Quantitative Measurements of Kidney and Cyst Sizes in Patients with Autosomal Dominant Polycystic Kidney Disease (ADPKD)

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1. MOTIVATION

The Autosomal Dominant Polycystic Kidney Disease (ADPKD) is one of the most common genetic disorders, affecting an estimated 12.5 million people worldwide. Over the course of the disease numerous cysts develop in the kidneys and the liver, thus increasing the size of the kidneys and destroying the kidney parenchyma. In the end-stage of the disease, dialysis and ultimately replacement therapy become oftentimes necessary. The size of the kidneys and therefore the progression of the disease is naturally related to the impairment of the renal function, but seemingly not in a straightforward manner.

In order to perform studies to better understand the course of disease of ADPKD and how it leads to renal failure, as well as to develop and evaluate new methods of treatment, it is necessary to be able to do qualitative and quantitative measurements of the size of the kidneys, the cysts and the remaining parenchyma. Magnetic Resonance Imaging (MRI) has already been used in several studies concerning ADPKD, but to our knowledge, segmenting and evaluating the data has been done primarily "by hand" or with simple thresholding and not with more sophisticated segmentation approaches. Therefore it is the aim of this work to perform an accurate segmentation of the kidneys, the cysts and the remaining parenchyma in 3D volumes, while keeping user interaction to a minimum.

2. STATE OF THE ART

Currently the most often employed method to perform volumetric measurements of cysts and kidney is a manual segmentation using stereology [1]: A regular grid showing crosses as the grid points is superimposed on a slice view of the volume. An observer manually determines slice by slice whether a grid point is positioned over the kidney, a cyst or any other tissue. This method is obviously rather laborious and also, depending on the spacing of the superimposed grid, rather imprecise.

Other methods used, include a manual slice by slice segmentation of the kidneys, combined with a simple thresholding operation to segment the cysts. The problem here is, that when the resolution (number of slices) of the image sequences is increased, the manual segmentation of the kidneys is just not feasible for larger studies. Additionally, bias effects in the MRI data make a cyst segmentation by thresholding quite unreliable.

3. METHODS

In this work T2 weighted MRI images are used. T2 weightings have the advantage that water and therefore the cysts are very clearly visible. Nevertheless, due to image inhomogeneities and the fact that sometimes cysts also contain blood which makes them appear much darker, it is not possible to segment the cysts reliably by just thresholding the images.

Still nore complicated is the segmentation of the kidneys. In the presence of many cysts, it is a very hard problem to automatically determine the border between the kidney and the liver and even harder to separate the cysts into liver cysts and kidney cysts. As the cysts completely deform the kidneys, it is also not possible to employ prior knowledge about the shape of the kidney. Due to these problems semi-automatic methods were chosen for the segmentation.

For the segmentation of the kidneys the Random Walk [2] technique is used. The Random Walk segmentation starts out with some manually set seed points belonging to each region that shall be segmented (see figure). It

Data	Manual	RW	Rel. Err.	Abs. Err.
1	483.18	469.1	2.91%	14.08
2	574.04	502.4	12.48%	71.64
3	600.18	588.6	1.93%	11.58
4	608.43	563.7	7.35%	44.73
5	614.7	588.4	4.28%	26.3
6	621.79	600.1	3.49%	21.69
7	648.22	607.3	6.31%	40.92
8	699.53	671.6	3.99%	27.93
9	765.19	728.2	4.83%	36.99
10	796.46	705.8	11.38%	90.66
11	796.65	780.4	2.04%	16.25
12	813.26	760.4	6.50%	52.86
13	819.03	797.1	2.68%	21.93
14	856.63	803	6.26%	53.63
15	861.36	819.1	4.91%	42.26
16	1060.13	1145.1	8.02%	84.97
17	1165.42	1125.8	3.40%	39.62
18	1195.33	1170.9	2.04%	24.43
Average:			5.27%	40.14
Average (w/o 2 and 10):			4.43%	35.01

Table: Evaluation of the Random Walk (RW) segmentation, using a manual segmentation as ground truth. In the datasets 2 and 10 it is very hard to tell the liver and kidney (due to the cysts) even in a manual segmentation, which makes some segmentation errors very likely. Results have therefore been provided with and without these datasets included.

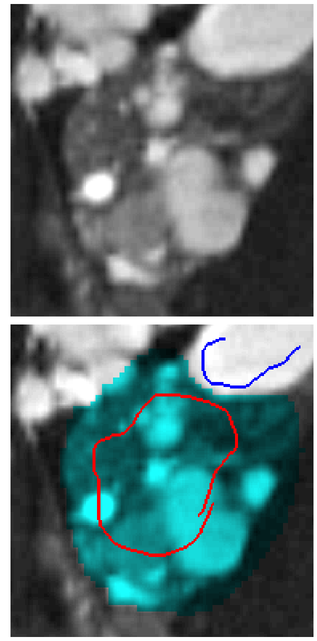

Figure: Top: Unsegmented kidney with cysts; Bottom: Random Walk segmented kidney with manually drawn labels

labels each pixel as belonging to one of those regions, depending on which seed point a random walker, started at that pixel location would reach first. In order to incorporate the image information in the segmentation process the transition probabilities of the random walker from a pixel to its neighbors depends on the local image gradient.

Computationally this is equivalent to solving a combinatorial, Dirichlet boundary problem, which reduces to solving a large and sparse system of linear equations. [2] employs a GPU based conjugate gradient (CG) method as their linear solver. In our implementation we use a CPU based multigrid method. On a Pentium 4 3.0 GHz with 2GB of main memory the calculation of the Random Walk segmentation takes about 50 seconds for a 5.7 million ($256 \times 256 \times 88$) voxel volume.

After the kidney is segmented, the cysts inside the kidney can be identified using a watershed transform on a smoothed gradient image. The watershed basins corresponding to cysts are selected manually, in order to avoid segmenting parts of the renal pelvis as cysts. The manual selection of watershed basins also allows the identification of individual cysts, which makes statistics about the cyst sizes possible. For the calculation of the watershed transform we use the Insight Toolkit [3].

4. RESULTS

The described methods have been incorporated into a commercially available software for clinical evaluation. The segmentation of the kidney by the Random Walk method was compared to a manual slice by slice segmentation (see table). The results show a difference between the measurements of about 4% to 5%. This is almost on par with the inter-observer variance of about 3.8% that we measured in previous experiments, with the manual segmentation. The time needed for the segmentation of one kidney was reduced from about half an hour to less than 5 minutes which significantly reduces the workload, while still obtaining an accuracy that is comparable to a completely manual segmentation.

In the final version of the paper we will also present more measurements concerning the cyst volume and statistics.

5. CONCLUSIONS

We have shown that image processing methods can improve the accuracy and reduce the effort in performing volumetric measurements in MRI images. Semi-automatic methods allow this while retaining the control in the hands of the physician performing the evaluation.

References

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