Molding of Patient-Specific Abdominal Aortic Aneurysm Phantoms for the Study of Ultrasound-measured Regional Wall Strain

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Introduction:

Abdominal aortic aneurysms (AAA) are currently the 13th leading cause of death in the United States with a mortality rate of over 15,000 people per year.

•More accurate criteria are needed to determine timing for repair

•Current criteria is based on maximum diameter, but many AAA ruptures occur at sizes smaller than those recommended for intervention.

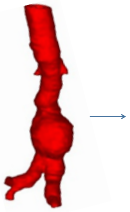
•**Objective:** Create patient geometry-specific, polyvinyl alcohol (PVA) AAA models to evaluate ultrasound strain measurements as predictive criteria for AAA rupture.

Methods:

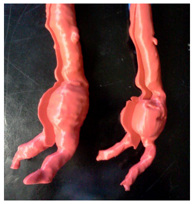
1. Anatomic data from patient CT scans were extracted using Mimics Innovation Suite (Materialise NV; Leuven, Belgium)
2. Digital 3D model was created of inner and outer AAA surfaces
3. Models were digitally split, printed on a Dimension Elite 3D printer, and used to make silicon negative molds
4. Inner lumen was filled with wax and suspended in the silicon outer lumen mold
5. Hollow aorta was poured into the silicon outer mold around the wax using a mixture of PVA (10% by weight), scatter and water
6. Molds were put through two, freeze-thaw cycles to create a preliminary model
7. The wax-filled model was then dipped in PVA to patch any holes, with five additional freeze-thaw cycles to plateau PVA acoustic speed, attenuation and elastic modulus (Dineley, 2006)
8. Wax was melted out of PVA
9. Final model is patient-specific abdominal aorta including the AAA with iliac outflow vessels
10. Model was connected to a hemodynamic simulator with ultrasound used to capture strain characteristics as the aneurysm ruptured

Methods:

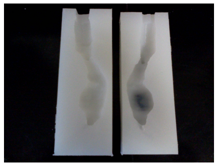
Patient CT Scan (Step 1)



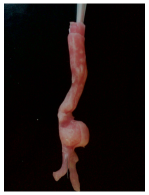
Digital 3D model (Step 2)



ABS plastic printed inner and outer lumens (Step 3)



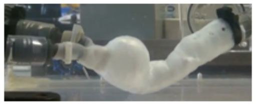
Silicon negative mold (Step 3)



Wax inner lumen (Steps 4-5)

Aortas dipped in PVA (Steps 6-7)

Hollow PVA aorta (Steps 8-9)

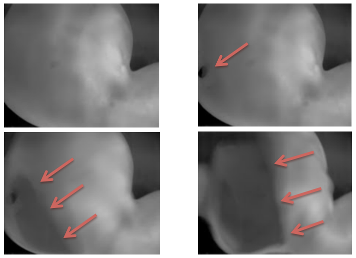


Hydrogel model attached to hemodynamic simulator (Step 10)

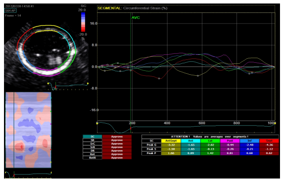
Results:

Location	Measurement from Ultrasound	Measurement from CT Scan
Neck at renals – inner lumen	2.4 cm	2.20 cm
Neck at renals – wall thickness	0.3 cm	0.34 cm
Renal to Renal	2.8 cm	2.85 cm
Mid neck – inner lumen	2.1 cm	2.2 cm
Entry to Aneurysm – outer lumen	4.5 cm	4.3 cm
Aneurysm sac – proximal – wall thickness	0.3 cm 0.6 cm	0.24 cm 0.64 cm
Aneurysm sac – proximal – inner lumen	5.2 cm	5.1 cm
Aneurysm sac – area of largest thrombis – wall thickness	2.3 cm	2.2 cm
Aneurysm sac – area of largest thrombis – outer lumen	4.5 cm	4.6 cm
Aneurysm sac – maximum diameter – outer lumen	5.6 cm	5.6 cm

Table comparing diameter and wall thickness measurements from ultrasound to CT scan



High speed videography (500 frames per second) during rupture showing the formation of a hole in the location of greatest weakness leading to a tear



Strain data from the aneurysm showing a strain differential of 10% at the location of rupture

Strain data from the aorta at the renal arteries showing a more homogenous distribution of strain

Results:

- The patient specific model resulted in realistic patient geometry with optimal ultrasound acoustic characteristics
- Diameter measurements of phantom under ultrasound correlated to CT-derived measurements
- Regional wall strain was easily measured using ultrasound strain analysis
- The greatest strain differential between two adjacent segments was found to be 10% in the location of rupture relative to an average strain of 2.4 ± 2.2% between any other adjacent segments
- Rupture started out as a small hole in the location of greatest weakness and led to a tear along the posterior lateral side of the aneurysm sac

Conclusions:

Patient geometry-specific, PVA phantoms of AAA can be reproducibly created to analyze regional wall strain with ultrasound. Further study of strain characteristics preceding AAA rupture are needed to establish ultrasound-based strain measurements as a clinical screening tool for AAA rupture risk.

Future Plans:

- Determine specific hemodynamic parameters and anatomic locations for rupture
- Use ultrasound to measure AAA wall strain and characterize changes in regional strain preceding rupture
- Develop a characteristic “strain fingerprint” to predict vulnerable, high risk AAA with ultrasound

References:

J. Dineley et al. Ultrasound Med Biol, 2006, Vol. 32, pp. 1349-1357

Deirdre M. King et al. Ultrasound Med Biol, 2011, Vol. 37, pp. 813-826