Renal cortical volume measured by MRI: a feasibility study towards estimation of total number of glomerular in the kidney

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Introduction

Total number of glomeruli, N(glom), has been shown to be a promising parameter for assessing kidney function in a variety of clinical settings, among these diabetic glomerulosclerosis and renal allograft transplantation. One approach to find N(glom) is by the equation: $N(glom)=V(cor)xVv(glom/cor)/V_N(glom)$, where V(cor) represents the cortical volume, Vv(glom/cor) is the glomerular volume density, i.e. the glomerular fraction of cortical volume, and $V_N(glom)$ is the glomerular mean volume. Both Vv(glom/cor) and $V_N(glom)$ can be obtained from biopsies using stereological principles [1]. In this study, we present a novel MRI technique to measure the renal cortical volume, V(cor), using two novel approaches (with and without MR contrast agent). This objective is motivated by the fact that renal function is primarily driven by the glomerular function taking place in the renal cortical segment, and thus, shrinkage or growth of renal cortex could become a determinant factor for the kidney function. Second, we derived N(glom) from found values of V(cor), Vv(glom/cor) and $V_N(glom)$, and compared these findings with a novel stereological method used as our reference [2]. The study was conducted in both healthy and diseased pigs.

Materials and methods

We included 22 adult Danish Landrace pigs: 13 healthy (sham) and 9 with relieved unilateral ureteral obstruction (UUO). MRI was performed 8 weeks after surgical procedures, and MRI volumetry of both kidneys was performed using two different strategies: A) one without MR contrast-agent, and B) one with MR contrast-agent (Omniscan). MRI was conducted with a clinical 1.5 T Philips Achieva system and a cardiac SENSE-coil. A) was performed using a 2D IRTSE sequence. Scan parameters were: 8-15 coronal slices with a thickness = 3.0 mm, FOV = 320x320 mm^2, acquisition matrix = 256x256 and reconstructed matrix = 512x512, TR = 4500 ms, TE = 8 ms, and spin-echo turbo factor = 28. Two sets of images were taken, one using TI=100 ms and another using TI=900 ms (pixelwise multiplication of the two set of images produced a resulting image used for analysis). B) The contrast-agent method was performed using a dynamic gradient-spoiled TFE sequence. Iv injection of 10 ml of Omniscan was performed as a single bolus (10 ml/s) during the dynamic MRI sequence with a single-frame acquisition time of 15 s. Other sequence parameters were: 16-23 slices, 2.5 mm slices, reconstruction matrix = 512x512, FOV = 320x320 mm^2, TR = 7.3 ms, TE = 2.6 ms. In both approaches, V(cor) was estimated using 3D volumetric segmentation of the renal cortex by the computer program Cardiac-3D (Systematic, Aarhus, Denmark). Further, V(cor) was found with respect to intra- and interindividual variances. After MRI, nephrectomy was subsequently performed and reference values of V(cor) were estimated by stereology. Each biopsy was divided into a medullary part and a cortical part using a stereomicroscope. The mass of the cortical part was measured, and a volume for each cortical-biopsy was calculated. The biopsies were embedded in plastic and cut exhaustively into 20 µm thick slices. Using the analysis software "VIS" (Visiopharm, Hørsholm, Denmark), digital images were acquired of all slices and glomeruli were counted. The volume and number of glomeruli for each biopsy generated the glomerular density, Nv(glom/cor), for each biopsy and for each kidney, the latter being a mean of all six biopsies withdrawn from the kidney. The total number of glomeruli in renal cortex could be calculated by estimating the volume of renal cortex: $N(glom) = Nv(glom/cor) \times V(cor)$.

Results

An example of the segmented renal cortex using MRI is shown in Fig 1. MRI-based measurements of V(cor) in all kidneys were estimated relatively precisely, both with and without contrast agent, as compared with reference values (Fig 2 and Fig 3); UUO(ipsi) is ipsilateral kidney, UUO(contra) is contralateral kidney, and sham served as controls. In UUO kidneys, the non-contrast MRI method gave V(cor) values comparable to those found by stereological means, whereas contrast-agent MRI method overestimated V(cor) slightly. In addition, we found that semiautomatic and manual segmentation resulted in almost similar V(cor) values. Reproducibility of estimated cortical volumes offered both intra- and interindividual differences below 5%. N(glom) estimated by stereology was $1.30\pm0.28 \times 10^6$ for UUO(ipsi) kidneys and $1.59\pm0.28 \times 10^6$ for control kidneys.

Discussion

This study demonstrated that V(cor) can be measured accurately with MRI using semiautomatic segmentation. Both MRI methods with and without contrast agents were feasible, however, V(cor) found with MRI methods based on contrast agent as well as a method without contrast agent tended to slightly overestimate V(cor) in diseased kidneys, while the MRI method without contrast agent, estimated V(cor) correctly. We found that MRI volumetry of renal cortex can be performed with high precision and high reproducibility. This study presents a novel non-contrast-agent MRI method that allows accurate estimation of V(cor), both in healthy and diseased animals. We believe that it could become a supplementary tool to daily invasive measures in kidneys. In addition, we were able to calculate N(glom) in agreement with those published in literature [3].

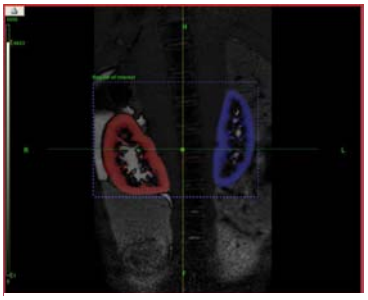

Fig 1. Example of segmentation of cortex based on the non-contrast MRI approach.

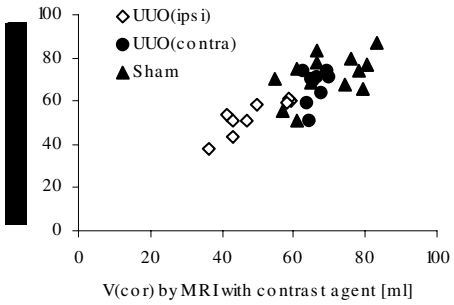

Fig 2: V(cor) with MRI and stereology.

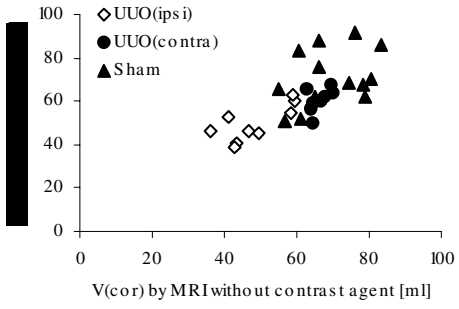

Fig 3: V(cor) with MRI and stereology.

References:

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