Short communication

Kidney Function vs. Kidney Mass-Volume Calculated by Digital Image Processing

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Abstract

Reduction of nephron mass below a certain level leads to progressive chronic renal failure. As the kidneys are difficult to weight, it is usually estimated by measuring of glomerular filtration rate. The aims of the study were: a) to calculate kidney volume (KV) by computerized kidney imaging by magnetic resonance imaging (MRI); b) to compare KV with glomerular filtration rate; c) to examine long-term influence of KV on glomerular filtration rate. Six living related kidney donors (D) and their recipients (R) were included in the study. Radionuclide ^{99m}Tc-DTPA glomerular filtration rate (GFR) (total and relative contribution of each kidney to overall GFR), and estimated GFR (eGFR) were determined parameters of kidney function (KF). The kidneys were reconstructed by MRI. The obtained data were used for 3D kidney presentation by digital image processing and the whole KV was between 120.66 cm^3 and 212.93 cm^3. All D had normal kidney function before donation and normal/ satisfactory remnant KF one month after donation. Significant correlation between donor KV and GFR_0 before and after transplantation was found ($p<0.05$). The graft function measured at the end of the first posttransplant month was not dependent on transplanted KV. Four R with normal graft function and their D have been followed for more than one year. Positive but not significant correlations between the KV and GFR of the graft or remnant donor kidney were maintained during the follow-up. These preliminary results encourage us to continue the study and to examine the predictive value of calculated graft volume for subsequent function.

Introduction

According to Brenner's hyperfiltration hypothesis, once nephron mass is reduced to a critically low level, kidney damage occurs as a result of hypertrophy and sclerosis of the overworked nephrons (1). This is particularly important in a transplanted kidney. Here, the initial nephron mass is provided by a single kidney, which may than lose its nephrons due to an acute rejection and/or the use of nephrotoxic drugs. This raises the possibility that kidney transplantation may result in nephron underdosing. On the other hand, living donor transplantation should always prioritize donor well-being. Therefore, determination of kidney mass become an important tool in transplant nephrology from the standpoint of both recipient and the living donor. To assess the effect of renal mass various surrogate markers have been introduced, such as donor kidney volume or donor kidney weight over the recipient's body surface area or body weight or body-mass index (2, 3, 4). Most investigators used computerized tomography and magnetic resonance imaging (MRI) to calculate kidney volume or weight or directly weighted the kidneys (2, 3, 4).
Our study was preformed to determine the accuracy of MRI as a tool for kidney volume estimation in order to: *a) calculate kidney volume (KV) by MRI computerized kidney imaging; b) correlate KV with glomerular filtration rate (GFR); and c) examine long-term influence of KV on GFR.*

Patients and methods

Six living related kidney donors and their recipients were included in the study. The kidney donors were subjected to an extensive medical, physical and radiological examination recommended by the European Guidelines (5). These kidneys were suspected of being cancerous, and so needed checking by MRI before donation. Donor kidney function was estimated by measuring serum creatinine concentration and calculation of creatinine clearance from 24 h urine, while glomerular filtration rate (GFR) was calculated using MDRD formula (eGFR) (6) and radionuclide ^{99m}Tc-DTPA (nuclear GFR) before donation and 12 months or later after operation. Having the accuracy in mind, this was used here as one of the methods for examination of donors separate GFR, one of the parameters necessary for the decision about which kidney should be nephrectomized. Separate GFR of donor kidneys planned to be transplanted (GFR_0) was also calculated for each donor by MDRD formula as a percentage (obtained by ^{99m}TcDTPA as the relative contribution of the kidney planned to be transplanted) of eGFR and assigned as estimated GFR_0 ($eGFR_0$). Only kidneys with lower contributions to the GFR were chosen for subsequent

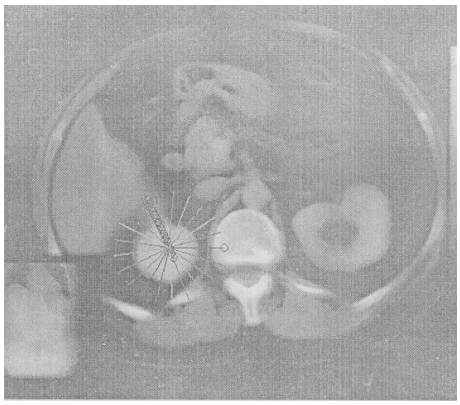

Fig. 1A

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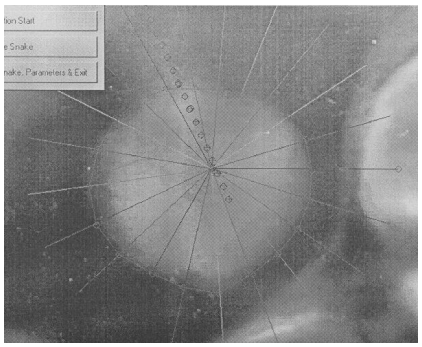

Fig. 1B

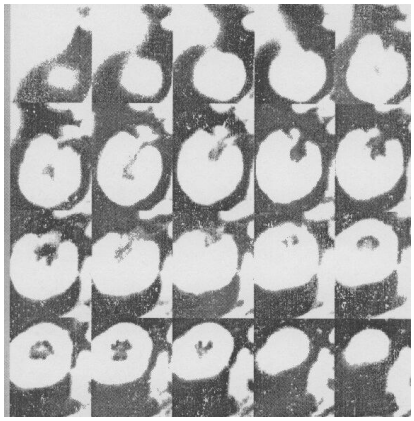

Fig. 1C

Figure 1. MRI slice images were processed by segmentation (A), region merging (B) and selection of the region belonging to the kidney (C) using the snake model

transplantation. Recipient graft function was followed by measuring of creatinine concentration, clearance of creatinine calculated from 24 h urine, and GRF (eGFR) using MDRD formula.

Images obtained by conventional MRI were used for three dimensional (3D) presentation of kidneys. All obtained MRI slice images were processed by segmentation, region merging and selection of the region belonging to the kidney using snake model (Figures 1, 2, 3) (7). When all digital images are processed, the program calculates organ volume on the basis of heights and areas of slice images. Obtained slice thickness was 6 to 8 mm with 6.6 and 12 mm the gap between, with 12 to 20 slices covering the marked kidney areas. The corresponding pixel dimensions were 0.416 x 0.416 mm^2 and 1.96 x 1.96 mm^2. Each pixel in 3D images represents a part of volume, the dimensions of which are defined by the resolution of the image. Organ volume can be simply calculated as the product of the number of pixels that define the organ and the volume of one single pixel. The program for testing the proposed method is written in program package Matlab 4.2c for PC computers.

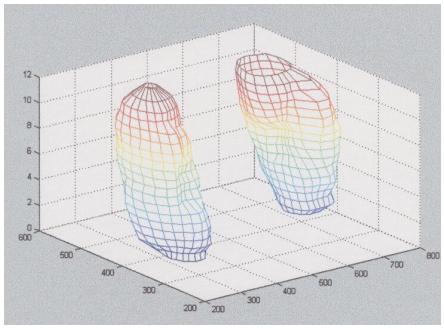

Figure 2. Wire model of 3D reconstructed kidney with the pixel number inside the snake contour (y axe= kidney length in cm)

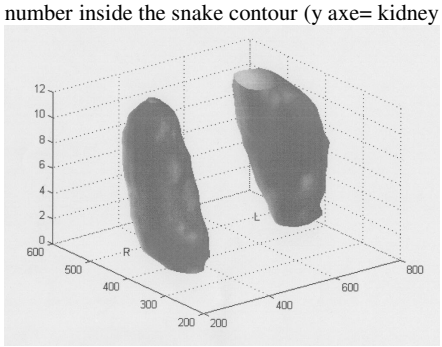

Figure 3. 3D reconstruction of the kidney by shaded kidney area (y axe= kidney length in cm)
Total right kidney (R) volume= 211289 x slice thickness
Total left kidney (L) volume= 245298 x slice thickness

Results

The characteristics of kidney function and volume before transplantation are presented in Table 1. All donors had normal kidney function before donation. No significant difference between donor GFR and eGFR was found. The whole kidney volumes before donation were between 120.66 cm^3 and 212.93 cm^3. Positive correlation between donor kidney volume and GFR_0 before and after transplantation was found ($p<0.05$).

Table 1. Kidney function and volume before transplantation

	SCr, µmol/l	CCr, ml/min	GFR, ml/min eGFR, ml/min/1.73m^2	GFR_0: $eGFR_0$ Right/left ml/min	Kidney volume Right/left, cm^3
Mean± SD	87±12.3	103.1± 11.5	96.7±7.4	44.7±6.0*/ 52±7.6	182.9± 55.5*/ 180.8± 44.4
			87.1±17.3	38.3±13.2/ 48.8±8.4	
range	69-104	90-124	90-110	32-50/ 45-66	120.2-255.4/
			69.68-99.4	34-67/ 27.7-56.5	141.3-225.2

*Positive correlation between SKGFR and kidney volume, p=0.04
sCr= serum creatinine concentration, 24 h urine creatinine clearance, GFR = total glomerular filtration rate measured with radionuclide ^{99m}Tc-DTPA , eGFR= estimated GFR calculated with MDRD formula, GFR_0= relative contribution of single kidney to total GFR, $eGFR_0$= relative contribution of single kidney to total eGFR

Four recipients and their donors with stable and normal graft/remnant kidney function have been followed for more than one year (Table 2). In comparison to basal values, eGFR of the graft or remnant kidney tended to increase slightly. Similarly, mean kidney volume either transplanted or remnant was increased 214±91 cm^3 vs. 209±24.6 cm^3, and the difference reached significance for the remnant donor kidney (p=0.04). In addition, the positive correlation between the graft volume (NS) or remnant donor kidney volume (p=0.03) and GFR was maintained during the follow-up.

Table 2. Transplanted/remnant kidney function and volume in four donors and their recipients first year after transplantation/operation

	SCr[1], µmol/l range	CCr[1], ml/min range	eGFR, ml/min/1.73m^2	Kidney volume[1], cm^3 range
Donors	110.2±29.6	59.2±14.1	54.43±10.7	209.3±24.3*
	83-152	45-75		177.9-234.5
Recipients	117.2±17.2	65±10.6	53.85±7.57	214.3±91.3
	102-140	55-80		131.1-311.9

[1]X± SD, *Kidney volume vs CCR= positive correlation p=0.03; donor kidney volume pre transplant (Table 1): donor remaining kidney volume (Table 2), p=0.04
sCr= serum creatinine concentration, 24 h urine creatinine clearance

Discussion and conclusion

According to these results it could be concluded that calculation of kidney volume by digital signal processing of kidney imaging using MRI seems to be accurate; glomerular filtration rate depends on kidney volume more than 12 months post-operation; increasing both remnant and transplanted kidney volume might be the determinant of hyperfiltration. These preliminary results encourage us to continue the study and to examine the predictive value of calculated graft volume for subsequent function.

References

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