Assessment of Intrarenal Oxygenation in Renal Donor With Blood Oxygenation Level—dependent Magnetic Resonance Imaging

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OBJECTIVE To examine change of the apparent relaxation rate R2* values in living kidney donors after uninephrectomy using blood oxygenation level—dependent magnetic resonance imaging.

METHODS Between July 2011 and January 2012, 45 kidney donors were enrolled into this study. Blood oxygenation level—dependent magnetic resonance imaging scanning was performed before surgery, 3 and 7 days postoperatively. Participants were followed up for 1 year.

RESULTS The R2* values in medulla (mR2*) were significantly greater than that of cortex (cR2*), both in resected kidney and remaining one. cR2* values of the remaining kidney was 17.52 ± 1.36 s^{-1} and then decrease significantly by 8.97% to 15.95 ± 1.14 s^{-1} at 3 days (P <.001) and by 7.82% to 16.15 ± of 1.05 s^{-1} at 7 days. No significant modification occurred in mR2* after surgery. Multivariate regression analysis showed that the decrease in cR2* values of the remaining kidney was positively associated with sex (r = 0.418), body surface area (r = 0.307), and preoperative cR2* values (r = 0.659). Comparing with glomerular filtration rate at 7 days, a further increment in the glomerular filtration rate was noted at 1 year in patients with cR2* values decrease of ≥10% at 1 week (62.63 ± 11.69 vs 56.97 ± 7.51 mL/min/1.73 m^2, P = .02) but not in the other patients (66.43 ± 10.89 vs 62.78 ± 13.74, P = .064).

CONCLUSION Kidney donation will induce early, profound oxygenation modification within the renal cortex of the remaining kidney. Donors with cR2* value decrease of ≥10% at 1 week have a more favorable renal function compensation at 1 year. UROLOGY 83: 1205.e1—1205.e5, 2014.

The surgical removal of a normal kidney leads to dramatic hemodynamic, morphologic, and functional adaptation for the remaining kidney, including early increase in glomerular filtration rate (GFR), effective renal plasma flow, and filtration fraction.[1-3] This adaptation implies a physiology alternation and altered tissue oxygen bioavailability status.[4] The are few reports about the early effects of uninephrectomy in humans, particularly in pathologic condition, mostly renal tumors.[5,6] Comparing with general population, kidney donors enjoy a similar long-term survival and comparable risk of developing into an end stage of renal diseases.[7-10] However, the early changes in kidney parenchyma oxygen bioavailability status after renal donation and their effects on renal function in the long term are far from being well addressed.

Blood oxygenation level—dependent magnetic resonance imaging (BOLD MRI) is a noninvasive method to assess intrarenal oxygen bioavailability using deoxyhemoglobin as an endogenous contrast agent.[11] Oxyhemoglobin is a diamagnetic molecule that creates no magnetic moment as oxygen molecules are bound to iron, whereas deoxyhemoglobin is a paramagnetic molecule that generates magnetic moments by its unpaired iron electrons.[12] Changes in deoxyhemoglobin concentration involve generation of phase incoherence of magnetic spins, leading to reduction of the T2* relaxation time which in turn attenuate signal in gradient echo sequences and an increase in the apparent spin-spin relaxation rate denoted as R2* (R2* = 1/T2*). As presented in previous study that R2* was directly proportional to the amount of deoxyhemoglobin in blood,[11] the increased R2* level implies an increased deoxyhaemoglobin level. This behavior, combined with the fact that oxygen pressure (pO_2) in blood is in equilibrium with pO_2 in tissue, potentates BOLD MRI to be an attractive tool for high resolution mapping of the intrarenal oxygenation.

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MRI at higher field strengths such as 3.0 T has higher inherent signal-to-noise ratios.[13,14] For BOLD MRI, there is increased sensitivity to susceptibility effects at higher field strengths in distinguishing discrete cortical and inner medullary regions of the kidney and approximate measured differences in oxygen tension.[15] In this study, 3.0-T BOLD MRI was applied to noninvasively measure intrarenal oxygenation modifications induced by unilateral nephrectomy in kidney donors.

MATERIALS AND METHODS

Patients

The study was approved by the ethics committee of the West China Hospital, Sichuan University (REC reference number 07/Q1405/21), and all patients gave fully informed consent before inclusion. Between July 2011 and January 2012, we prospectively evaluated 45 living kidney donors in a consecutive fashion as they presented to transplant clinic for transplantation. Potential participants had to be aged at least 18 years, not pregnant, and without a contraindication to an MRI examination. In addition, all patients undergo a thorough preoperative evaluation process to ensure they are medically fit for donation and their kidney is suitable for transplantation. Results from BOLD MRI are not considered as criteria in selection of patients.

A 99mTc-mercaptoacetyltriglycine renal scintigraphy was performed in all patients, and effective renal plasma flow was calculated using a camera-based technique. Serum creatinine levels were determined preoperatively and at postoperative day 7 in all patients and 1 year postoperatively in 34 patients. The GFR was estimated by Cockoroft-Gault formula.[16] The preoperative single-kidney GFR was calculated as the preoperative total GFR multiplied by the differential ratio of the single-kidney effective renal plasma flow. To rule out the difference in body surface area (BSA) among included patients, preoperative and postoperative GFR were adjusted to the standard BSA (1.73 m^2). BSA was calculated as described in the literature.[17]

BOLD Methodology

All patients were designed to undergoing 3 times of MRI scanning, within 5 days before surgery and at the third and seventh day after the surgery. MRI was performed with a 3.0-T MR scanner (Siemens Magnetom Trio Tim, Germany), using a multiple gradient-echo breath-hold acquisition. An 8-channel phased-array coil was used for signal reception. The MRI parameters were as follows: 6 oblique-coronal slices through both kidneys and the remnant one; range of echo time 2.5-59.32 ms, field of view = 380 × 380 mm, 256 × 256 matrix, slice thickness = 5 mm, space = 1 mm, flip angle = 33°, time of repetition = 75 ms, band-width, 540 Hz per pixel. Twelve T2*-weighted images corresponding to 12 different gradient echoes were acquired for each section within one 10-second breath hold.

A color T2* map of the kidney was generated using Functools on the MR working station. On the color map, bright green represents the highest T2* levels, indicating the lowest concentration of deoxyhaemoglobin, whereas blue represents the lowest T2* levels, indicating the highest concentration of deoxyhaemoglobin. T2* levels were measured using the regions of interest (ROIs) tool. For each examination, 6 ROIs were drawn in the cortex and the medulla, respectively, using regular T2-weighted images as anatomic reference to determine the cortical or medullary region. Each ROI consisted of 20-60 pixels. Then, T2* values were converted to R2* value (R2* = 1/T2*).

Table 1. The characteristics of included patients

Characteristics	Value	*P*
Sex		
Male	11	
Female	34	
Age (y)	48.24 ± 8.14	
Weight (kg)	58.07 ± 6.69	
Height (m)	1.60 ± 0.06	
BSA (m^2)	1.60 ± 0.10	
Serum creatinine (μmol/L)		
Preoperative	65.34 ± 11.41	<.001
7 d postoperative	105.07 ± 22.62	
1 y postoperative	97.54 ± 19.09	
GFR of the resected kidney (mL/min/1.73 m^2)	48.87 ± 10.23	
GFR of the remaining kidney (mL/min/1.73 m^2)		
Preoperative	48.75 ± 8.93	<.001
7 d postoperative	61.61 ± 13.41	
1 y postoperative	65.40 ± 11.82	
Preoperative R2* of resected kidney (s^{-1})		
Cortex	17.50 ± 1.52	<.001
Medulla	38.84 ± 4.43	
Preoperative R2* of remaining kidney (s^{-1})		
Cortex	17.52 ± 1.36	<.001
Medulla	37.99 ± 4.92	

BSA, body surface area; GFR, glomerular filtration rate; R2*, the apparent spin-spin relaxation rate.

Data Analysis

All continuous data are presented as mean ± standard deviation and compared using Student *t* test, chi-square test for categorical data. When necessary, 1-way analysis of variance with posthoc test was applied to perform the pairwise multiple comparisons of continuous data between groups. Univariate and multivariate stepwise regression analyses were used to test the relationship between R2* value and patient characteristics. All tests were 2-sided, and $P < .05$ was considered statistically significant. All statistical analyses were performed using Statistical Package for Social Sciences software (SPSS 18.0, Chicago, IL).

RESULTS

We included 45 donors among whom 11 were male and 34 were female donors. Twenty-five patients underwent laparoscopic nephrectomy, and the other 20 patients received open nephrectomy. The demographic characteristics of the included patients are displayed in Table 1. The preoperative serum creatinine level was 65.34 ± 11.41 μmol/L, and it increased to 105.07 ± 22.62 μmol/L at 7 days, and then stabilized at a slightly lower level of 97.54 ± 19.09 μmol/L at 1 year. The preoperative GFR was 97.62 ± 18.08 mL/min/1.73 m^2, and the GFR of resected kidney was 48.87 ± 10.23 mL/min/1.73 m^2. The GFR of remaining kidney increased by 26.38% from 48.75 ± 8.93 to 61.61 ± 13.41 mL/min/1.73 m^2 at 1 week ($P < .001$) and by 34.15% to 65.40 ± 11.82 mL/min/