IN VIVO ABDOMINAL AORTIC 3D DEFORMATIONS DUE TO MUSCULOSKELETAL MOTION

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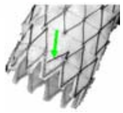
INTRODUCTION

- Abdominal aortic aneurysm (AAA)
  - Widening of abdominal aorta at the weakened aortic wall
  - 200,000 people/year diagnosed in the US
  - Rupture of an aortic aneurysm is a catastrophe
- *In vivo*, abdominal aortic aneurysm stent grafts are reported to fracture at a rate of 8% in 19 months
- Mean and cyclic strains induced by cardiac pulsatility or respiration have been hypothesized to cause these fractures
- The effect of musculoskeletal motion on the abdominal aorta has not been studied.
- **Our goal was to quantify *in vivo* deformation of the abdmonial aorta due to musculoskeletal motion**



METHODS

Experimental Setup

Imaging Protocol

- Approved by the Stanford University Panel on Human Subjects in Medical Research
- Written consent was obtained from each volunteer (1 male and 9 female healthy subjects: 36±9 years old)

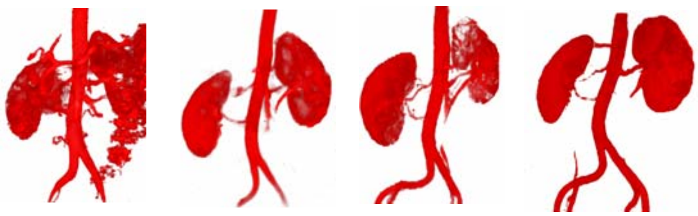
Body positions

- Supine
- Supine twist: Supine with maximal hip rotation to the left
- Fetal: Maximal hip flexion and spine bending, left decubitus
- Fetal twist: Fetal with maximal hip rotation to the left

Fetal position in Magnet (1.5T GE signa EXCITE)

Imaging Method

Contrast Enhanced Magnetic Resonance Angiography



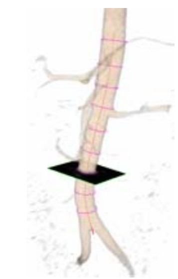
Supine   Supine-Twist   Fetal   Fetal-Twist

- 1.5T GE Signa EXCITE
- IV catheter line in antecubital vein of right arm
- 20 cc gadolinium at 3 mL/sec with 20 cc saline flush
- Field of view : 30 by 30 cm
- Acquisition matrix : 512 by 512
- Approximately 30 seconds with a breath hold

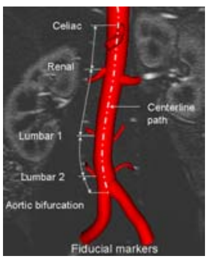
Image Processing

Centerline path generation

Volume rendered 3D Magnetic Resonance Angiography Image



Centerline path created by averaging 2D level set segmentations of the lumen boundary



Fiducial markers for analysis

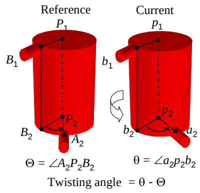
Quantification Method

Axial Strain

- Change in the arclength of a segment between branches over its original length
  - $\varepsilon = \Delta L / L$

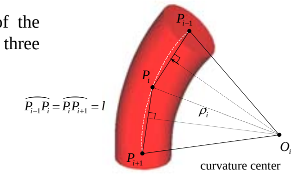
Axial Twisting

- Calculate changes in the angle of separation using branch bifurcation angle
- A parallel path to the centerline was generated to find the angle of separation in a tortuous vessel
  - Divide a vessel into small segments such that each segment can be assumed to be planar



Curvature

- Curvature was defined as the inverse of the radius of circumscribed circle about three consecutive points
  - Radius of curvature at $P_i = \rho_i$
  - Curvature at $P_i = 1/\rho_i$



RESULTS

Axial Strain

	Supine→ Supine-Twist	Supine→ Fetal	Supine→ Fetal-Twist	Supine-Twist→ Fetal	Supine-Twist→ Fetal-Twist	Fetal→ Fetal-Twist
Seg1	-0.9±3.2%	-3.1±6.5%	-3.2±5.8%	-2.1±7.1%	-2.2±5.4%	0.1±4.9%
Seg2	0.7±3.1%	-0.4±2.7%	-1.7±5.5%	-1.0±2.4%	-2.4±4.2%	-1.4±3.8%
Seg3	**-3.4±1.8%***	-3.9±9.5%	-3.1±7.5%	-0.6±7.2%	0.2±5.9%	1.1±6.2%
Seg4	2.0±8.1%	-6.9±10.4%	-6.9±8.8%	**-8.7±6.4%***	**-8.5±6.9%***	0.9±8.5%

Axial Twist (°/cm)

Seg1	**1.1±0.9***	**2.9±2.2***	**3.3±3.2***	**3.5±1.7***	**3.0±2.3***	**2.7±2.9***
Seg2	**2.0±1.1***	**1.7±0.8***	**1.7±1.4***	**1.3±1.1***	**1.5±1.1***	**1.4±0.9***
Seg3	2.5±2.7	**2.9±2.1***	**4.5±3.4***	**3.2±2.3***	**4.0±3.2***	**2.9±2.6***
Seg4	**1.9±1.7***	**2.8±1.7***	**6.0±5.5***	3.2±3.5	**7.0±6.3***	**4.1±3.8***

Curvature Change (cm^{-1})

Seg1	-0.003±0.01	**0.02±0.02***	**0.02±0.02***	**0.02±0.01***	**0.02±0.02***	0.004±0.02
Seg2	**0.01±0.01***	0.02±0.03	0.01±0.03	0.004±0.02	0.003±0.02	-0.001±0.02
Seg3	0.005±0.02	0.02±0.04	0.024±0.042	0.014±0.04	0.02±0.03	0.005±0.04
Seg4	-0.003±0.02	-0.001±0.04	-0.003±0.04	0.002±0.04	0.001±0.03	-0.002±0.04

* indicates statistical significance (paired, two-tailed t-Test)

DISCUSSION

Abdominal aortic deformation due to musculoskeletal motion

- Hip flexion and spine bending caused significant abdominal aortic deformation
  - Axial shortening (-9%) occurred at the distal part of the abdominal aorta
    - The section from the celiac to the aortic bifurcation experienced approximately -2.2% shortening on average
  - Axial twisting was statistically significant in all body positioning
  - Curvature of the segment between celiac and renal artery was increased especially when fetal positioning was involved
    - Average radius of curvature changed from 48±30 cm to 28±6 cm (supine → fetal)
    - Twisting motion was less influential in curvature change

Implications for designing benchtop test

- Cyclic deformation of the abdominal aorta may cause significant fatigue in stent grafts
- These findings may aid in developing pre-clinical tests for abdominal aortic stent grafts

Acknowledgements

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