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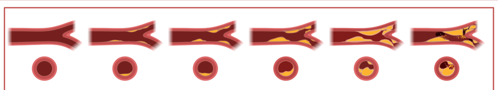
ABSTRACT

Peripheral Artery Disease (PAD) is the chronic obstruction of blood flow to the extremities caused by plaque buildup. Poor circulation results in exertional pain, numbness, and weakness, and in severe cases, can manifest critical conditions, including gangrene and limb loss. PAD affects approximately 8.5 million Americans and costs the United States $21 billion annually in direct medical expenses. High expenditures are attributed to operation and intervention failures resulting in frequent need for revascularization. Treatment of PAD typically involves lifestyle/diet adjustments, bypass surgery, or angioplasty/stenting. Unfortunately, repeated limb deformation during locomotion often results in adverse repair device-artery interactions, which hinder the long-term efficacy of endovascular therapies. Patient and lesion-specific device selection guided by computational modeling can help improve clinical outcomes, but these models rely heavily on accurately recorded three-dimensional arterial geometry and plaque composition. Intravascular ultrasound (IVUS) is a minimally invasive method of endovascular imaging that allows evaluation of the geometry and composition of the arterial wall, but its two-dimensional nature is often insufficient to capture complex three-dimensional plaques. We have developed a method of obtaining three-dimensional arterial geometry from two-dimensional IVUS images to build Computer-Aided Design models of calcified human femoropopliteal arteries. Our imaging method will allow for the characterization of calcium, necrotic core, fibrofatty, and fibrous tissue using IVUS. Correlation of IVUS images with conventional histology, micro-CT imaging, and clinical CTA data will help inform computational models.

BACKGROUND



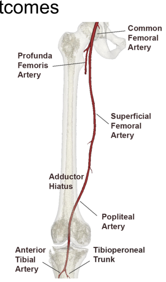
Progression of Arterial Plaque Formation

Peripheral Artery Disease

- Gradual narrowing of arteries in the extremities
- Caused by plaque deposits
- Affects 22 million people worldwide
- If untreated, PAD can lead to…
  - Gangrene
  - Limb Loss
  - Walking Disability
- Treated with…
  - Lifestyle/diet adjustments
  - Angioplasty/stenting
  - Bypass surgery
- Occurs in areas subject to deformation during limb flexion
- Therapies have poor long-term outcomes

Femoropopliteal Artery

- Starts as the common femoral artery in the thigh
- Flows into the tibial arteries in the calf
- Supplies blood to the legs
- Artery deforms during locomotion at the Adductor Hiatus and below the knee
- Often requires revascularization

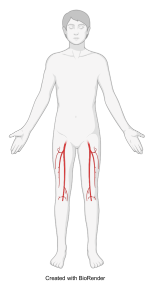


Intravascular Ultrasound

- Uses an ultrasound-equipped catheter to image arteries
- Captures 2D cross-sectional images of vessel walls
- Used to visualize arterial features during surgery
- Can capture 'virtual histology'
  - Characterizes plaques based on pixel density

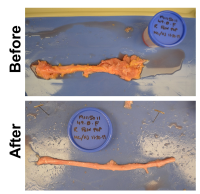
METHODS

Aim: Reconstruct calcified femoropopliteal arteries from IVUS images



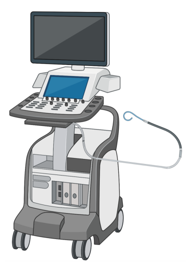
Artery Collection

Matching left and right femoropopliteal arteries and surrounding tissues were collected from donors by Live On Nebraska. Deidentified donor demographic information was recorded with samples. Arteries were stored at 4 °C before tissue processing.



Tissue Processing

Artery samples were processed within one week of collection. Surrounding tissues were dissected and discarded. Only diseased and potentially calcified arteries (identified by palpation) were included in this study. Samples were stored separately at -20 °C until imaging.



IVUS Imaging

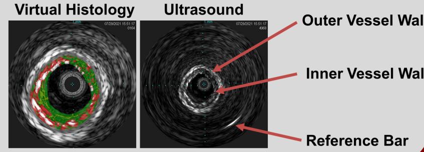
Dissected femoropopliteal arteries were submerged in saline and flushed with a roller pump before imaging. A Volcano PV.014P Eagle Eye catheter was pulled through the vessel by an MD2 translation stage programmed to withdraw at 1 mm/s while IVUS captured virtual histology.

Data Processing & 3D Reconstruction

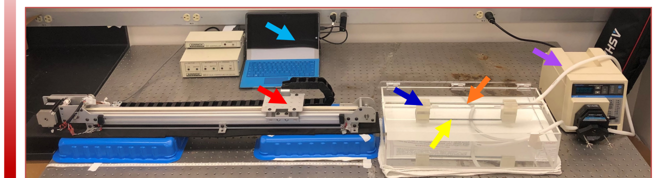
IVUS scans were uploaded to Materialize Mimics for reconstruction. Their 3D shapes were built from sequential ultrasound images spaced 1mm apart. Calcium deposits were segmented and layered over the reconstructed artery. A 3D model was printed using FormLabs SLA printer.

Virtual Histology Legend

Green – Fibrous Plaque
Light Green – Fibrofatty Plaque
Red – Necrotic Core
Bright White – Dense Calcium

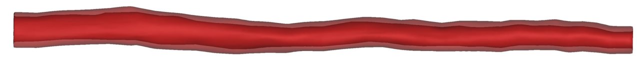


RESULTS



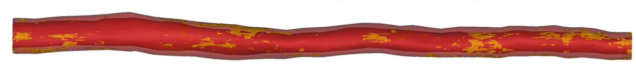
Artery Mount: A PV.014P Eagle Eye catheter was fixed to an MD2 translation stage (red arrow), controlled by a wired computer (cyan arrow) connection. Arteries were mounted to pipe fittings affixed to 3D printed blocks (navy arrow) submerged in room temperature saline. Blocks were supported by a metal rod (orange arrow)—The distance between blocks was adjusted by a threaded bar (yellow arrow). Arteries were flushed by a roller pump (purple arrow) before imaging.

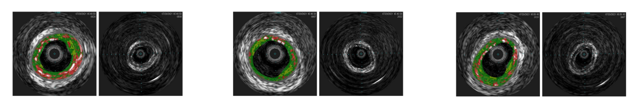
3D Reconstruction of the Femoropopliteal Artery



Calcium Deposits

Calcium Deposits Overlayed on the Artery





Proximal **Medial** **Distal**

3D Femoropopliteal Artery Reconstruction: IVUS images of a 64 y/o female femoropopliteal artery were loaded into Materialize Mimics. A 13.5 cm segment of the artery was built using the multiple slice edit tool. Sporadic slices were used to interpolate interlaying artery regions and smoothed in Materialize 3-Matic. Calcium deposits were reconstructed using the thresholding and Boolean operator tools of Mimics.

CONCLUSIONS

- Our established protocol allows the use of IVUS imaging for non-destructive 3D characterization of human femoropopliteal arteries
- Resulting 3D reconstructions provide sufficient detail and can in the future be used for computational modeling
- Further adjustments to our artery mount (e.g., pressurization) may better represent physiologic conditions
- Correlation to other imaging techniques will refine the results and inform computational models

ACKNOWLEDGMENTS

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