Modern μCT in kidney analysis: semi-supervised learning meets Stereology

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Background

Kidney volume, nephron number and glomerular volume are key features in renal morphometry. Their alterations may play a significant pathophysiological role in the development and/or progression of a range of kidney and heart related diseases. Nowadays the gold-standard method in Stereology (i.e., estimation of shape parameters by means of sampling) for kidney morphometry is the exhaustive physical fractionator/dissector method (often combined with Cavalieri for kidney volume estimation). Main disadvantages include the destructive nature of the technique and long processing time.

Aim

We present a semi-automatic detection and segmentation framework of glomeruli and kidney volume using a semi-supervised learning framework based on 3D μCT images. Results will be validated with classical Stereology.

Experimental Design

28 anaesthetized adult mice were perfused with polyurethane cast resin mixed with novel Angiofil contrast agent (Fumedica AG, Switzerland). The kidneys (cast plus tissue) were scanned with SkyScan 1172 ex-vivo μCT with resolution down to 2 μm isotropic voxel size.

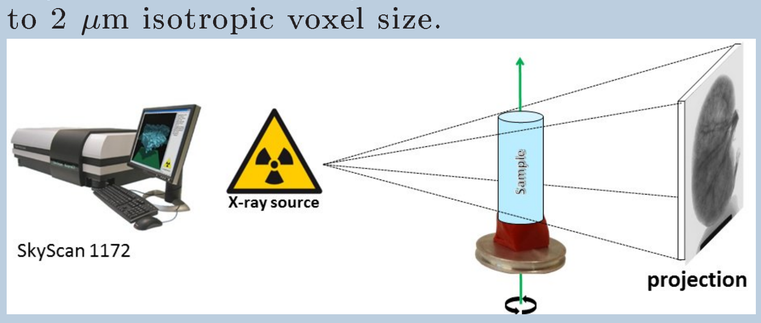


Figure 1: Our ex-vivo μCT scanner

Challenges

Large datasets (volumes consisting in 2500x3000x6500 voxels approx.) with a spherical target object of radius 30 μm (i.e. glomeruli defined within a cube of approx. 30x30x30 voxels). Stereology estimates around 14'500 nephrons within an adult mouse kidney of volume 200 mm^3.

Textured background with no significant intensity difference between fore and background.

Data

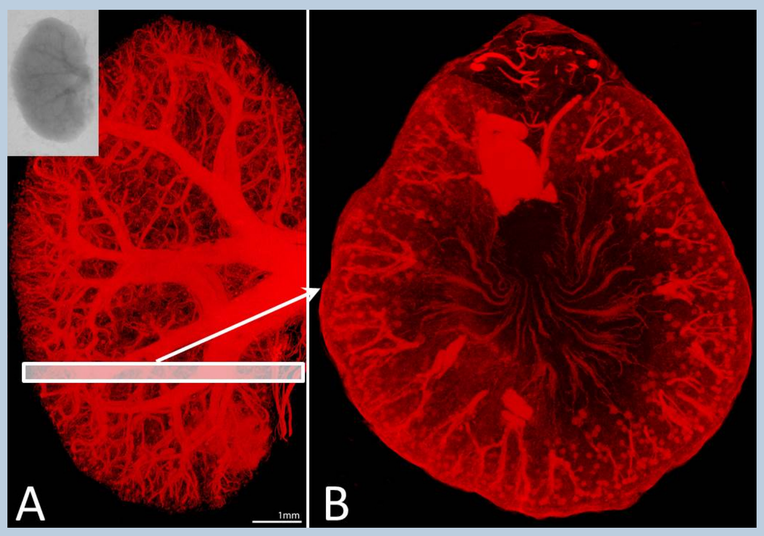


Figure 2: Single projection (upper-left), reconstructed 3D volume rendering (A), volume of interest (B). Glomeruli located exclusively in the outer region (cortex). Scale bar 1mm.

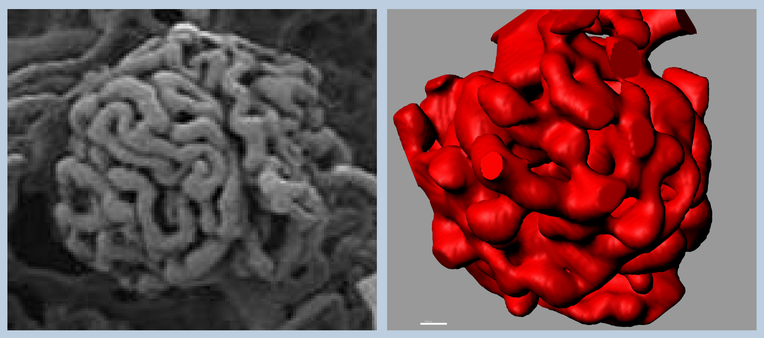


Figure 3: Glomerulus i) SEM (left) ii) 3D isosurface (right). Spherical shape (if considered as a solid).

Methods

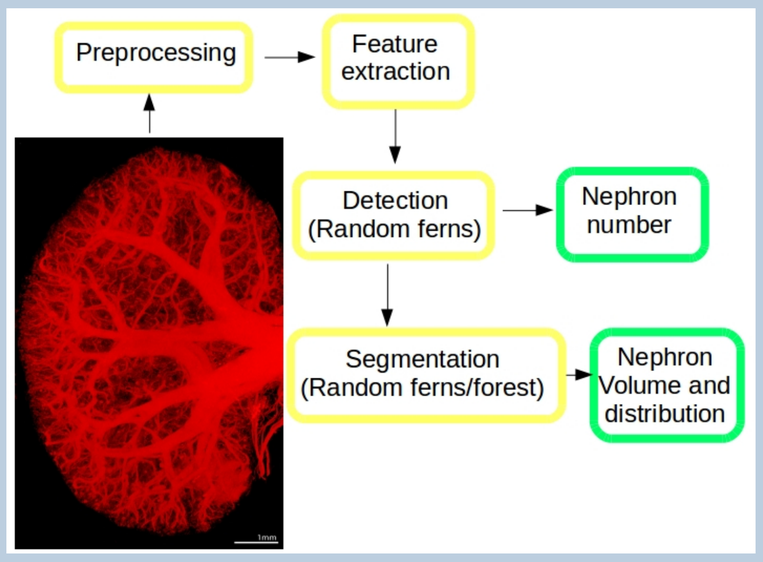


Figure 4: Proposed pipeline: the feature extraction is a key step for a good classifier performance. For the sake of speed random ferns (Özuysal (2010)) are preferred whereas for a more accurate segmentation random forest (Breiman (2001)) will be considered.

Preliminary results

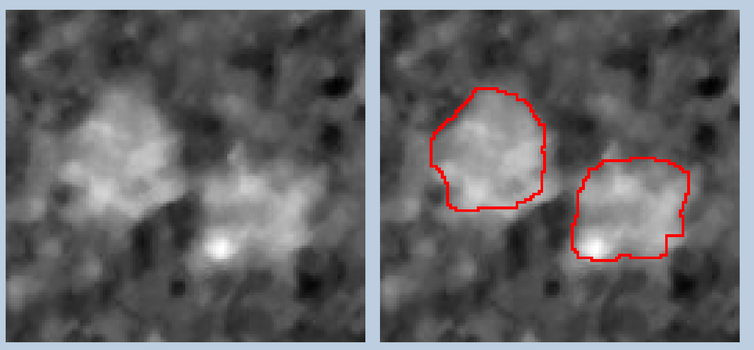


Figure 5: Outline of a 3D-Kmeans algorithm for 2 classes (fore and background).

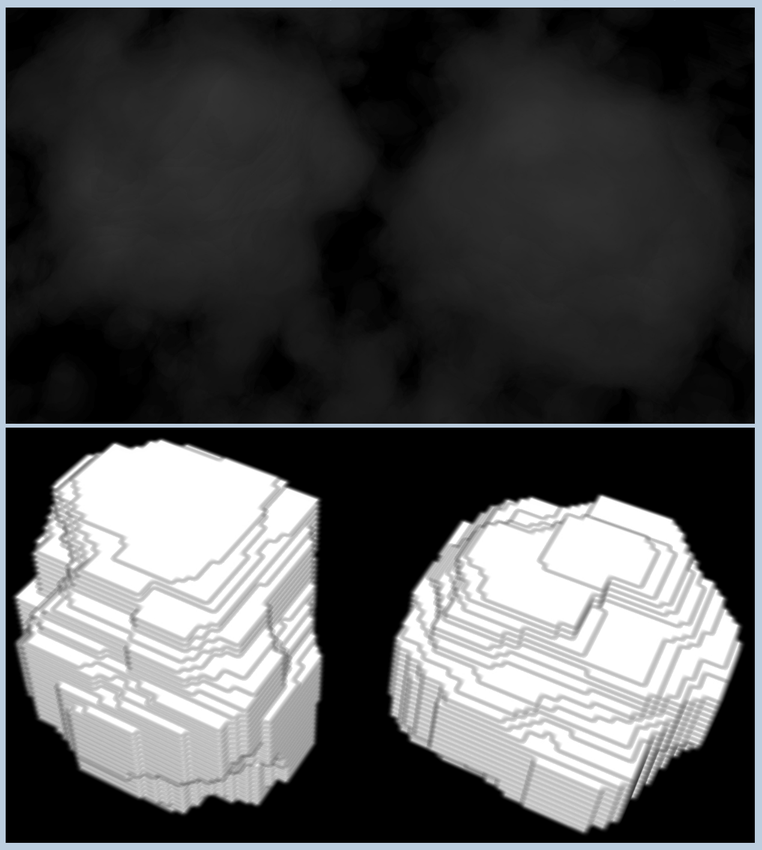


Figure 6: Original volume of interest (size 130x120x45) with two glomeruli (up), the segmentation output from a 3D-Kmeans algorithm for 2 classes (down). Sharp edges due to the hard-thresholding nature of K-means.

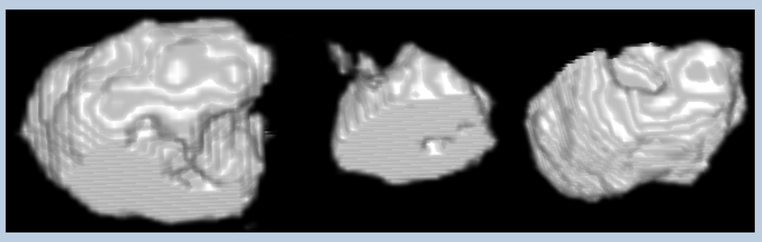


Figure 7: Random forest segmentation with features computed within a window of 11x11x11 voxels. Note smoother borders in comparison with a 3D-Kmeans classifier (cf. Fig.6).

1mm