Computer-Assisted Diagnostic Tool to Quantify the Pulmonary Veins in Sickle Cell Associated Pulmonary Hypertension

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Purpose

- This study investigates if a size change in the pulmonary veins (PV) of sickle cell disease (SCD) patients could be linked to sickle-cell associated pulmonary hypertension (PHT).
- The PV are segmented in CT-Angiography (CTA) and the size is quantified non-invasively.

Introduction

- SCD patients have abnormal, rigid, sickle shape red blood cells:
  - Block blood vessels;
  - Pain & organ damage;
  - Pulmonary hypertension.
- PHT is a frequent complication of SCD; approximately 75% of SCD patients develop PHT at the time of death.
- Right heart catheterization remains the gold standard for diagnosis, but it is invasive.
- Image analysis using CTA may serve as a noninvasive surrogate for reliably assessing severity of PHT and facilitate prognosis and acute management in SCD patients.

Main Challenges

- The number of pulmonary veins is unknown a priori. Patients present many different patterns of pulmonary venous drainage.

- Faint Edged. The contrast material is degraded when reaching the pulmonary veins.

- Material

  - 20 pulmonary CTA scans:
    - 10 from SCD patients with related PHT;
    - 10 negative controls without SCD or PHT.
  - Patients and controls are matched by age.

Method

Preprocessing

1. Two user-defined seed points in the left heart atrium:
   - 1 close to the right ostia;
   - 1 close to the left ostia.
2. The image is denoised with an anisotropic diffusion filter.
   - It preserves edges and increases homogeneity.

\[ \frac{\partial g}{\partial t} = div(c(|\nabla g(x,t)|\nabla g(x,t))) \]

Segmentation

3. The left heart atrium and the pulmonary veins are segmented with a fast marching method.

\[ F(x)|\nabla T(x)| = 1 \]

4. The left atrium is isolated by penalizing high curvature regions. A geodesic active contour is employed.

\[ \phi + F(1 - \epsilon \kappa)|\nabla \phi| - f_N FV \phi = 0 \]

Skeletization and Distance Map

5. The skeleton is found by eroding the object’s surface iteratively.

6. The minimum distance from each point to the contour is computed.

Ostia Determination and Pulmonary Veins Quantification

7. Ostia And Veins Determination
   - The ostia is determined by the intersection of the skeleton and the contour of the atrium.
   - Then, each vein is represented with a tree structure in order to keep track of branches.

8. Quantification
   - The diameters are measured at the ostium and at 5, 10 and 15 mm from the ostium.
   - For each distance, the sum of diameters is computed.
   - All branches are taken into account.

Results

- Different patterns of venous drainage were detected: 5 veins were found in 4 patients and 1 control; 1 common ostium was found in 1 patient and 2 controls.

Figure 1: Boxplots for patients versus controls:
(a) the cumulative diameter of the pulmonary veins at different distances from the ostia;
(b) the cumulative diameter of the pulmonary veins normalized by the BMI.

<table>
<thead>
<tr>
<th>Cumulative Diameter</th>
<th>0 mm</th>
<th>5 mm</th>
<th>10 mm</th>
<th>15 mm</th>
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<tr>
<td></td>
<td>0.007</td>
<td>0.002</td>
<td>0.002</td>
<td>0.007</td>
</tr>
<tr>
<td>Cumulative Diameter / BMI</td>
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<td>0.001</td>
<td>0.001</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 1: P-values for the different measures as indicators of pulmonary hypertension.

Conclusion

- A semi-automatic method for the segmentation and quantification of pulmonary veins from 3D CTA was developed.
  - The method is robust against variations in anatomy (such as variable number of veins and branching) and low contrast in the veins (due to the CTA acquisition protocol).
  - The cumulative diameters of the pulmonary veins at the ostia, and at 5, 10 or 15 mm from the ostia are significantly larger in the sickle cell anemia patients as compared to controls.
  - CT and image processing show great promise as a noninvasive assessment tool for pulmonary physiology and clinical surveillance.

Future Work

- Quantitative validation
- Correlation with hemodynamics