Original Article

Feasibility study of relative renal function assessment by contrast-enhanced abdominal CT in comparison to 99mTc-MAG3 renal scintigraphy

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Abstract

Objective: To determine the feasibility of using contrast-enhanced abdominal CT to assess relative renal function.

Materials and Methods: This retrospective study reviewed data from 32 patients who had had investigations by contrast-enhanced abdominal CT and 99mTc-MAG3 renal scintigraphy, within a period of not more than 30 days. Post-processing CT images of kidneys were by manual segmentation and calculated to interpret the relative renal function.

Results: There was strong correlation between CT derived relative renal function and 99mTc-MAG3 renal scintigraphy ($r = 0.971$, $p < 0.001$) and no statistically significant difference in renal function between the two techniques ($p = 0.572$).

Conclusion: Contrast-enhanced abdominal CT can determine relative renal function as accurately as renal scintigraphy. It is an appropriate alternative method, especially in hospitals where renal scintigraphy is not available.

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Introduction

Relative renal function is the most important preoperative parameter to inform the decision making process and give guidance to enable optimal management of patients with kidney pathologies, such as atrophic kidney, ureteropelvic junction obstruction and renal malignancy. It is also vital in the assessment of potential kidney donors[1,2].

The gold standard to determine relative renal function (RRF) is Renal scintigraphy[3]. At present, Technetium-99m-mercaptoacetyltriglycine is the most frequently used isotopes due to its higher extraction fraction and it results in a high quality of gamma camera image[4]. However, renal scintigraphy is less available, time-consuming, relatively expensive, and has additional costs therefore it is less practical for use in all except tertiary hospitals.

In practice, contrast-enhanced abdominal computed tomography (CE-CT) is commonly used for preoperative assessment of the anatomy of the kidney. Computed tomography is now available in most hospitals and the physiologic properties of the Iodinated contrast agent have many benefits, specifically nearly complete glomerular excretion, less tubular excretion, and less extrarenal excretion, which make it suitable for assessing renal function during renal scintigraphy[5].

The aim of this study is to determine the feasibility of efficacy of using CE-CT to assess RRF in comparison to ^{99m}Tc-MAG3 renal scintigraphy (MAG3).

Materials and Methods

Patients

Data was collected for this retrospective study between January 2012 and December 2019 in Rajavithi Hospital. One hundred thirty-four patients who had had both MAG3 and CE-CT at least both plain phase and arterial phase performed were enrolled onto this study. The exclusion criteria were a longer than 30 day period between CE-CT and MAG, single kidney and surgical intervention between CE-CT and MAG3. Ninety-eight patients were excluded due to the longer than 30 day gap. One patient was excluded due to having a single kidney. Three patients did not meet the exclusion criteria but were excluded due to incomplete imaging data records in the database. Therefore 32 patients met the inclusion criteria and their data was included in the analysis.

Theory of equations

In the pharmacokinetic model, contrast enhancement is directly related to iodine concentration in tissue. Attenuation value of contrast enhancement (CE_{att}) can be calculated by subtracting total attenuation value of region of interest in the plain phase (PP_{att}) from total attenuation value of region of interest in the arterial phase (AP_{att}) which will represent iodine concentration. The proportion of CE_{att} of the right kidney ($^{RK}CE_{att}$) to both kidneys can be used to represent relative renal function of the right kidney (RRF_{RK}) as in Eq. 2. And relative renal function of the left kidney (RRF_{LK}) can be calculated in the same way as shown in Eq. 3.

$$CE_{att} = AP_{att} - PP_{att} \quad \text{(Eq. 1)}$$

$$RRF_{RK} = [{}^{RK}CE_{att} / ({}^{RK}CE_{att} + {}^{LK}CE_{att})] \quad \text{(Eq. 2)}$$

$$RRF_{LK} = [{}^{LK}CE^{att} / ({}^{RK}CE_{att} + {}^{LK}CE_{att})] \quad \text{(Eq. 3)}$$

All Digital Imaging and Communications in Medicine (DICOM) Files were analyzed using Slicer 4.10.2, an open source software. A region of interest (ROI) was drawn around the kidney cortex, which was performed in the arterial phase, in all slices as shown in figure 1. Mean attenuation of the arterial phase of each kidney in Hounsfield units (HU) and kidney cortex volume were registered. The ROI previous created was used to analyze Plain CT to calculate mean attenuation. In some cases where there was motion of the artifact, image transformation function in software was used to correct images to near equivalence in the arterial phase. Total attenuation was calculated by multiplying the mean attenuation and kidney cortex volume. All measurements were carried out by a resident of urology and were reviewed by a radiologist.

Statistical analysis was performed using the IBM SPSS version 20.0.0. Pearson's correlation coefficient was used to establish the correlation of RRF results from CE-CT and MAG3. A two-sided paired t-test was used to establish statistical equivalence.

Results

Of the 32 patients, 10 patients (31.25%) were male and twenty-two patients (68.75%) were female. The age ranged from 15 to 90 years

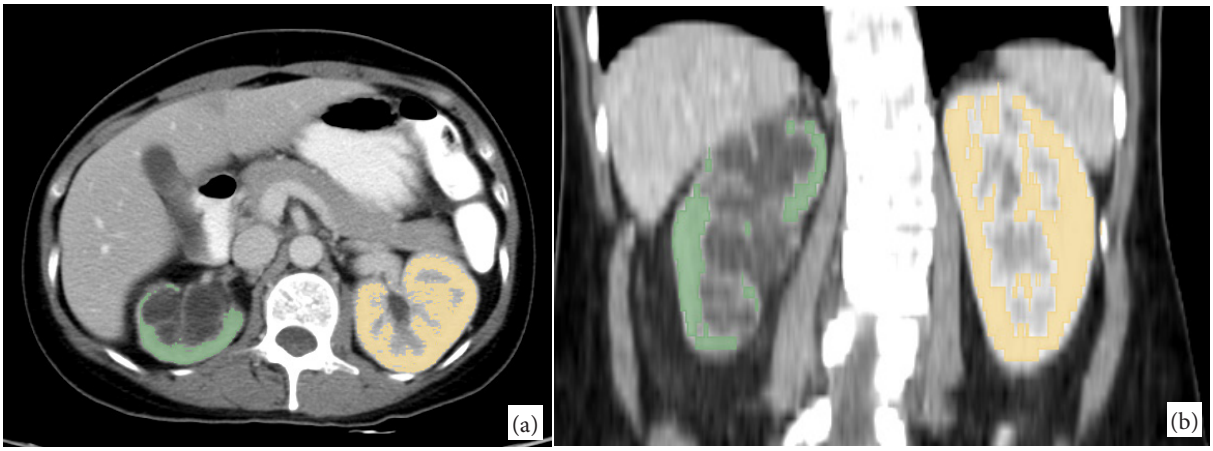

Figure 1. CT image in arterial phase. (a) A region of interest (ROI) was drawn around kidney cortex in every slice of axial image. (b) Coronal view of CT image reconstructed from axial image after ROI was drawn

Table 1. Demographic data.

Demographic data	
Sex, n (%)	
Male	10 (31.25)
Female	22 (68.75)
Mean Age (years) mean (±SD)	46.69±18.97
Mean eGFR (mg/dL) mean (±SD)	88.094±23.32
Diagnosis, n (%)	
Ureteropelvic junction obstruction	10 (31.25)
Renal stone	8 (25.00)
Non-obstructive hydronephrosis	5 (15.63)
Stricture ureter	3 (9.38)
Donor kidney	2 (6.25)
Retrocaval ureter	2 (6.25)
Abdominal aortic aneurysm	1 (3.12)
Renal infarction	1 (3.12)

(mean, 46.69 ± 18.97 years). The average eGFR was 88.094 ± 23.32 mg/dL.

Diagnoses of all patients were as follows: 10 patients ureteropelvic junction obstruction (31.25%), 8 patients renal stones (25%), 5 patients non-obstructive hydronephrosis (15.63%), 3 patients stricture of the ureter (9.38%), 2 patients donor kidneys (6.25%), 2 patients retrocaval ureter (6.25%), 1 patient abdominal aortic aneurysm (3.12%), and 1 patient renal infarction (3.12%).

The relative renal function of right kidney from MAG3 and CE-CT were 48.06 ± 26.67% and 48.70 ± 26.07%, respectively. From left kidneys were 51.95 ± 26.67% and 51.92 ± 26.07%. RRF between two studies showed a strong correlation ($r = 0.971$, $p < 0.001$) and there was no significant different in the paired t-test ($p = 0.572$). Mean different between two studies was 0.65%.

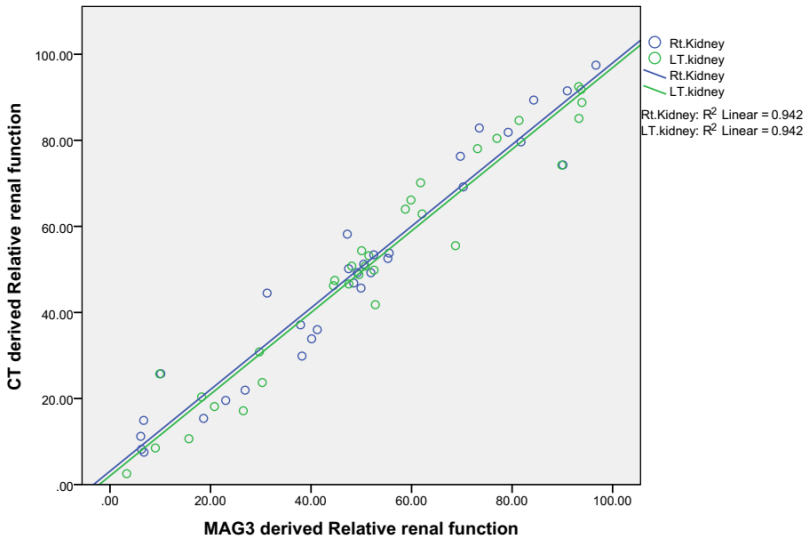

Figure 2. Correlation between RRF derive from CE-CT and MAG3.

Discussion

Although renal scintigraphy is the standard investigation to evaluate RRF it is less available, time consuming, and adds additional costs. In addition, there are several confounding factors when it comes to interpretation of the RRF for example depth of skin, poor renal function, and operator dependence on drawn ROI of kidney with a possible poor demarcation, especially in cases where there is low glomerular filtration rate.

In general, most patients would have a CE-CT performed, usually a triple phase CT, to access the anatomy of the kidney and pathology before surgery. In theory, CE-CT could be used to interpret the RRF as efficiently as renal scintigraphy due to pharmacodynamic of the iodinated contrast material which has a nearly 100% excretion rate by glomerular filtration[4].

There are a few studies which have investigated the feasibility of using a CT scan to interpret RRF. Most studies show that the excretory phase of the CE-CT has a high correlation with renal scintigraphy derived RRF[6-9]. Nilsson H, et al[7] compared the excretory phase and arterial phase to investigate RRF. The results show that the excretory phase was more accurate than the arterial phase in investigation of RRF. The author explain that the conventional CT scan takes time to complete a scan of both kidneys.

This time lag could cause overestimation of the efficacy of the right kidney because it usually appears inferior to the left kidney which has more time to accumulate the contrast during the complete CT scan. In modern time the majority of CT scanners are multidetector. This effect will be considerably less important in the calculation of RRF.

Although the excretory phase reflects the level of iodine contrast passing through the glomeruli it is more user dependent on the drawn ROI because the iodine contrast will present as being present in the renal collection system (renal calyx, renal pelvis, and ureter) which are less demarcated than the drawn ROI. In addition, when the contrast has been excreted to the renal collecting system, it will obscure the renal stone which usually reduces the overestimation of RRF. Since the timing of the excretory phase varies, ranging from 90 to 180 second after IV contrast injection, confirmed in previous studies[6-9], it is usually not included in the standard protocol of CE-CT. It needs to be performed additionally to the standard protocol of CE-CT which increases cost and causes additional radiation exposure in the patient while the arterial phase is usually performed using the standard protocol of CE-CT.

The advantage of arterial phase is well demarcating of kidney cortex cause less user dependence and can easily to refrain pathology in renal correcting system. This phase has primary reflect to renal blood flow. As result of El-Diasty TA, et al[10] study, renal perfusion parameter will be accurate if ROI should draw only kidney cortex.

Renal scintigraphy in the arterial phase doesn't represent the true GFR because the contrast medium has not yet passed through glomeruli. However, the renal physiology between renal perfusion and GFR have a linear relationship[11] which means that the proportion of renal perfusion will be equal to the proportion of renal GFR in both kidneys.

In this study, the results showed a very strong correlation between the RRF derived from the arterial phase of the CE-CT and that derived from the MAG3 ($r = 0.971$, $p < 0.001$). These findings were similar to those found in a previous study by Nilsson H, et al which investigated the excretory phase of the CE-CT, which was even better than the RRF derived from the arterial phase CE-CT[7]. There was no significant difference in the RRF derived from the CE-CT when compared to the MAG3 ($p = 0.572$).

This study is retrospective in design and hence one of the limitations is the lack of control of the time factor in the investigations. If there is a longer time between studies the results of the RRF may be affected if the pathology causes an ongoing decrease in kidney function. Further studies need to be prospective in nature and ensure that both the CECT and MAG3 are performed within a short period of time.

The performance of segmentation of both kidneys in post-process imaging of CE-CT is time consuming which makes it hard to apply in clinical practice. In the Artificial Intelligence era, the timing of this process will become increasingly reduced and maybe it can be used more easily in clinical practice in the future.

Conclusion

Contrast-enhanced abdominal CT can determine relative renal function as accurately as

renal scintigraphy. It is an appropriate alternative method, especially in hospitals where renal scintigraphy is not available. However, it cannot entirely replace renal scintigraphy because of the consequences of the higher radiation dose and its limited use in cases where there is a low glomerular filtration rate

Conflict of Interest

The authors declare no conflict of interest.

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