Novel Application of A Corresponding Point Algorithm for Unbiased Smoothing

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INTRODUCTION

- Computationally comparing anatomical geometries is important in biomechanics
  - Shape modeling and Image analysis
  - Provides insight into anatomical changes related to disease and dysfunction
- Error can be introduced via many factors
  - Slice thickness, Missing landmarks, Segmentation & Smoothing approaches, etc.
- Automatic smoothing of 3D geometries has been previously proposed[1-2]
  - Require high level of detail
  - Unable to predict missing landmarks
  - Requires a large amount of computational power

OBJECTIVES

- Develop an unbiased template based smoothing protocol using a large deformation diffeomorphic metric mapping corresponding point algorithm (Deformetrica[3])
  - Morph same template mesh into multiple patient-specific geometries
  - Must be able to smooth 3D geometries as well as or better than manual smoothing
  - Account for missing or incomplete image data
  - Maintain anatomical features with high curvature
- Be able to account for aliasing in MR or CT data resulting from different slice thicknesses

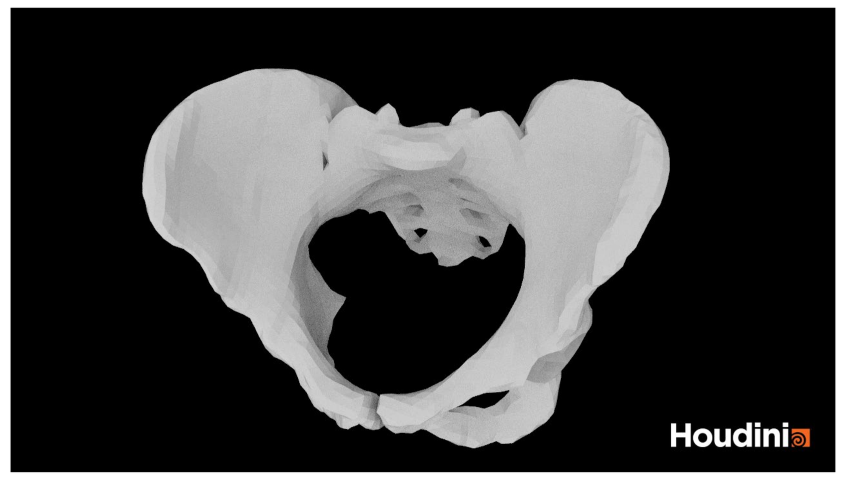
SMOOTHING PROTOCOL

1. Create template geometry – Smooth, high quality mesh with desired number of vertices
2. Acquire subject-specific geometries – Segmented from clinical images with aliasing
3. Iterative Closest Point (ICP) Analysis to translate and rotate subject geometries to the template
4. Run Deformetrica – Fits the template shape to all subject shapes simultaneously
5. Evaluate quality of fit – Iterate step 4 until Deformetrica settings yield representative smoothed shapes

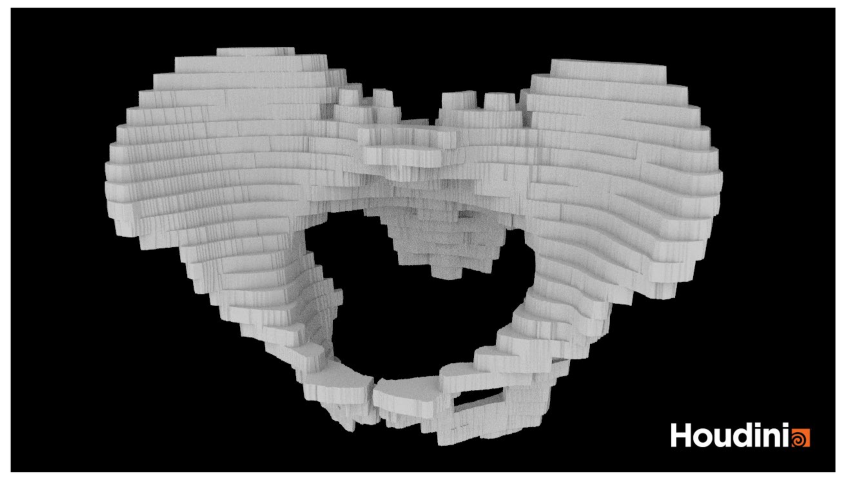
ASSESSMENT OF QUALITY OF FIT

- Template shape generation
  - 24 high-resolution CT pelvic scans
  - All fitted with the same mesh
  - Average pelvis was generated
- Ground truth shape generation
  - Created from one high-definition CT pelvic scan
- Aliased shape generation
  - 6 different amounts of data removed to simulate aliasing
  - 50%, 33%, 25%, 20%, 17%, and 14% of the original data kept

- Assessment of fits to ground truth
  - Smoothed all 6 "aliased" pelvises and the original pelvis using Deformetrica
  - Compared the point-to-point and surface-to-surface distances of each pelvis to the ground truth shape
- Success criteria:
  - Average point-to-point distance < 1.5 mm
  - At least 90% of distances < 2.5 mm

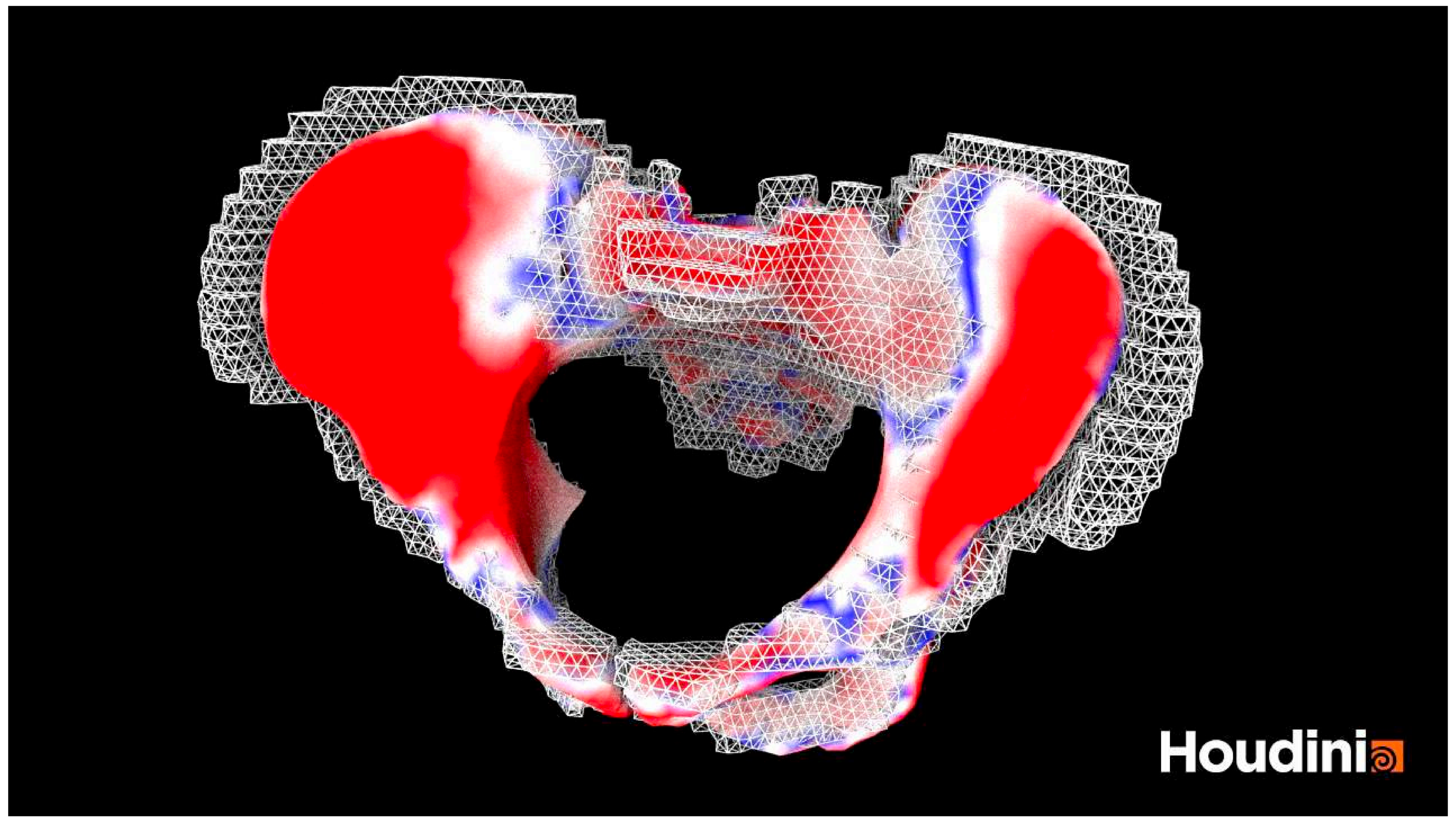


Template



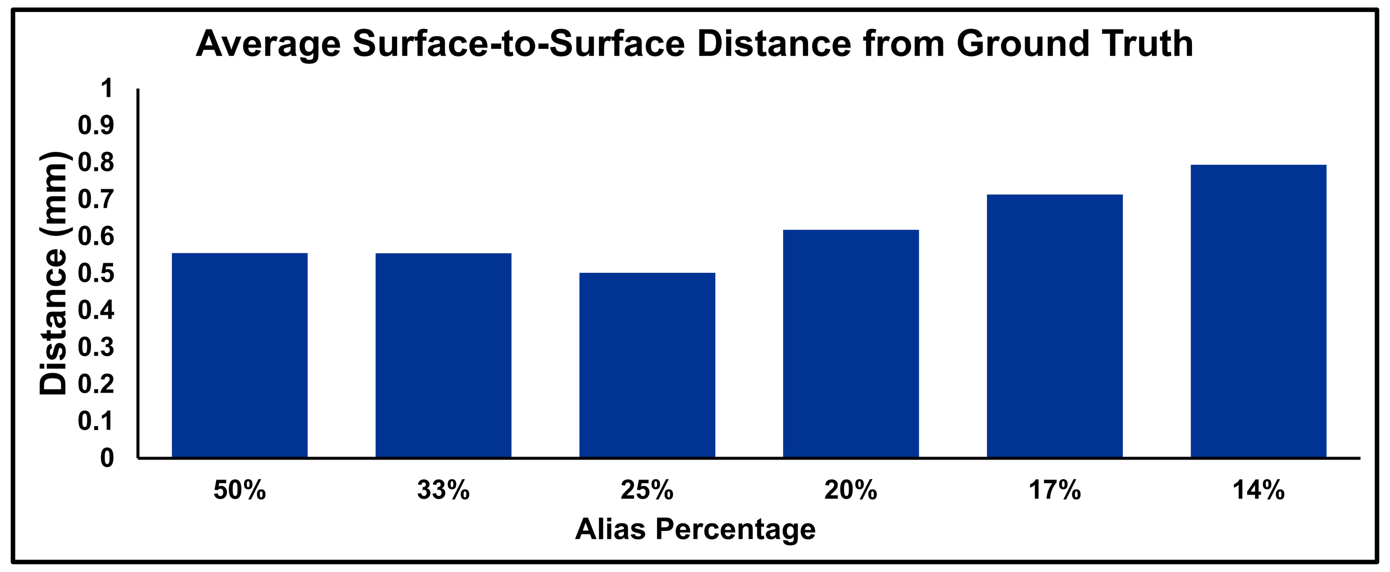
14% Aliased Pelvis
(the most data removed)

RESULTS: SURFACE-TO-SURFACE FIT



Animation comparing the template fit to the ground truth. Wireframe represents the 14% aliased pelvis. Colormap represents relative distance to the ground truth. Red is > 2 mm, white is < 1 mm, and blue is ≈ 0 mm.

RESULTS



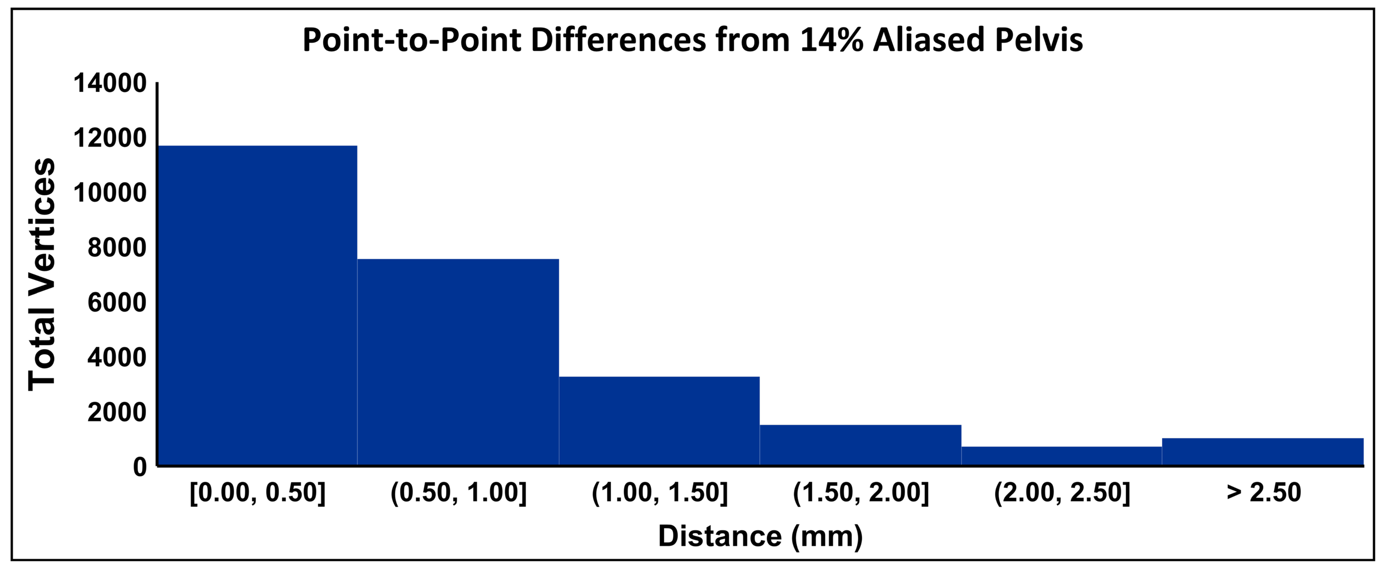


Table of Relevant Comparison Values for all Shapes

Degree of Aliasing	Average Distance (mm)	Max Distance (mm)	Percent Below 2.5 (% of total vertices)
50%	0.55	6.24	98.0
33%	0.55	6.47	98.4
25%	0.50	5.86	98.4
20%	0.61	6.90	97.7
17%	0.71	7.04	97.4
14%	0.79	7.64	96.0

DISCUSSION

- Approach is robust for large degree of aliasing
  - Data can be improved further using more detailed template
  - Allows for use of previously unusable image sets in shape modeling and finite element studies
- Pelvis chosen for geometric complexity
  - Future work will look at other bones and soft tissues
- Still large computational time
  - However, frees individual from time doing manual smoothing

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