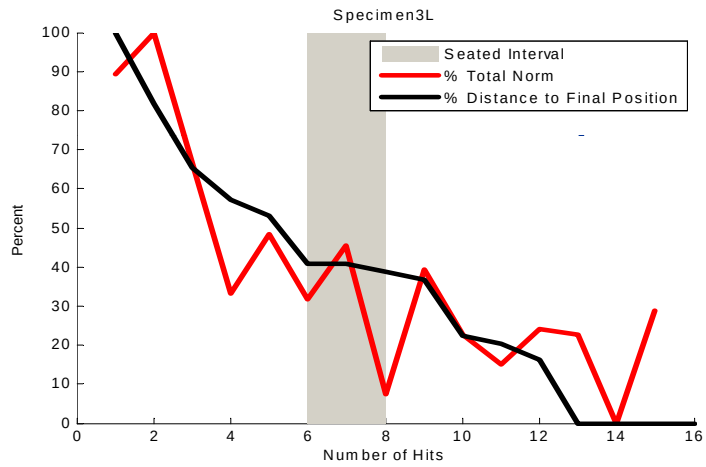

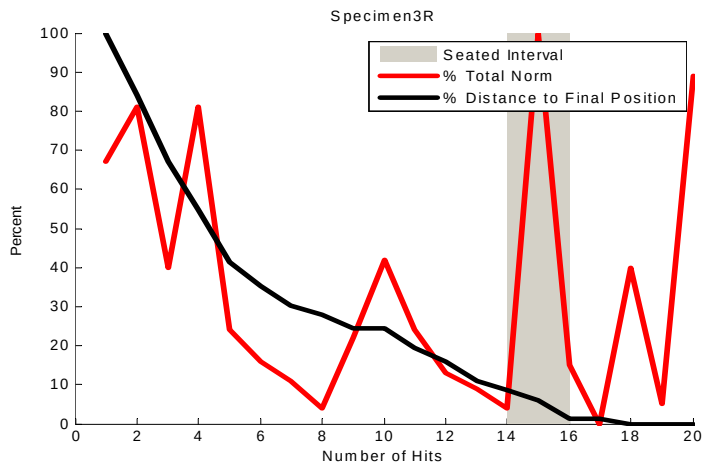

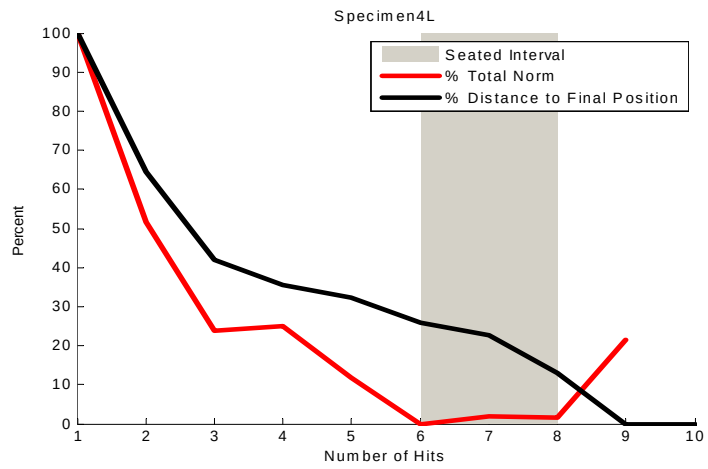

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A real time metric was developed to predict seating of the prosthesis during impaction.

- Seating indicated by increase in time to 99% of total norm after two point moving average filter applied
- Seating predicted prior to fracture in all cases

Specimen	Seating Interval	Predicted Seated Hit
1R	6-8	8
1L	9-11	6
2L	8-10	12
3L	6-8	10
3R	14-16	9
4L	6-8	8

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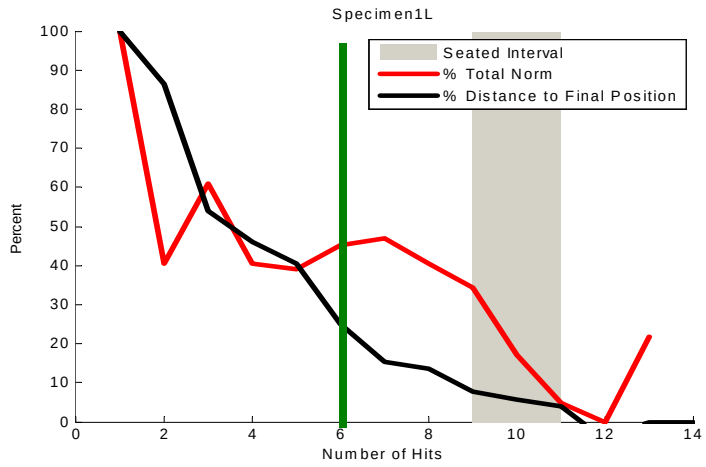

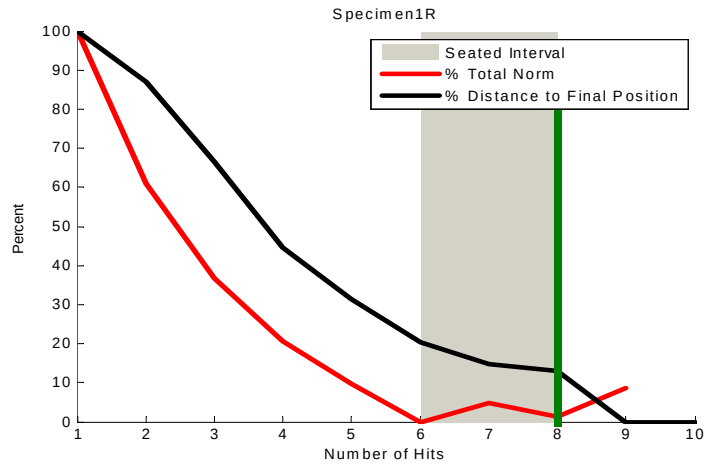

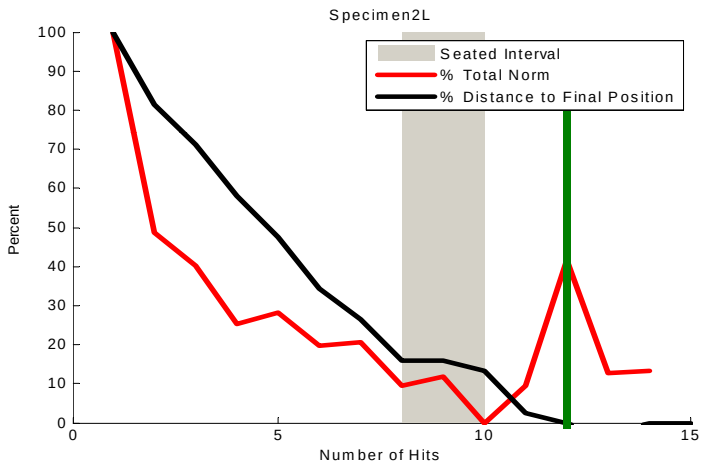

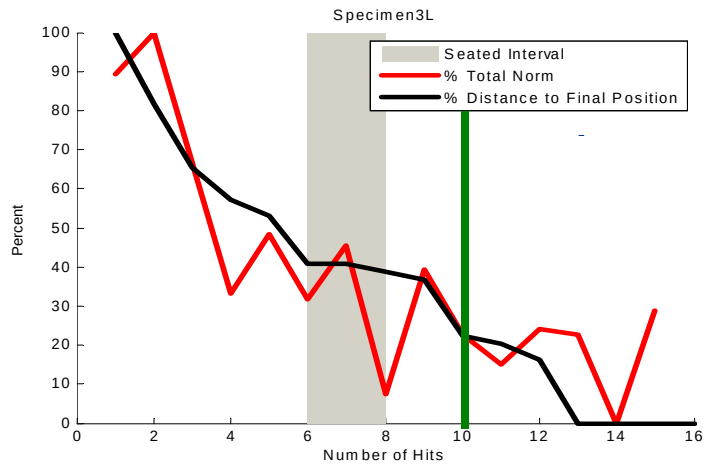

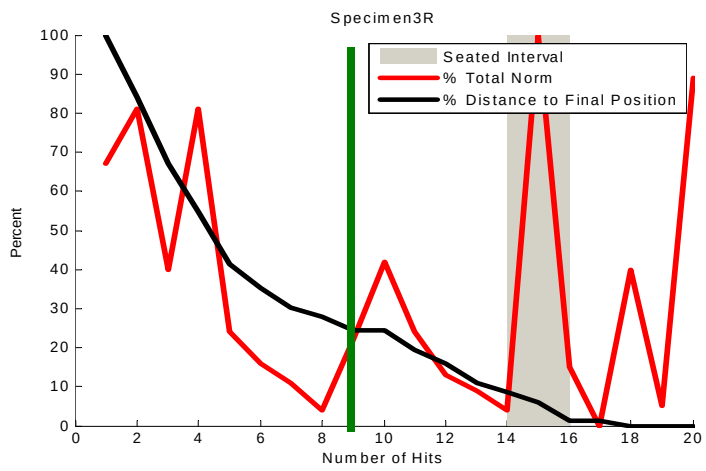

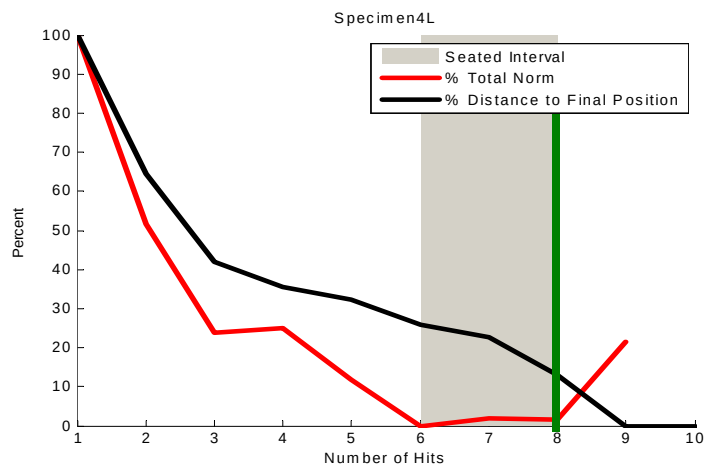

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We tried a number of different data analysis techniques to extract signal characteristics.

Frequency

- Dominant frequency via CWT
- Energy in high vs. low frequency bands
- Mean frequency of highest RMS IMF
- Mean square value of signal in frequency band
- Mean of cross power spectral density between hits
- Variance of cross power spectral density between hits
- Static stiffness via the FRFs from accelerations

Interrelation

- Area under coherence function between hits
- Transmissibility between transverse accelerometers
- Maximum cross correlation

Stationarity

- Signal stationarity via Hilbert Huang Transform

Energy Dissipation

- Time to 99% of total norm
- Decay of highest RMS IMF via Hilbert Transform
- Changes in system parameters via FRFs
- Damping estimate via continuous wavelet transform
- Coulomb and viscous damping of filtered signal

Time History

- Norm of Acceleration / Norm of Force
- Mobility
- Max transverse accel./max Z-direction accel.
- Inverse of complexity

Neural Networks

- ANN trained with wavelet decomposed signal

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Parallels Replicate Seating

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Parallels Cadaver Seating

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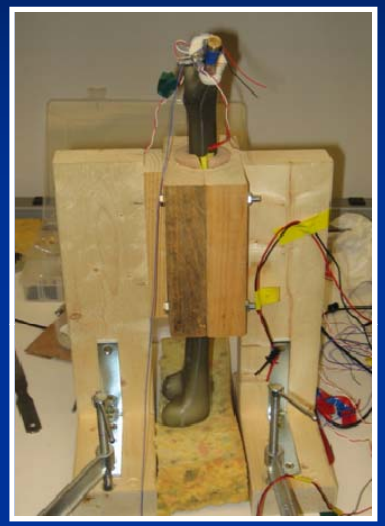
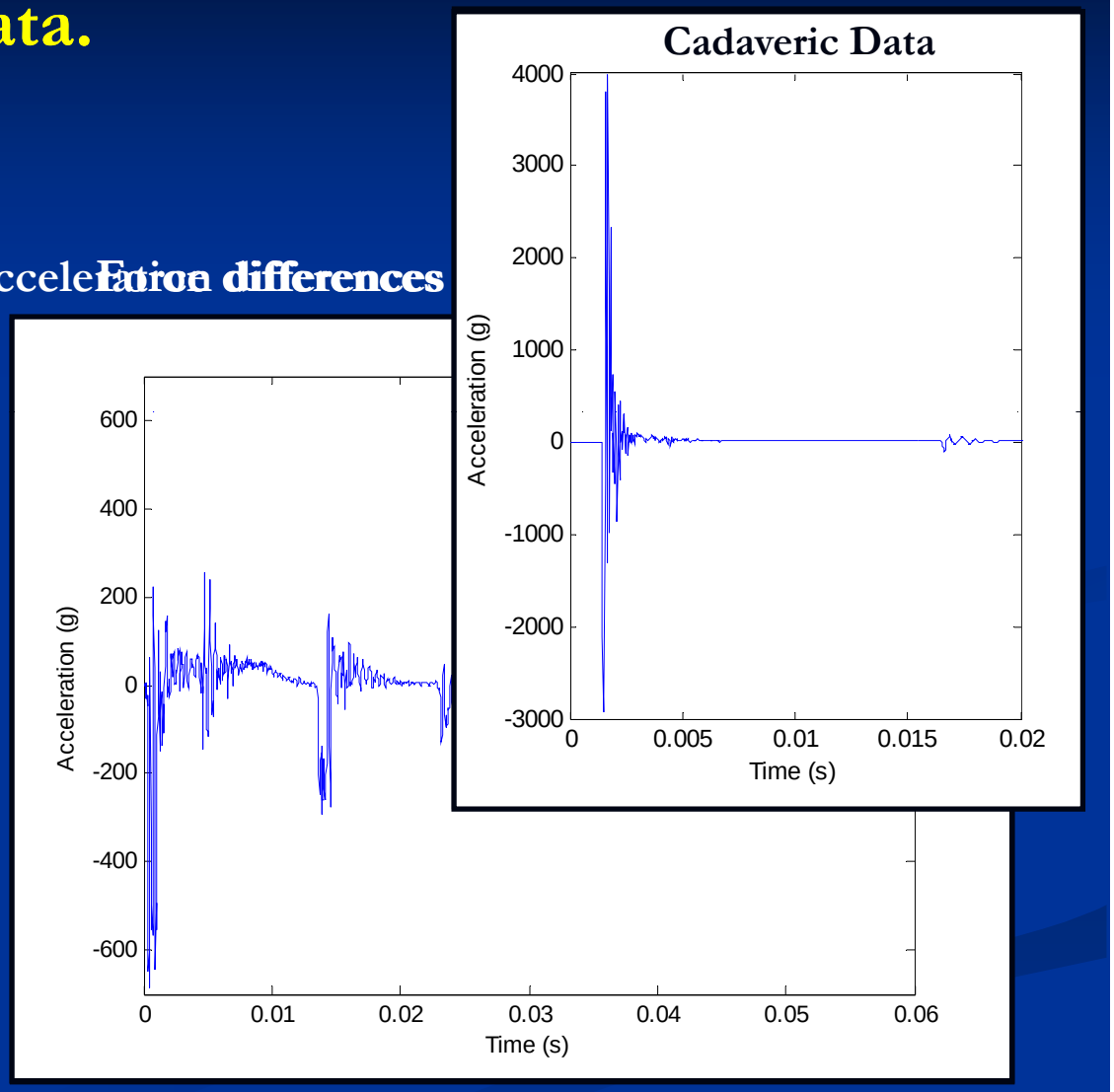
There were differences between cadaveric data and replicate data.



Different boundary conditions

Hammer tip was made of steel similar to surgeons hammer

Acceleration differences



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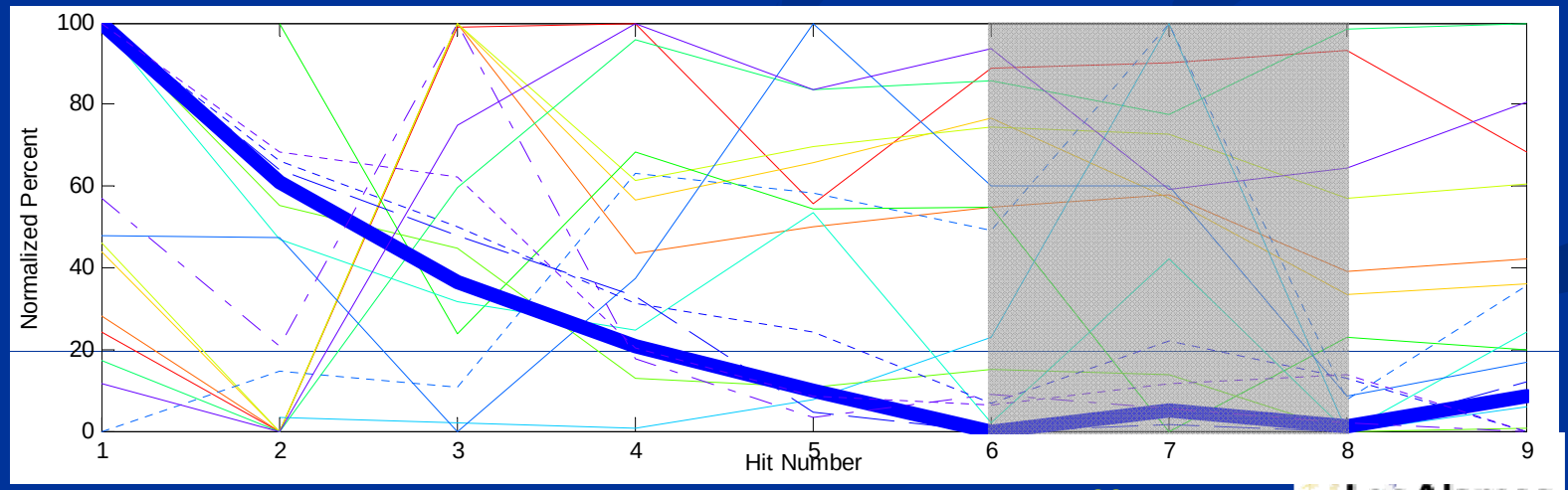
We are one step closer to having a qualitative red light / green light solution.

- Data collected from 8 femurs on 5 cadaveric specimens
- Several metrics were investigated
- Total norm in z-direction worked best
  - No metrics from transverse acceleration or acoustic data successful



Los Alamos

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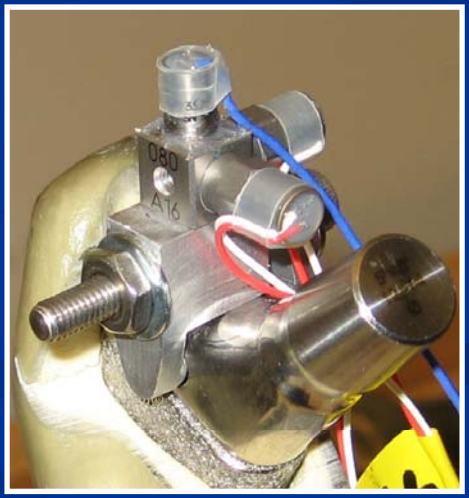
Several possibilities for future work remain.

- More cadaveric testing
  - To increase sample size and data quality
  - To further investigate metrics
  - To perform surgery using minimally invasive technique
- Implement metrics in real time dynamic seating indicator
- Refine fully removable sensing hardware



Acknowledgements

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  - The Los Alamos National Laboratory - University of California Engineering Institute for hosting the Los Alamos Dynamics Summer School
  - Funding support from Los Alamos National Laboratory
  - Vibrant Technologies (MeScope software)
  - The Mathworks, Inc. (Matlab, Simulink, XPCTarget)
  - ABAQUS, Inc. (ABAQUS finite element analysis software)
  - The support from our mentor Phil Cornwell and Dr. Michael Meneghini
  - University of California San Diego School of Medicine
  - Zimmer Incorporated

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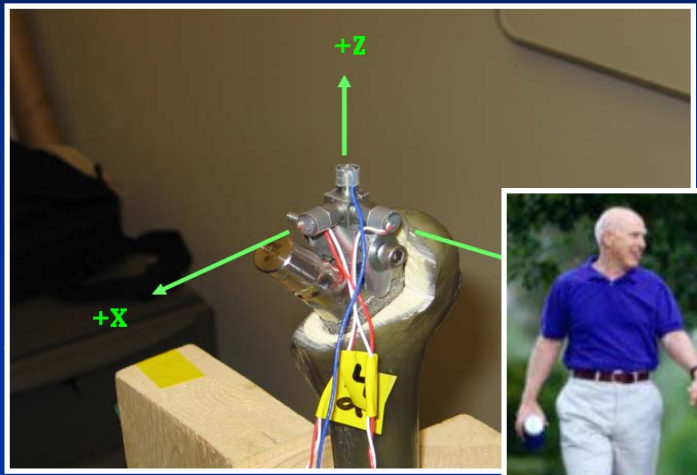
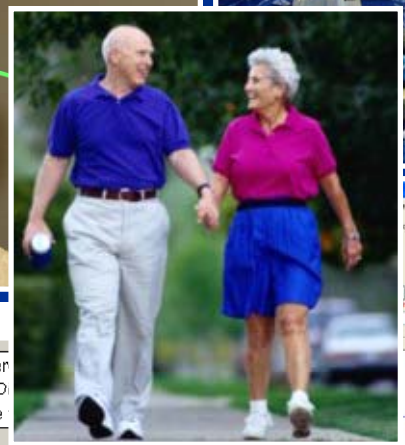
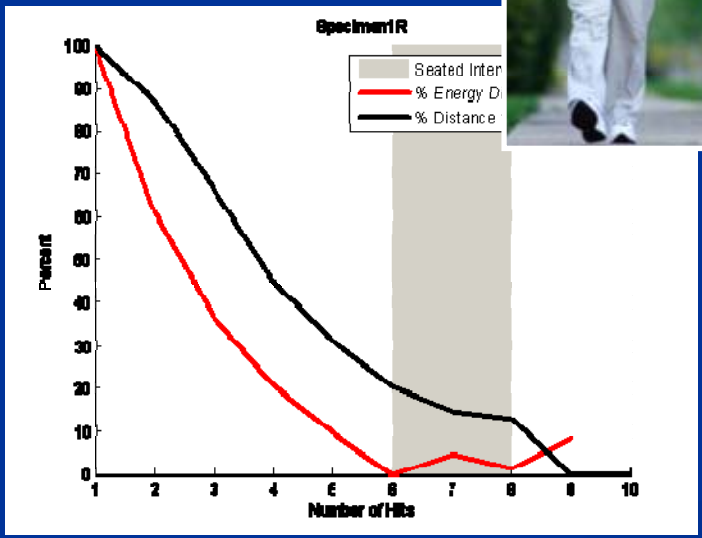
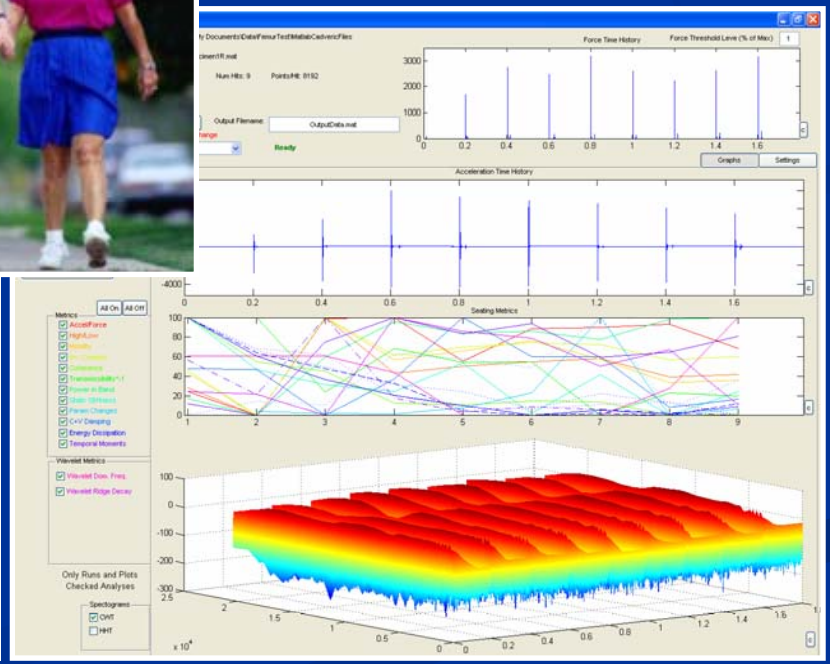
Are there any questions?









Los Alamos