Ассоциации МРТ паренхиматозных изменений почек и биохимических показателей их дисфункции при резистентной артериальной гипертонии

Н.И. Рюмшина, И.В. Зюбанова, А.Е. Сухарева, М.А. Манукян, Н.Д. Анфиногенова, А.М. Гусакова, А.Ю. Фальковская, В.Ю. Усов

Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук, 634012, Российская Федерация, Томск, ул. Киевская, 111а

Аннотация
Актуальность. Поскольку резистентная артериальная гипертония (РАГ) обычно сопровождается поражением почек, особенно при сочетании с сахарным диабетом 2-го типа (СД2), раннее выявление изменений в почках помогает избежать тяжелых сердечно-сосудистых осложнений. В связи с недостатком данных о визуальных маркерах почечной дисфункции при РАГ нашей целью было определить взаимосвязь между объемами почечной паренхимы и сывороточными маркераами, определяющими их функцию, у пациентов с РАГ.

Материал и методы. 34 пациента соответствовали критериям включения и представляли исследуемую группу. Функцию почек оценивали по уровню сывороточного креатинина и цистатина-С, а также по расчетной скорости клубочковой фильтрации (рСКФ). Размер почек по данным МРТ определяли по абсолютному и индексированному объемам паренхимы.

Результаты. Согласно данным МРТ, основными выявленными изменениями почечной паренхимы при РАГ оказались неровные бугристые контуры, истончение коркового слоя, уменьшение размеров почек, округлая форма; рСКФ имела прямую корреляцию средней мощности со всеми изученными параметрами почечной паренхимы. Наиболее сильная взаимосвязь была продемонстрирована индексом bsa-TKV (r = 0,6166; p = 0,000). Индекс ht-TKV показал связь с eGFR (r = 0,4751; p = 0,007) и с креатинином (r = –0,4302; p = 0,016). По нашим данным, индекс ht-T-Cortex-V < 32,4 (чувствительность 83,3%, специфичность 60,7%, p = 0,03) можно расценивать как прогностический маркер развития почечной дисфункции.

Заключение. МРТ позволяет выявить ранние паренхиматозные изменения в почках при РАГ. Получены уникальные результаты, отражающие зависимость функционального состояния почек от объема почечной паренхимы при РАГ. Определены МРТ-маркеры для прогнозирования хронической болезни почек (ХБП) у лиц с РАГ.

Ключевые слова: резистентная артериальная гипертония, маркеры дисфункции почек, магнитно-резонансная томография, абсолютный объем почек, нормализованный объем почек, расчетная скорость клубочковой фильтрации.

Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Прозрачность финансовой деятельности: никто из авторов не имеет финансовой заинтересованности в представленных материалах или методах.

Соответствие принципам этики: одномоментное наблюдательное исследование проведено в соответствии со стандартами надлежащей клинической практики и принципами Хельсинской декларации. Исследование одобрено локальным этическим комитетом (протокол № 134 от 11.06.2015 г.).

Associations between MRI signs of kidney parenchymal changes and biomarkers of renal dysfunction in resistant hypertension


Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences, 111a, Kievskaya str., Tomsk, 634012, Russian Federation

Abstract

Objective. Resistant hypertension (RHT) is often associated with kidney injury and chronic kidney disease, especially in diabetic patients. Early detection of renal changes contributes to avoiding severe cardiovascular complications, but imaging characteristics of renal dysfunction in RHT remain unclear. The aim of the present study was to determine the relationships between the renal parenchyma volumes and biomarkers reflecting kidney function in a cohort of patients with RHT.

Material and Methods. The study comprised 34 patients with RHT meeting the inclusion criteria. Evaluation of renal function was based on the measurements of estimated glomerular filtration rate (eGFR) and serum levels of creatinine and cystatin C. Renal sizes were assessed by MRI based on absolute and normalized parenchymal kidney volumes.

Results. Primary MRI-based changes in renal parenchyma in patients with RHT demonstrated altered cortical surface, attenuated cortical thickness, lower renal volumes, and round shape of the kidneys compared with the reference characteristics. Positive correlation of moderate power was found between eGFR value and all parameters characterizing renal parenchyma. The strongest direct correlation was found between eGFR and bsa-TKV ($r = 0.6166$, $p = 0.000$); ht-TKV correlated with eGFR ($r = 0.4751$, $p = 0.007$) and creatinine ($r = –0.4302$, $p = 0.016$). According to linear regression analysis, ht-T-Cortex-V < 32.4 was a key element of MRI-presentation of renal dysfunction in patients with eGFR below 60 mL/min/1.73 m² (sensitivity of 83.3%, specificity of 60.7%, $p = 0.03$).

Conclusion. MRI study allowed to detect early renal parenchymal changes suggesting the presence of association between renal function and renal parenchymal volume in RHT patients. For the first time, the study revealed MRI-pattern of renal dysfunction in RHT.

Keywords: drug-resistant hypertension, renal dysfunction markers, magnetic resonance imaging, absolute renal volume, normalized renal volume, estimated glomerular filtration rate.

Conflict of interest: the authors do not declare a conflict of interest.

Financial disclosure: no author has a financial or property interest in any material or method mentioned.

Adherence to ethical standards: a single-stage retrospective study was conducted in accordance with the standards of Good Clinical Practice and the principles of Declaration of Helsinki. The study was approved by the local Ethics Committee (protocol No. 134 from 11.06.2015).


Introduction

True resistant hypertension (RHT) is a poorly studied nosological entity due to the difficulty in differentiating it from hypertension in patients who do not adhere to treatment [1]. Little is known about the causes, pathogenic mechanisms, patient characteristics, prognostic factors, and outcomes of RHT. The prevalence of RHT was reported to range from about 7% to nearly 27% in different populations of patients who receive treatment for hypertension [2]. Considering high prevalence of this condition, it is vital to improve knowledge regarding all aspects of RHT diagnosis and treatment.

Target organ study is pivotal for making correct diagnosis and providing proper treatment for RHT. Besides, damage to vital organs in RHT independently increases the risk of cardiovascular adverse events according to European Society of Cardiology’s risk estimation system. There is a similarity between the mechanisms causing the remodeling of the myocardium, blood vessel wall, and kidney parenchyma, all of which accelerate kidney and heart failure
Material and Methods

A cross sectional observation study was performed in compliance with European standards for good clinical practice and Declaration of Helsinki. The protocol of the study was approved by the local Ethics Committee (protocol No. 134 from June 11, 2015). The recruitment of patients took place from November 2013 to October 2018. RHT diagnosis was established based on the guidelines generated by the European Society for Hypertension [4].

Inclusion criteria were age of 18–80 years, the presence of RHT, and both sexes. All participants provided signed informed consent while agreeing to participate in the study. Exclusion criteria were oncological diseases, inflammatory diseases, kidney trauma injury, and absolute and relative contraindications for MRI examinations.

On the contrary, state-of-the-art magnetic resonance imaging (MRI) allows for both qualitative and quantitative examination of renal structure and function. Moreover, evidence suggests that structural changes in the kidneys occur earlier than altered serum markers of renal dysfunction [7]. Currently, the use of renal MRI is uncommon in RHT patients in everyday clinical practice. There are the gaps in our knowledge on the associations between altered renal parenchymal ultrastructure and kidney function. In this study, we aimed to determine the relationships between the renal parenchymal volumes and biomarkers reflecting kidney function in a group of RHT patients.

Considering that renal sizes depend on patient anthropometry features, the values of total overall, cortical, and medullary renal volumes (TKV, T-Cortex-V, and T-Medulla-V) were normalized by height (ht-TKV, ht-T-Cortex-V, and ht-T-Medulla-V), body surface area (BSA) (bsa-TKV, bsa-T-Cortex-V, and bsa-T-Medulla-V), and body mass index (BMI) (bmi-TKV, bmi-T-Cortex-V, and bmi-T-Medulla-V), respectively, as follows:

The eFilm 3.4 software (MergeHealth, 2010) was used to analyse images and measure the parameters of interest. Serum cystatin-C and creatinine concentrations were assessed to characterize renal excretory function. eGFR was determined according to equation recommended by Chronic Kidney Disease Epidemiology Collaboration. Office blood pressure was assessed according to routine methodology. Automatic oscilloscope monitors AVRM-04 (Meditech, Hungary) and BPLab (Peter Telegin LLC, Russia) were used to provide 24-hour blood pressure monitoring.

Data were processed with STATISTICA 10.0 software for Windows. Normality of distribution of variables was determined by the Shapiro-Wilk’s test. Data are presented as mean, standard deviation (M ± Sd), median (Me), and interquartile interval (Q1; Q3). Categorical variables are presented as absolute numbers and percentages (n and %). t-test was used to identify the differences between continuous variables in independent samples. Nonparametric Mann-Whitney test was used to identify the significance of differences of data lacking normal distribution. Multiple comparisons tests for...
three independent samples were performed based on the Kruskal–Wallis test. The Pearson correlation coefficient ($r_f$) and univariate regression analysis allowed to assess the associations between the variables. Receiver operating curve (ROC) analysis was used to construct ROC curves and determine the cut off values of quantitative variables; area under the curve was calculated. Values were considered statistically significant when $p$ was < 0.05.

**Results**

**Clinical characteristics of patients**

The study comprised a total of 34 patients aged 57.8 ± 8.4 years with the verified diagnosis of RHT. Known RHT duration was 21 [15; 35] years; 12 patients had stage II, and 22 patients had stage III hypertension; 26 patients had CKD G2 (eGFR ≤ 90 mL/min per 1.73 m$^2$), and 5 patients had CKD G3 (eGFR < 60 mL/min per 1.73 m$^2$); 41% patients had diabetes mellitus. Absolute and relative clinical characteristics and risk factors in patients of study group are given in Table 1.

Results of instrumental studies and biochemical renal tests are presented in Table 2.

**Kidney volumes**

MRI-based mean absolute and indexed renal parenchymal volumes are presented in Table 3.

The values of TKV significantly differed between men and women ($p = 0.002$) (Table 4).

---

**Table 1. Basic clinical characteristics of study patients. Qualitative data**

<table>
<thead>
<tr>
<th>Parameters / Параметры</th>
<th>Total group of patients / Количество пациентов</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years / Возраст, лет</td>
<td>57.8 ± 8.4</td>
</tr>
<tr>
<td>BMI, kg/m$^2$ / ИМТ, кг/м$^2$</td>
<td>34 ± 5.5</td>
</tr>
<tr>
<td>Waist circumference, cm / Окружность талии, см</td>
<td>106.1 ± 13.2</td>
</tr>
<tr>
<td>Duration of hypertension, years / Длительность гипертонии, лет</td>
<td>23 ± 11.6</td>
</tr>
<tr>
<td>Office SBP, mmHg / Офисное САД, мм рт. ст.</td>
<td>164 (153; 162)</td>
</tr>
<tr>
<td>Office DBP, mmHg / Офисное ДАД, мм рт. ст.</td>
<td>92.7 ± 17</td>
</tr>
<tr>
<td>24-h ambulatory SBP, mmHg / ДАД по данным СМАД, мм рт. ст.</td>
<td>158 (150; 167)</td>
</tr>
<tr>
<td>24-h ambulatory DBP, mmHg / ДАД по данным СМАД, мм рт. ст.</td>
<td>89 (76; 102)</td>
</tr>
<tr>
<td>Creatinine, μmol/L / Креатинин, ммоль/л</td>
<td>80.5 ± 14.3</td>
</tr>
<tr>
<td>eGFR, mL/min/1.73 m$^2$ / рСКФ, мл/мин/1.73 м$^2$</td>
<td>77.2 ± 15.2</td>
</tr>
<tr>
<td>Cystatin C, mg/L / Цистатин С, мг/л</td>
<td>725.7 ± 202.1</td>
</tr>
<tr>
<td>Number of antihypertensive drugs / Количество антигипертензивных препаратов</td>
<td>4 (3; 5)</td>
</tr>
</tbody>
</table>

Note: BMI – body mass index, SBP – systolic blood pressure, DBP – diastolic blood pressure, SBP – systolic blood pressure, eGFR – estimated glomerular filtration rate.

Patients were assigned to three groups based on eGFR:
group 1 comprised patients with eGFR > 90 mL/min/1.73 m²;
group 2 comprised patients with eGFR = 60–90 mL/min/
1.73 m²; and group 3 comprised individuals with eGFR < 60
mL/min/1.73 m². No differences between TKV values were
found between groups (p > 0.05). On the contrary, significant
differences were found in ht-TKV values between the groups
with normal renal function, reduced renal function, and stage
3 CKD. Data showed that the groups significantly differed in
cortical volume. The lower the renal cortex index was, the
lower the eGFR values was (Figure 2). A significant difference
was seen in minimal renal cortical volume measured by T2
SE images.

Further correlation analysis was done to detect the
associations between parenchymal volumes and renal function.
ht-TKV was the most informative parameter (Table 5).

Table 4. Comparison of absolute and normalized renal volumes in men and women

<table>
<thead>
<tr>
<th>Characteristics / Параметры</th>
<th>Females / Женщины</th>
<th>Males / Мужчины</th>
<th>p-value / Значение p</th>
</tr>
</thead>
<tbody>
<tr>
<td>TKV</td>
<td>333 ± 77.6</td>
<td>425 ± 66.1</td>
<td>0.002</td>
</tr>
<tr>
<td>ht-TKV</td>
<td>94.9 ± 17.8</td>
<td>93 ± 15.9</td>
<td>0.7</td>
</tr>
<tr>
<td>bsa-TKV</td>
<td>173.8 ± 33.2</td>
<td>202.1 ± 33.5</td>
<td>0.03</td>
</tr>
<tr>
<td>bmi-TKV</td>
<td>9.5 ± 2.5</td>
<td>13.9 ± 2.6</td>
<td>0.000</td>
</tr>
<tr>
<td>T-Cortex-V</td>
<td>118.5 ± 40.5</td>
<td>167.1 ± 31.7</td>
<td>0.001</td>
</tr>
<tr>
<td>ht-T-Cortex-V</td>
<td>33.7 ± 9.9</td>
<td>36.5 ± 6.9</td>
<td>0.4</td>
</tr>
<tr>
<td>bsa-T-Cortex-V</td>
<td>61.8 ± 18.4</td>
<td>79.4 ± 15.1</td>
<td>0.01</td>
</tr>
<tr>
<td>bmi-T-Cortex-V</td>
<td>3.4 ± 1.2</td>
<td>5.5 ± 1.2</td>
<td>0.000</td>
</tr>
<tr>
<td>T-Medulla-V</td>
<td>216.8 ± 50.6</td>
<td>257 ± 46.7</td>
<td>0.03</td>
</tr>
<tr>
<td>ht-T-Medulla-V</td>
<td>61.83 ± 12.5</td>
<td>56.5 ± 11.5</td>
<td>0.2</td>
</tr>
<tr>
<td>bsa-T-Medulla-V</td>
<td>113 ± 23.9</td>
<td>122.7 ± 24.0</td>
<td>0.2</td>
</tr>
<tr>
<td>bmi-T-Medulla-V</td>
<td>8.2 ± 1.7</td>
<td>8.5 ± 1.8</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Note. data are expressed as mean ± standard deviation. TKV — total kidney volume, ht-TKV — total kidney volume indexed by height, bsa-TKV — total kidney volume indexed by body surface area, bmi-TKV — total kidney volume indexed by body mass index, T-Cortex-V — total cortical volume indexed by height, bsa-T-Cortex-V — total cortical volume indexed by body surface area, bmi-T-Cortex-V — total cortical volume indexed by body mass index, T-Medulla-V — total medullary volume, ht-T-Medulla-V — total medullary volume indexed by height, bsa-T-Medulla-V — total medullary volume indexed by body surface area, bmi-T-Medulla-V — total medullary volume indexed by body mass index.


Table 5. Correlations of eGFR values and creatinine levels with indexed kidneys volumes

<table>
<thead>
<tr>
<th>Characteristics / Параметры</th>
<th>eGFR / рСКФ</th>
<th>p-value / уровень p</th>
<th>Creatinine / Креатинин</th>
<th>p-value / уровень p</th>
</tr>
</thead>
<tbody>
<tr>
<td>TKV</td>
<td>0.5406</td>
<td>0.002</td>
<td>-0.1275</td>
<td>0.494</td>
</tr>
<tr>
<td>ht-TKV</td>
<td>0.4751</td>
<td>0.007</td>
<td>-0.4302</td>
<td>0.016</td>
</tr>
<tr>
<td>bsa-TKV</td>
<td>0.6166</td>
<td>0.000</td>
<td>-0.2843</td>
<td>0.121</td>
</tr>
<tr>
<td>bmi-TKV</td>
<td>0.5838</td>
<td>0.001</td>
<td>-0.0852</td>
<td>0.648</td>
</tr>
<tr>
<td>T-Cortex-V</td>
<td>0.4935</td>
<td>0.005</td>
<td>-0.1031</td>
<td>0.581</td>
</tr>
<tr>
<td>ht-T-Cortex-V</td>
<td>0.4906</td>
<td>0.009</td>
<td>-0.3094</td>
<td>0.090</td>
</tr>
<tr>
<td>bsa-T-Cortex-V</td>
<td>0.5401</td>
<td>0.002</td>
<td>-0.2028</td>
<td>0.274</td>
</tr>
<tr>
<td>bmi-T-Cortex-V</td>
<td>0.5439</td>
<td>0.002</td>
<td>-0.0707</td>
<td>0.706</td>
</tr>
<tr>
<td>T-Medulla-V</td>
<td>0.4809</td>
<td>0.006</td>
<td>-0.1282</td>
<td>0.492</td>
</tr>
<tr>
<td>ht-T-Medulla-V</td>
<td>0.3456</td>
<td>0.057</td>
<td>-0.3998</td>
<td>0.026</td>
</tr>
</tbody>
</table>
Moreover, being an essential indicator of preserved renal function, eGFR had positive relationships with almost all volumetric parameters. We observed a direct association of eGFR with renal parenchymal measurements.

Data of one-way regression analysis showed the linear relationships of eGFR and serum creatinine with TKV indexed by height (ht-TKV–eGFR: $r^2 = 0.17, p = 0.013$; ht-TKV–creatinine: $r^2 = 0.16, p = 0.021$) (Figure 3).
ROC analysis allowed to identify MRI marker of renal dysfunction in patients with eGFR below 60 mL/min/1.73 m². The risk of developing CKD and RHT increased along with a decrease in renal parenchymal volume. ht-T-Cortex-V demonstrated the highest diagnostic value (Figure 4).

The results of ROC analysis for other indices were calculated, but were less significant. ht-T-Cortex-V < 32.4 was an MRI marker of renal dysfunction with sensitivity of 83.3% and specificity of 60.7% (p = 0.03) in patients with eGFR below 60 mL/min/1.73 m².

In RHT patients with CKD and T2DM (n = 4), the values of eGFR were below 60 mL/min/1.73 m², i.e. corresponded to CKD grade 3 in the presence of mean ht-T-Cortex-V of 26.9.

Discussion

Our study allowed to identify MRI signs of renal changes characteristic of RHT and prove their clinical significance based on their correlational relationships with renal functional parameters.

We also detected the significant differences in the renal volumes and volumetric indexes depending on gender: the values were higher in men than in women except for the height-indexed values. The sex-related differences persisted when indexed by BMI and BSA, but not height. This observation agrees with the results of Framingham Heart Study, which provided reference TKV values of 415.2 and 322.2 cm³ for men and women, respectively [9]. Our results showed TKV values of 425.1 ± 66.1 cm³ and 333.1 ± 77.5 cm³ in men and women, respectively. No associations were found between renal volumes and age. Our data showed that eGFR significantly decreases along with a decrease in the renal volume. Similar results were obtained by Noda et al. when they compared the renal cortical volumes in groups assigned based on eGFR values [11].

Being a marker of renal dysfunction in RHT, ht-T-Cortex-V was involved in especially remarkable relationships, and we detected a threshold value of 32.4 cm²/m², below which we predicted a decrease in eGFR lower than 60 mL/min/1.73 m². Besides, we found the associations between ht-TKV and creatinine, whereas eGFR value showed correlations of varying degree with all absolute and normalized renal volumes. It does agree with the correlations between eGFR and ultrasonography-based kidney volumes [21].

To interpret obtained results, we would like to mention several pathophysiological processes occurring in the renal parenchyma in RHT and eventually resulting in fibrosis development. Indeed, evidence suggests that age-related micro-anatomical changes in the renal structure include a decrease in the number of functional glomeruli due to nephrosclerosis (arteriosclerosis, glomerulosclerosis, and ductal atrophy with interstitial fibrosis), increase in the number of extracellular matrix fibres, and, to a certain degree, a compensatory residual neophron hypertrophy. Low oxygenation of renal cortex due to chronic hypoxia in RHT contributes to renal function decline [12]. Moreover, comorbidity of T2DM and CHF accelerate the progression of renal fibrosis progression and, correspondingly, attenuate renal function. RHT coexists with T2DM [14] and CKD [15] in the third of patients whose kidneys become the main target organs. MRI signs of renal decline are seen significantly earlier in the presence of RHT concomitant with CKD and T2DM, and MRI approaches allow to assess both renal linear sizes and renal shape closely associated with patient age, body weight, and CKD burden [16].

According to expert opinion, diagnostic value of MRI is similar to that of kidney biopsy, which is considered the method of choice for detecting fibrosis. Modern MRI modalities such as diffusion-weighted imaging (DWI), visualization of the level of oxygenation (BOLD), and arterial spin marking (BOLD) allow high-accuracy quantification of the degree of renal fibrosis without radiation and contrast agent exposure to patient. T1-mapping is a vigorously studied and the most promising method for quantifying renal parenchyma fibrosis. The T1-weighted signal from the renal cortex is elevated in individuals with a decrease in eGFR and impaired corticomedullary differentiation [17]. Taking into account that CKD is a multifactorial disease, the integration of multiparametric MRI with accurate assessments of kidney perfusion, oxygenation, fibrosis severity, and biochemical tests can provide a reliable assessment of the stage of CKD and potentially predict the progression of the disease.

Approaches to measuring renal sizes are diverse. Perhaps, the elliptical approach to quantifying TKV may be the most reliable and easy to perform. In previous studies, TKV and ht-TKV were suggested to be informative renal markers in patients with renal pathology [19]. Our investigation demonstrated ht-T-Cortex-V as a potential MRI sign of renal dysfunction. ht-T-Cortex-V has a high diagnostic value as a marker of renal dysfunction in RHT, ht-T-Cortex-V < 32.4 was an MRI marker of renal dysfunction with sensitivity of 83.3% and specificity of 60.7% (p = 0.03) in patients with eGFR below 60 mL/min/1.73 m².

To interpret obtained results, we would like to mention several pathophysiological processes occurring in the renal parenchyma in RHT and eventually resulting in fibrosis development. Indeed, evidence suggests that age-related micro-anatomical changes in the renal structure include a decrease in the number of functional glomeruli due to nephrosclerosis (arteriosclerosis, glomerulosclerosis, and ductal atrophy with interstitial fibrosis), increase in the number of extracellular matrix fibres, and, to a certain degree, a compensatory residual neophron hypertrophy. Low oxygenation of renal cortex due to chronic hypoxia in RHT contributes to renal function decline [12]. Moreover, comorbidity of T2DM and CHF accelerate the progression of renal fibrosis progression and, correspondingly, attenuate renal function. RHT coexists with T2DM [14] and CKD [15] in the third of patients whose kidneys become the main target organs. MRI signs of renal decline are seen significantly earlier in the presence of RHT concomitant with CKD and T2DM, and MRI approaches allow to assess both renal linear sizes and renal shape closely associated with patient age, body weight, and CKD burden [16].

According to expert opinion, diagnostic value of MRI is similar to that of kidney biopsy, which is considered the method of choice for detecting fibrosis. Modern MRI modalities such as diffusion-weighted imaging (DWI), visualization of the level of oxygenation (BOLD), and arterial spin marking (BOLD) allow high-accuracy quantification of the degree of renal fibrosis without radiation and contrast agent exposure to patient. T1-mapping is a vigorously studied and the most promising method for quantifying renal parenchyma fibrosis. The T1-weighted signal from the renal cortex is elevated in individuals with a decrease in eGFR and impaired corticomedullary differentiation [17]. Taking into account that CKD is a multifactorial disease, the integration of multiparametric MRI with accurate assessments of kidney perfusion, oxygenation, fibrosis severity, and biochemical tests can provide a reliable assessment of the stage of CKD and potentially predict the progression of the disease.

Approaches to measuring renal sizes are diverse. Perhaps, the elliptical approach to quantifying TKV may be the most reliable and easy to perform. In previous studies, TKV and ht-TKV were suggested to be informative renal markers in patients with renal pathology [19]. Our investigation demonstrated ht-T-Cortex-V as a potential MRI sign of renal dysfunction. ht-T-Cortex-V has a high diagnostic value as it is independent on gender and anthropometry while being valuable for evaluation of renal function.

T2DM and CKD aggravate adaptive hypertrophy of functional glomeruli in RHT patients and are associated with unfavourable global glomerulosclerosis and arteriolar hyalinosis [18]. Therefore, we pioneered suing MRI for both qualitative and quantitative studies of kidneys in patients with RHT. The convenience of proposed MRI-based method consists in easily achievable distinction between renal cortical and medullary layers without using contrast agents.
Direct associations found between MRI-assessed TKV and eGFR in our study are similar to the correlations between eGFR values and ultrasonography-based kidney volumetric parameters [21].

### Study limitations

Renal function was assessed based on eGFR value calculated using the serum creatinine level whereas the use of insulin and some other markers of glomerular filtration are considered more precise. Our single-centre study included relatively small number of patients. Renal MRI and follow up examinations were performed by one experienced researcher.

### Conclusions

Quantitative assessment of MRI metrics provides information essential for understanding renal changes in RHT. As a measure of renal function, eGFR is closely associated with height-indexed ht-TKV and ht-T-Cortex-V. Considering sex-independent strong relationship between ht-T-Cortex-V and renal function, we encourage other researchers to use this index in future research. Further identification of factors associated with the structural renal changes may contribute to the development of targeted therapy for RHT where renal derangement may be considered a therapeutic option. In this regard, the assessment of potential effects of renal denervation on the loss of renal parenchyma is warranted. Further studies are needed to test the hypothesis that abnormal renal filtration function in RHT is closely associated with the processes of renal tubulointerstitial fibrosis and decline in kidney cortical volume whose severity depends on the array of hemodynamic and non-hemodynamic factors including arterial blood pressure, hemodynamic load duration, chronic low-intensity inflammation, and metabolic abnormalities. Testing this hypothesis may involve the assessment of relationships of renal sizes, especially ht-T-Cortex-V, with arterial blood pressure, hypertension duration, T2DM, and biochemical parameters. Better understanding of renal changes in RHT pathophysiology is vital for improving clinical outcomes in this vulnerable category of patients. Based on obtained results, we encourage medical doctors to refer RHT patients for comprehensive MRI examinations in order to detect early signs of CKD, provide accurate diagnosis, and generate new scientific knowledge.
Информация о вкладе авторов

Рюмина Н.И. – проведение МРТ почек, выполнение статистической обработки материала, создание иллюстративного материала, анализ полученных данных, подготовка черновика рукописи с проработкой интеллектуального содержимого, сопровождение рукописи на всех этапах подачи и редактирования в журнале.

Зобанова И.В. – набор клинического материала, проработка интеллектуального содержимого.

Сухарева А.Е. – проработка МРТ почек в подтверждение концепции и дизайн исследования, написание черновика рукописи с проработкой интеллектуального содержимого, утверждение рукописи перед подачей в редакцию.

Усов В.Ю. – разработка концепции и дизайн исследования, утверждение рукописи перед подачей в редакцию.

Information on author contributions

Ryuminina N.I. – conducting kidney MRT, performing statistical processing of the material, creating illustrative material, analyzing the data obtained, preparing a draft of the manuscript with the elaboration of intellectual content, accompanying the manuscript at all stages of submission and peer-review in the journal.

Zobanova I.V. – collection of clinical material, elaboration of intellectual content.

Sukhareva A.E. – elaboration of intellectual content and preparing a draft of the manuscript.

Ussov V.Yu. – development of the concept and design of the study, writing a draft of the manuscript with the elaboration of intellectual content, and approval of the manuscript for submission to the editorial office.

Усов В.Ю. – development of the concept and design of the study and approval of the manuscript for submission to the editorial office.
Сведения об авторах

Рюмшина Надежда Игоревна, канд. мед. наук, научный сотрудник, отделение рентгеновских и томографических методов диагностики, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0002-6158-026X.
E-mail: n.rumshina@list.ru.

Зюбанова Ирина Владимировна, канд. мед. наук, научный сотрудник, отделение артериальных гипертоний, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0001-6995-9875.
E-mail: zyubanovain@mail.ru.

Сухарева Анна Евгеньевна, канд. мед. наук, младший научный сотрудник отделения рентгеновских и томографических методов диагностики, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0003-4807-3762.
E-mail: doctor-anyuta@mail.ru.

Манукян Мушег Айкович, аспирант, отделение артериальных гипертоний, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0003-3577-1895.
E-mail: manukyan.musheg@yandex.ru.

Анфиногенова Нина Джоновна, д-р мед. наук, ведущий научный сотрудник, отделение популяционной кардиологии, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0003-1106-0730.
E-mail: cardio.info@gmail.com.

Гусакова Анна Михайловна, канд. фарм. наук, научный сотрудник, отделение клинической лабораторной диагностики, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0002-3147-3025.
E-mail: anna@cardio-tomsk.ru.

Фальковская Алла Юрьевна, д-р мед. наук, заведующий отделением артериальных гипертоний, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0002-5638-3034.
E-mail: alia@cardio-tomsk.ru.

Усов Владимир Юрьевич, д-р мед. наук, профессор, ведущий научный сотрудник, Научно-исследовательский институт кардиологии, Томский национальный исследовательский медицинский центр Российской академии наук. ORCID 0000-0001-7978-5514.
E-mail: ussov1962@yandex.ru.

Information about the authors

Nadezhda I. Ryumshina, Cand. Sci. (Med.), Research Scientist, Department of Radiology and Tomography, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0002-6158-026X.
E-mail: n.rumshina@list.ru.

Irina V. Zyubanova, Cand. Sci. (Med.), Research Scientist, Department of Hypertension, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0001-6995-9875.
E-mail: zyubanovain@mail.ru.

Anna E. Sukhareva, Cand. Sci. (Med.), Junior Research Scientist, Department of Radiology and Tomography, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0003-4807-3762.
E-mail: doctor-anyuta@mail.ru.

Musheg A. Manukyan, Postgraduate Student, Department of Hypertension, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0003-3577-1895.
E-mail: manukyan.musheg@yandex.ru.

Nina D. Anfinoghenova, Dr. Sci. (Med.), Leading Research Scientist, Department of Cardiovascular Epidemiology, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0003-1106-0730.
E-mail: cardio.info@gmail.com.

Anna M. Gusakova, Cand. Sci. (Pharm.), Research Scientist, Department of Functional and Laboratory Diagnostics, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0002-3147-3025.
E-mail: anna@cardio-tomsk.ru.

Alia Y. Falkovskaya, Dr. Sci. (Med.), Head of Department of Hypertension, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0002-5638-3034.
E-mail: alia@cardio-tomsk.ru.

Wladimir Y. Ussov, Dr. Sci. (Med.), Professor, Leading Research Scientist Department of Radiology and Tomography, Cardiology Research Institute, Tomsk National Research Medical Center, Russian Academy of Sciences. ORCID 0000-0001-7978-5514.
E-mail: ussov1962@yandex.ru.

Nadezhda I. Ryumshina, e-mail: n.rumshina@list.ru.

Received November 19, 2021