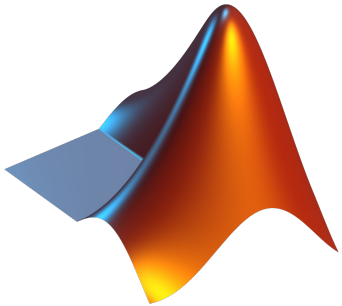
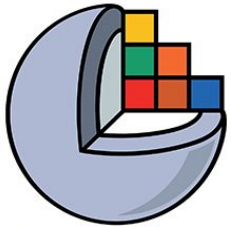
Morphologies Measurement Protocol Notes

O'Connell Biomechanics Lab
Yousuf + Sylvi
Winter 2025





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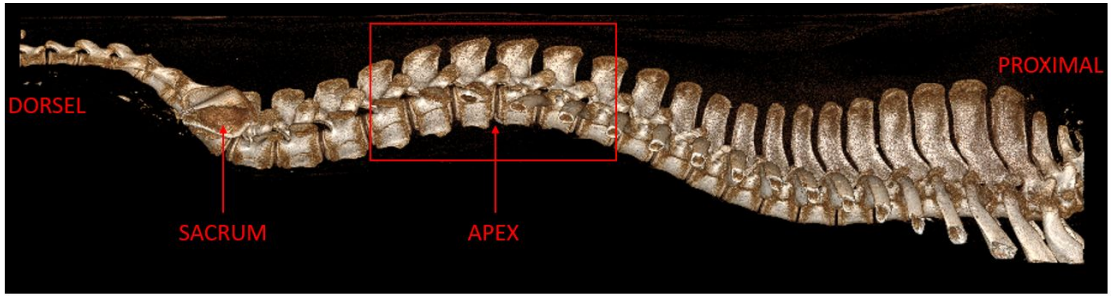
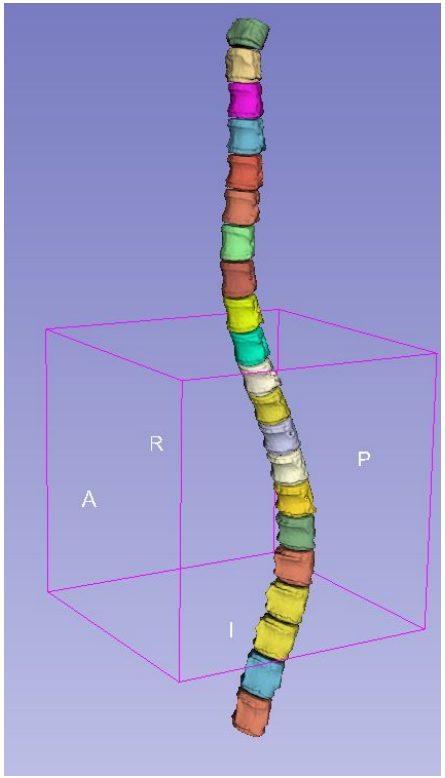
Measurement Protocol Overview

Raw imaging data

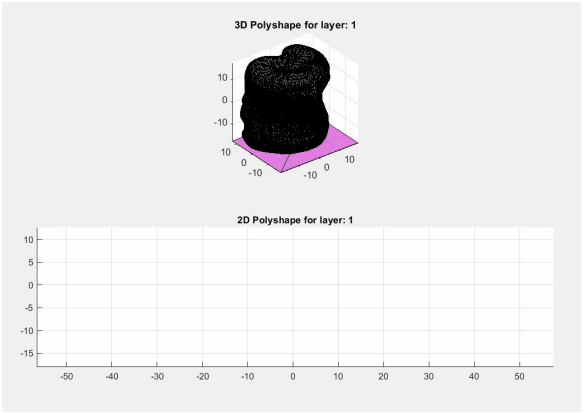


<u>Assumes</u>: 15 thoracic + 6 lumbar levels

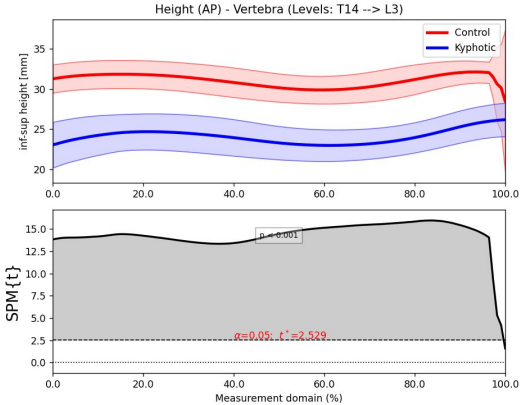
Full spine segmentation[1]



(Automated) MATLAB measurements



Statistical Analysis



[1] Manual segmentation protocols here

Programing Overview

Morphologies **Github here**[1], general pipeline:

Loading all vertebrae geometry files → disc construction → geometry alignment → slicer, height, and volume measurements → analysis

Morphologies

Author: Yousuf Abubakr (yousufabubakr123@berkeley.edu)

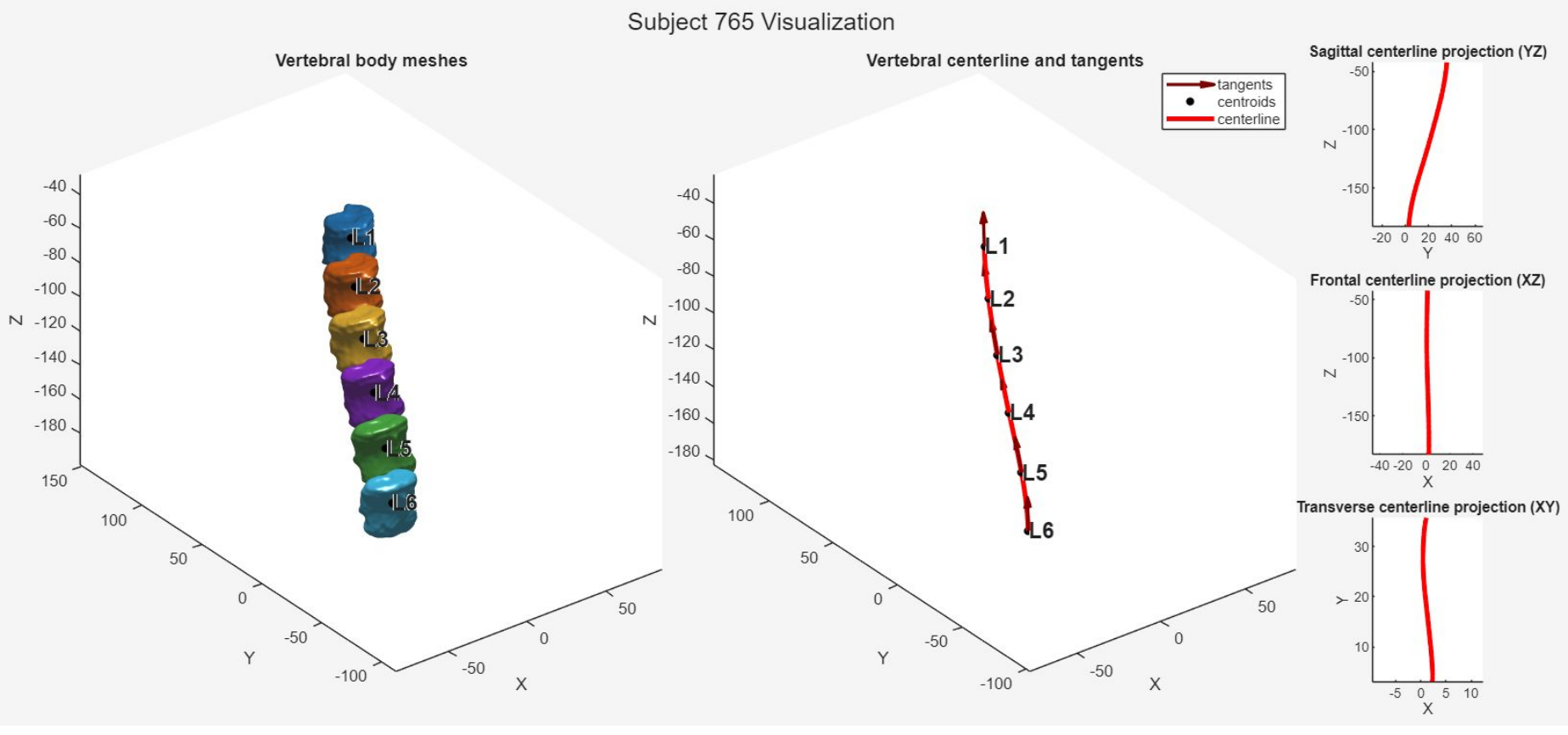
Lab: Grace O'Connell Biomechnics Lab (https://oconnell.berkeley.edu/)

Description: A toolkit for processing, analyzing, and visualizing morphological data from medical imaging datasets (e.g., STL meshes, MATLAB measurement files).

[1] *Github stats (as of 1/10/2026):* **total # lines of code = 5,405**, **total # of words = 23,804**, **total # of characters = 209,197**

MATLAB Program Overview

1.) Loading geometry: *loads vertebral body geometries & computes centerline path and tangents*



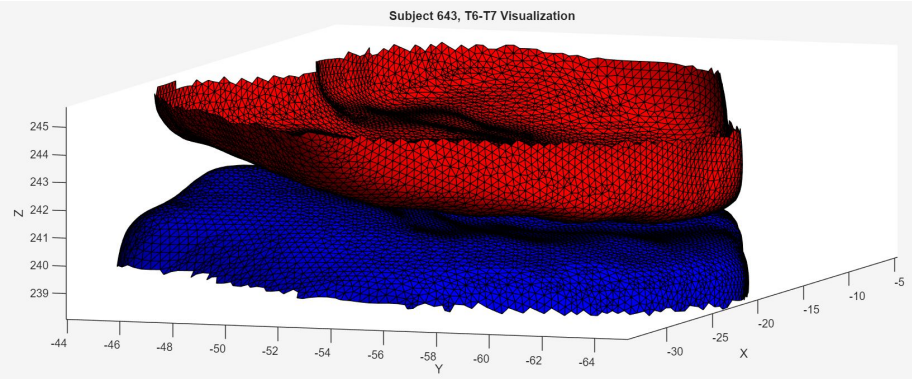
MATLAB Program Overview

2.) Disc construction: *interpolating across vertebral endplates to define and export disc volumes*

Step 1:

Extract triangulation representations of superior + inferior surfaces

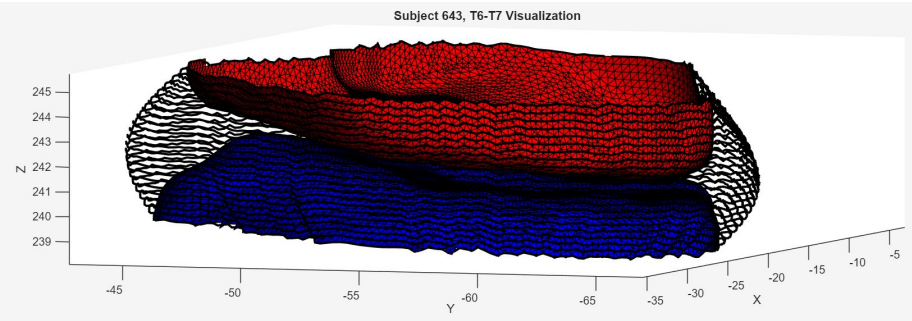
- **Red = superior surface of disc**
- **Blue = inferior surface of disc**



Step 2:

Obtain inferior → superior loft curves (pictured in black)

- **Associated parameters:**
  - **# of rings**
  - **bulge amplitude (default: 2 mm)**

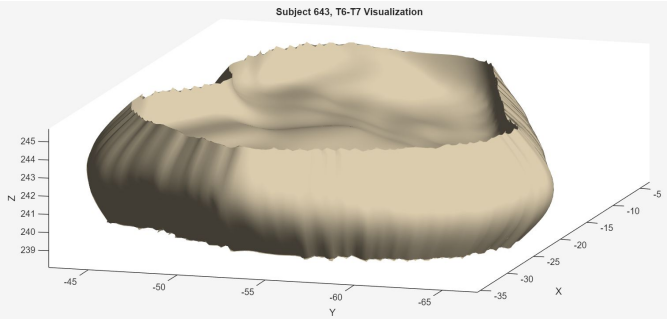


MATLAB Program Overview

2.) Disc construction: *interpolating across vertebral endplates to define and export disc volumes*

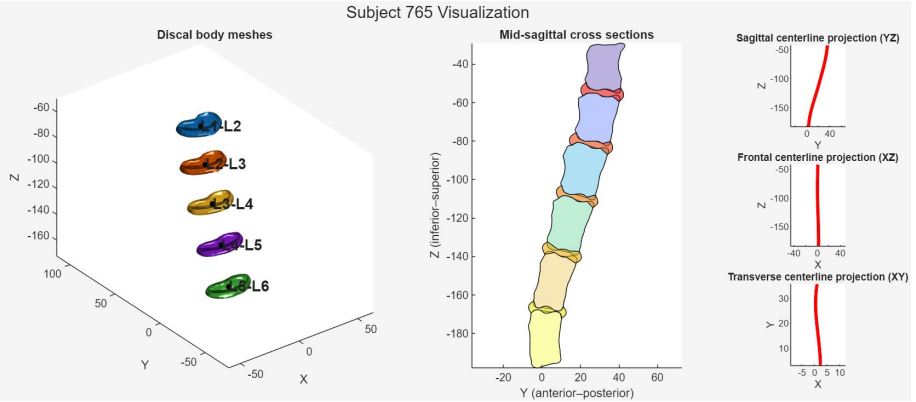
Step 3:

Stitch endplate surfaces to one another to create a full disc triangulation and export to .stl file



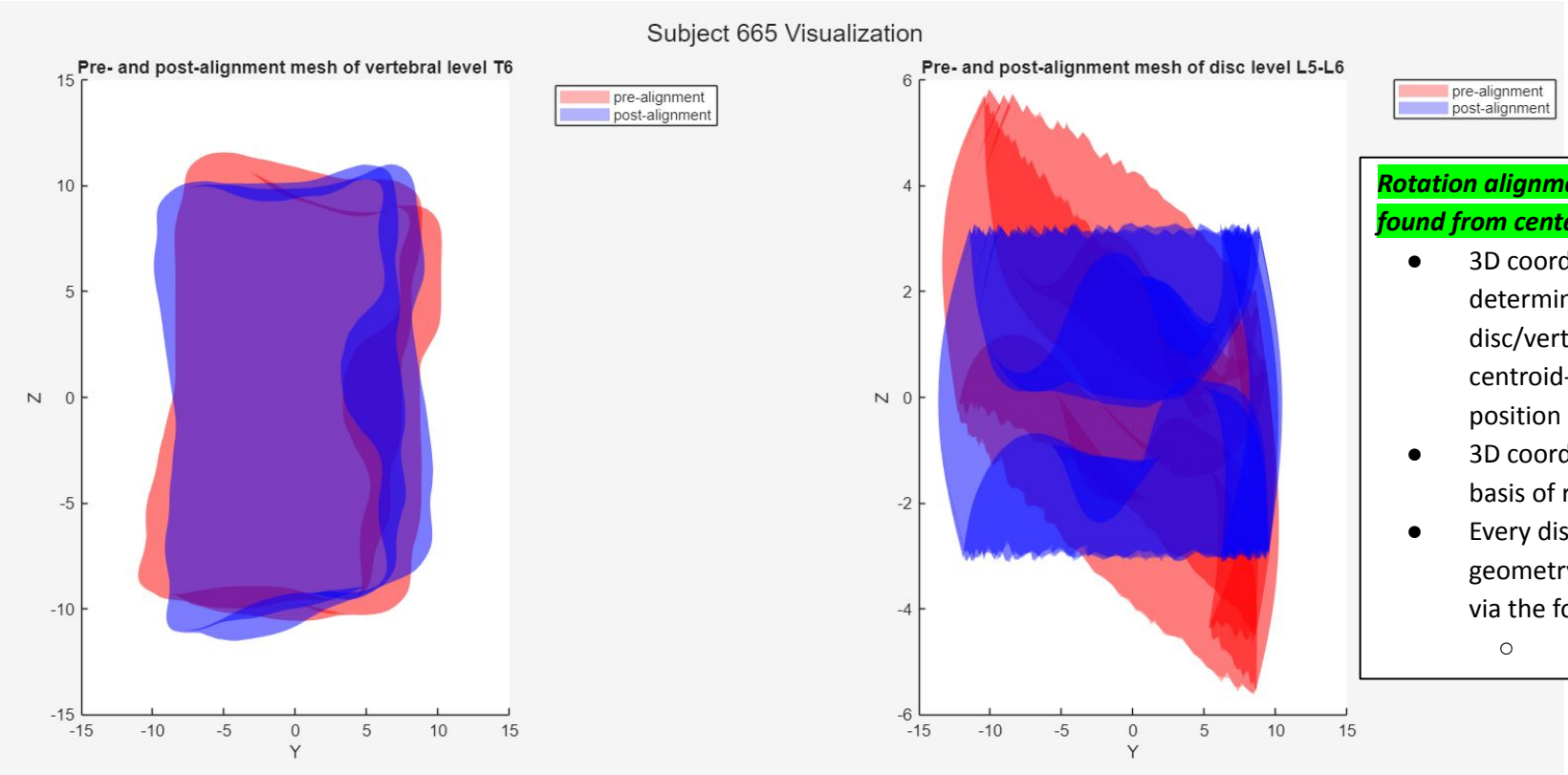
NOTES:

- **Water-tightness is NOT guaranteed**
- **Any further geometry processing and measurement processes are generalized for both vertebra and disc structures**



MATLAB Program Overview

3.) Geometry alignment: *centerline-based geometry alignment to standard coordinate reference frame*

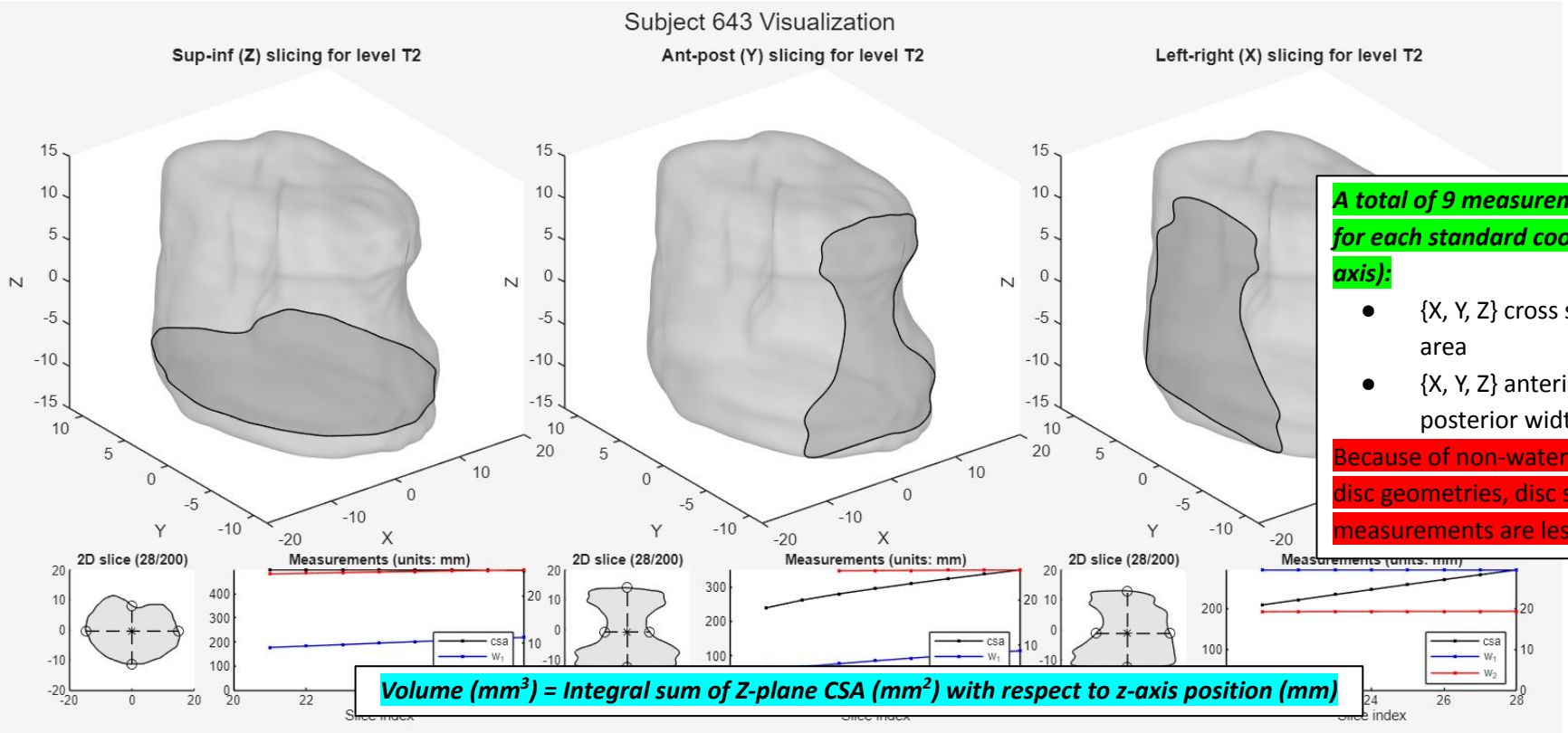


Rotation alignment matrix is found from centerline geometry:

- 3D coordinate frame is determined at every disc/vertebra centroid-centerline position
- 3D coordinate frame → basis of rotation matrix
- Every disc/vertebrae geometry is transformed via the formula:
  - $V_1 = (V_0 + t) * R$

MATLAB Program Overview

4.) Slicer/volume measurements: *slicing geometries and measuring CSAs, widths, and volumes*



A total of 9 measurements (3 for each standard coordinate axis):

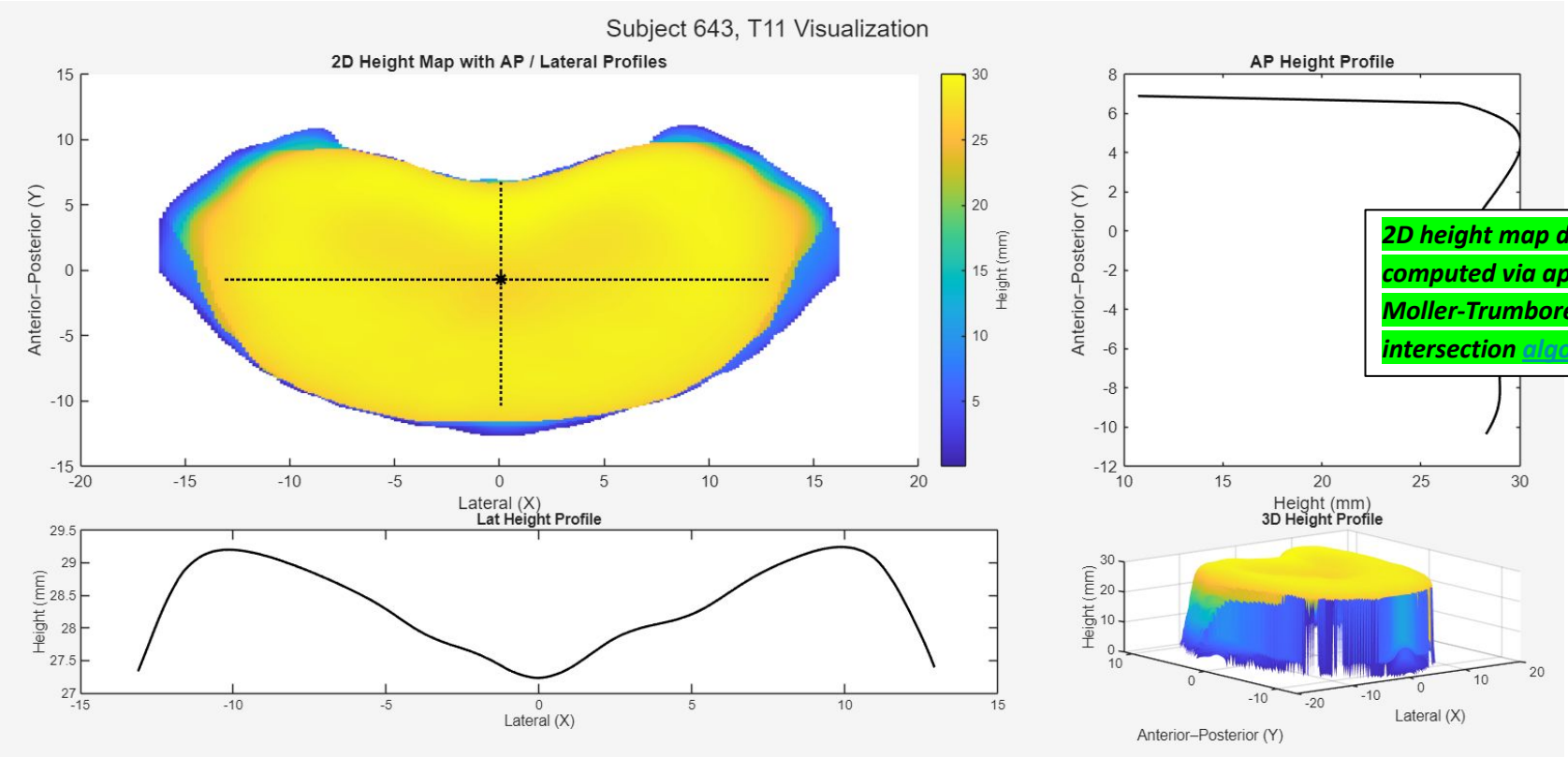
- {X, Y, Z} cross sectional area
- {X, Y, Z} anterior and posterior widths

Because of non-watertight disc geometries, disc slicer measurements are less stable

Volume (mm^3) = Integral sum of Z-plane CSA (mm^2) with respect to z-axis position (mm)

MATLAB Program Overview

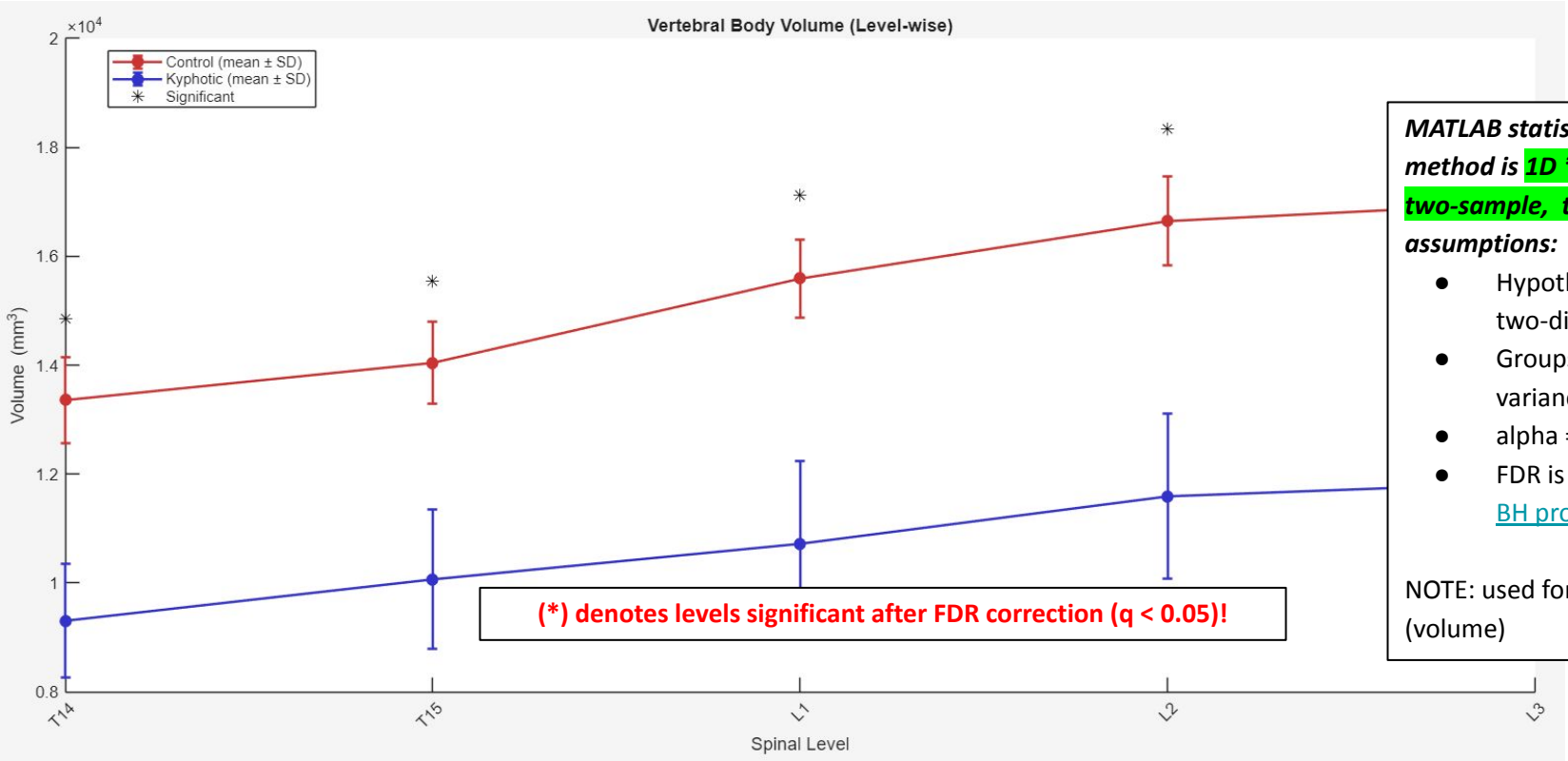
4.) Height measurements: *measuring 2D height distribution and extracting AP and LAT heights*



2D height map directly computed via application of Moller-Trumbore ray intersection algorithm

MATLAB Program Overview

5.) Analysis: *computing and visualizing summary statistics across control and kyphotic experimental groups*



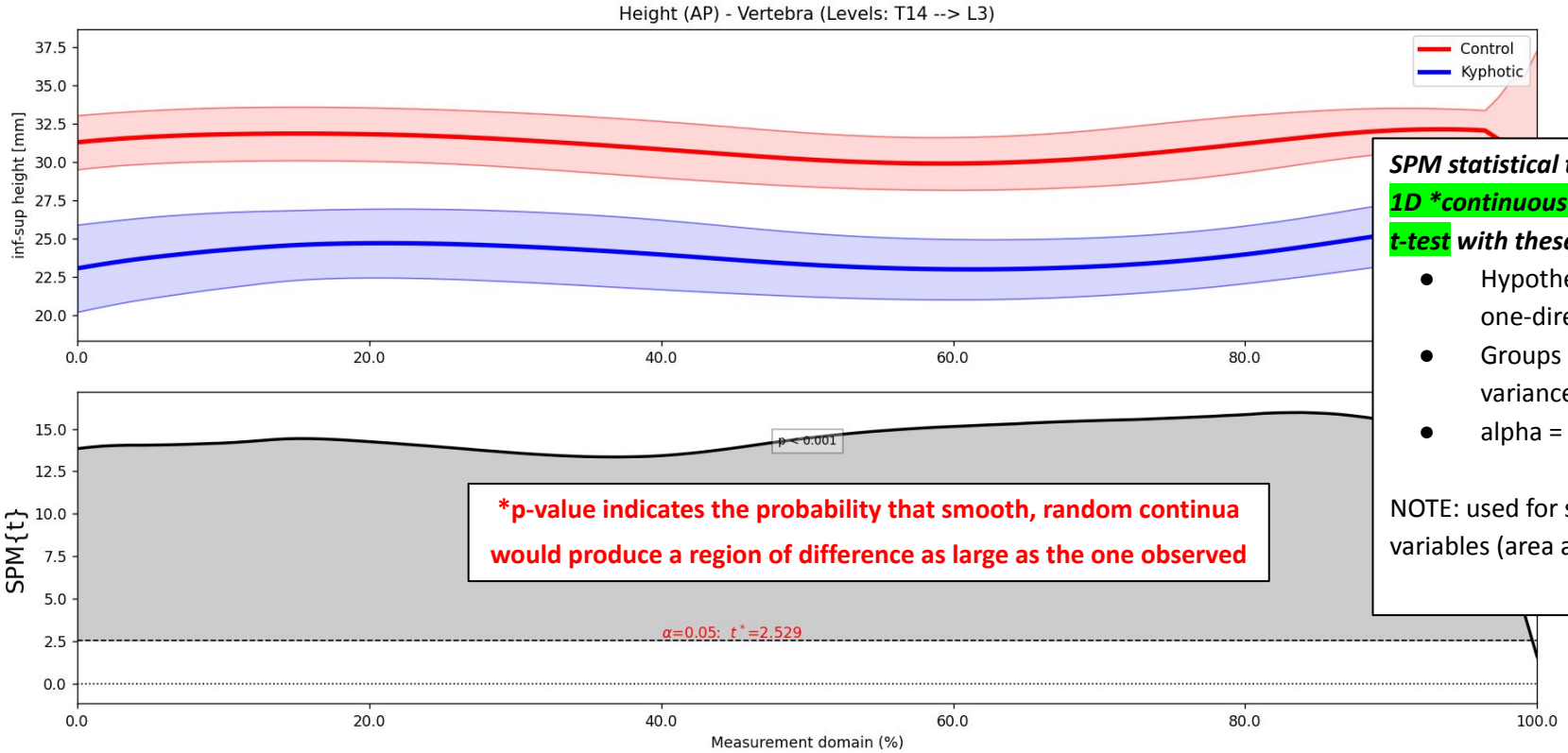
MATLAB statistical test method is 1D *discrete* two-sample, t-test with these assumptions:

- Hypothesis is two-directional
- Groups have unequal variances
- alpha = 0.05
- FDR is controlled with BH procedure

NOTE: used for body variables (volume)

MATLAB Program Overview

5.) Analysis: *computing and visualizing summary statistics across control and kyphotic experimental groups*



p-value indicates the probability that smooth, random continua would produce a region of difference as large as the one observed

SPM statistical test method is 1D *continuous* two-sample, t-test with these assumptions:

- Hypothesis is one-directional
- Groups have unequal variances
- alpha = 0.05

NOTE: used for spatial variables (area and height)

Morphologies Technical Overview

***Morphologies* source code here, head files:**

`main.m` ← *Execution hub of all programs and subprograms*

`makeConfig.m` ← *Configuration file for pipeline (# of slices, height resolution, etc)*

Primary routine files *(executed in main.m)*

`setSubjectInformation.m`	initializes pipeline data structures
`loadGeometryMetadata.m`	loads geometry into data structure
`constructDiscs.m`	disc construction
`alignGometries.m`	aligns vertebrae and disc geometries
`makeSlicerMeasurements.m`	makes slicer measurements
`makeHeightMeasurements.m`	makes height measurements
`makeVolumeMeasurements.m`	makes volume measurements
`exportData.m`	writes data to file
`summarizeData.m`	visualizes and exports data

Morphologies Technical Overview

***Morphologies* source code here, head files:**

`main.m` ◄---------- *Execution hub of all programs and subprograms*

`makeConfig.m` ◄---------- *Configuration file for pipeline (# of slices, height resolution, etc)*

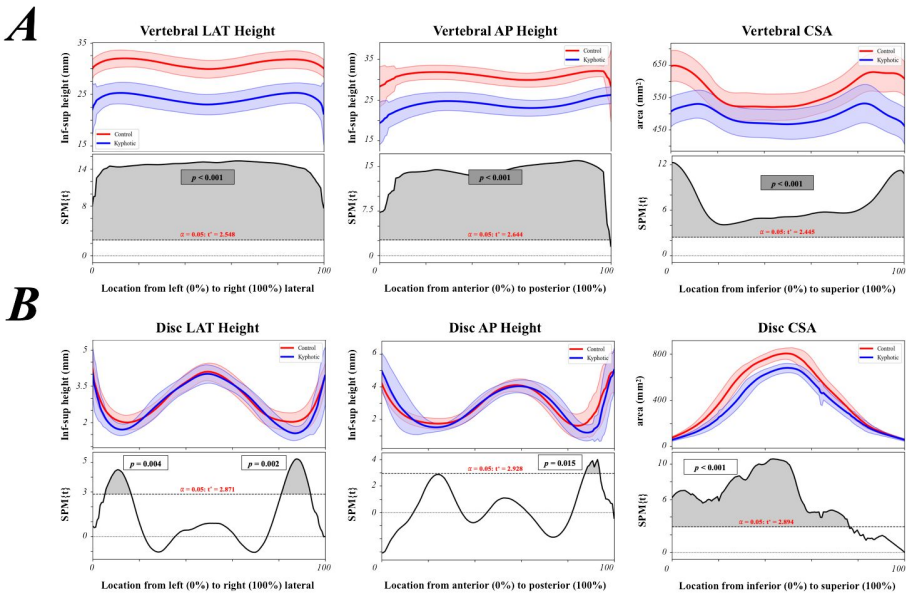
How to use source code:

1. ***Set configuration settings in makeConfig.m***
   a. ***IMPORTANT PARAMETERS:***
      i. ***numSlices, heightResolution, slicerIgnorance, heightIgnorance***
      ii. ***If pipeline detects any of these config parameters are different from the saved config settings in 'data/raw', the measurements will be rewritten!***
   b. ***Options for visualization (note: some plots are graphics intensive)***
   c. ***Disc construction parameters***
   d. ***Range of levels to be exported for SPM analysis***
2. ***Run main.m for MATLAB results and run 'analysis-utils/main.py' for SPM results***

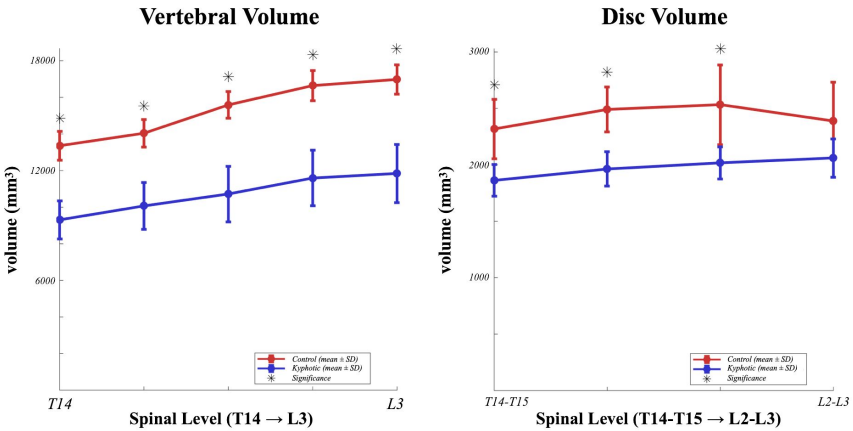
Summary of Results from *Morphologies*

Settings: *# of slices = 200, height resolution = 200, slicer & height ignorance = 0.1,* ***levels exported = T14 → L3***

Spatially-varying measurements



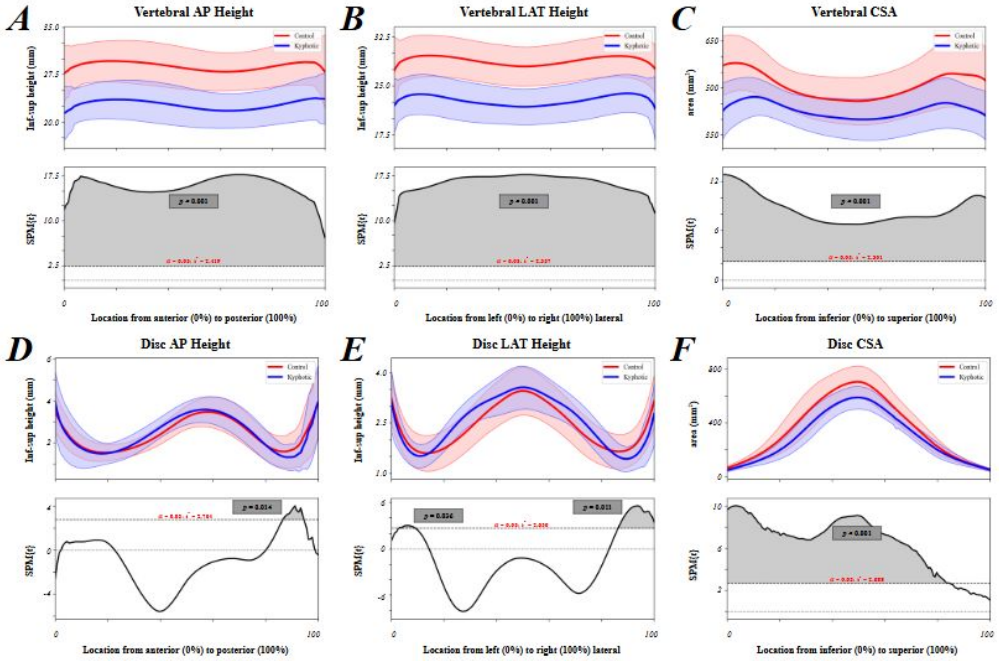
Spine-level scalar measurements



Summary of Results from *Morphologies*

Settings: *# of slices = 200, height resolution = 200, slicer & height ignorance = 0.1,* ***levels exported = T1 → L6***

Spatially-varying measurements



Spine-level scalar measurements