The Analysis Study of Effectiveness and Diagnostic Performance of Magnetic Resonance Imaging for Early Identification of Chronic Kidney Disease: A Comprehensive Systematic Review

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ABSTRACT

Background: Chronic kidney disease (CKD) is a global health and economic burden and a raising cause of global deaths. Functional magnetic resonance imaging (fMRI) has been used to evaluate renal oxygenation and fibrosis. The aim of this study to show effectiveness and diagnostic performance of magnetic resonance imaging for early identification of chronic kidney disease.

Methods: By the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020, this study was able to show that it met all of the requirements. Several different online reference sources, like Pubmed, SagePub, and Sciencedirect were used to do this.

Result: Eight publications were found to be directly related to our ongoing systematic examination after a rigorous three-level screening approach.

Conclusion: MRI biomarkers may be able to pick up early signs of disease progression that have not yet led to a discernible effect on markers in blood and urine. MRI is the only technique able to study the renal medulla in vivo, an area that may play an important role in the pathogenesis of CKD and AKI.

Keyword: Chronic kidney disease, diagnostic imaging, magnetic resonance imaging.
INTRODUCTION

Chronic kidney disease (CKD) is a major public health challenge and a leading cause of morbidity and mortality. About 8 – 16% of the world population is affected by CKD with increased risk for end-stage renal disease, cardiovascular disease, and death. To date, no specific treatment has shown to arrest the progression of CKD, except dialysis or kidney transplantation. Considering the high cost of renal replacement therapy, the growing prevalence of CKD has implications for health and social care systems especially for developing nations.1,2

Kidney disorders are usually diagnosed by biochemical measurements of serum and blood, but these tests are often insufficiently sensitive or specific to make a definitive diagnosis. Measuring serum creatinine, for example, is the most common method of detecting a reduction in glomerular filtration, but it is an insensitive marker of kidney function and it does not discriminate between the different causes of kidney injury. Anatomic changes can also be difficult to evaluate. In patients with renal artery stenosis, for example, similar degrees of vascular obstruction seen on ultrasound or angiography can have very different functional consequences. New methods for detecting molecular, anatomic, and functional changes within the kidney would therefore improve our ability to diagnose many different diseases.3–5

Functional magnetic resonance imaging (MRI) of the kidney has seen great advances, now offering quantitative biomarkers with the potential to improve the management of kidney disease alongside drug development. Despite several cross-sectional studies showing the correlation between MRI biomarkers, glomerular filtration rate, and pathologic lesions, the potential of kidney MRI to monitor response to therapy in chronic kidney disease (CKD) remains undescribed.6–8

Non-invasive and quantitative imaging technologies provide a unique opportunity to investigate
renal disease in living subjects over time. Magnetic resonance imaging (MRI) is a widespread technique that is able to provide excellent anatomical images with high contrast and an adequate image resolution. Further, functional magnetic resonance (MR) imaging techniques are increasingly performed to evaluate renal function and injury. These include perfusion, diffusion, and blood oxygenation level-dependent (BOLD) imaging. Because functional, molecular and cellular changes precede anatomic changes, functional MR imaging enables the early detection of renal disease as well as improved understanding of disease pathogenesis that could facilitate the development of better treatment options and improve patient prognosis.9,10

METHODS

Protocol

By following the rules provided by Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020, the author of this study made certain that it was up to par with the requirements. This is done to ensure that the conclusions drawn from the inquiry are accurate.

Criteria for Eligibility

For the purpose of this literature review, we compare and contrast effectiveness and diagnostic performance of magnetic resonance imaging for early identification of chronic kidney disease. It is possible to accomplish this by researching of effectiveness and diagnostic performance of magnetic resonance imaging for early identification of chronic kidney disease. As the primary purpose of this piece of writing, demonstrating the relevance of the difficulties that have been identified will take place throughout its entirety.

In order for researchers to take part in the study, it was necessary for them to fulfill the following requirements: 1) The paper needs to be written in English, and it needs to determine about effectiveness and diagnostic performance of magnetic resonance imaging for early identification of chronic kidney disease. In order for the manuscript to
be considered for publication, it needs to meet both of these requirements. 2) The studied papers include several that were published after 2014, but before the time period that this systematic review deems to be relevant. Examples of studies that are not permitted include editorials, submissions that do not have a DOI, review articles that have already been published, and entries that are essentially identical to journal papers that have already been published.

Search Strategy

We used "effectiveness and diagnostic performance of magnetic resonance imaging for early identification of chronic kidney disease.” as keywords. The search for studies to be included in the systematic review was carried out using the PubMed, SagePub, and Sciencedirect databases.

Data retrieval

After reading the abstract and the title of each study, the writers performed an examination to determine whether or not the study satisfied the inclusion criteria. The writers then decided which previous research they wanted to utilise as sources for their article and selected those studies. After looking at a number of different research, which all seemed to point to the same trend, this conclusion was drawn. All submissions need to be written in English and cannot have been seen anywhere else.

Only those papers that were able to satisfy all of the inclusion criteria were taken into consideration for the systematic review. This reduces the number of results to only those that are pertinent to the search. We do not take into consideration the conclusions of any study that does not satisfy our requirements. After this, the findings of the research will be analysed in great detail. The following pieces of information were uncovered as a result of the inquiry that was carried out for the purpose of this study: names, authors, publication dates, location, study activities, and parameters.

Quality Assessment and Data Synthesis
Each author did their own study on the research that was included in the publication's title and abstract before making a decision about which publications to explore further. The next step will be to evaluate all of the articles that are suitable for inclusion in the review because they match the criteria set forth for that purpose in the review. After that, we'll determine which articles to include in the review depending on the findings that we've uncovered. This criteria is utilised in the process of selecting papers for further assessment. in order to simplify the process as much as feasible when selecting papers to evaluate. Which earlier investigations were carried out, and what elements of those studies made it appropriate to include them in the review, are being discussed here.

Table 1. Search Strategy

<table>
<thead>
<tr>
<th>Database</th>
<th>Search Strategy</th>
<th>Hits</th>
</tr>
</thead>
</table>
Identification of studies via databases and registers

Records identified from*: PubMed (n:44067) SageJournal (n:14) Sciencedirect (n: 1393)

Records screened

Records remove before screening:
Duplicate records removed (39860)
Records marked as ineligible by automations tools (1197)

Reports sought for retrieval (12)

Records exclude*:
Wrong population (4267)
Wrong study design (92)
Wrong intervention (32)

Reports assessed for eligibility (12)

Reports not retrieved (0)

Reports exclude (4) due to:
No comparison (3)

Studies include in systematic review (8)

Figure 1. Article search flowchart
## Table 2. Critical appraisal of Study

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</tr>
</thead>
<tbody>
<tr>
<td>1. Bias related to temporal precedence</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Is it clear in the study what is the “cause” and what is the “effect” (i.e., there is no confusion about which variable comes first)?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>2. Bias related to selection and allocation</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Was there a control group?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>3. Bias related to confounding factors</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Were participants included in any comparisons similar?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Were the participants included in any comparisons receiving similar treatment/care, other than the exposure or intervention of interest?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Bias related to assessment, detection, and measurement of the outcome</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Were there multiple measurements of the outcome, both pre and post the intervention/exposure?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Were the outcomes of participants included in any comparisons measured in the same way?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Were outcomes measured in a reliable way?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Bias related to participant retention</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Was follow-up complete and, if not, were differences between groups in terms of their follow-up adequately described and analyzed?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>7. Statistical conclusion validity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Was appropriate statistical analysis used?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
RESULT

Using reputable resources like Science Direct, PubMed, and SagePub, our research team first gathered 45474 publications. A thorough three-level screening strategy was used to identify only eight papers as directly relevant to our ongoing systematic evaluation. Next, a thorough study of the entire text and further examination of these articles were selected. Table 1 compiles the literature that was analyzed for this analysis in order to make it easier to view.

Table 3. The literature include in this study

<table>
<thead>
<tr>
<th>Author</th>
<th>Origin</th>
<th>Method</th>
<th>Sample</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yu, B et al., 2022</td>
<td>China</td>
<td>A retrospective analysis was performed to</td>
<td>84</td>
<td>There was a significant difference in sex and body mass index (BMI) (P &lt;0.05) in the primary cohort, with no significant difference in age.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>analyze 44 healthy volunteers (group A) and</td>
<td></td>
<td>In the final results, the wavelet and Laplacian–Gaussian filtering are used to extract 1,892 image features from the original T1WI image, and the LASSO algorithm is used for selection.</td>
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<td></td>
<td></td>
<td>40 patients with stage III type 2 diabetic</td>
<td></td>
<td>One first-order feature and six texture features are selected through 10 cross-validations. In the mass, 1,638 imaging extracts features from the original T2WI image.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>nephropathy (group B) with microalbuminuria.</td>
<td></td>
<td>1 first-order feature and 5 texture features were selected. A total of 1,241 imaging features were extracted from the original ADC images, and 5 texture features were selected. Using LASSO-Logistic regression analysis, 10 features were selected for modeling, and a combined diagnosis model of diabetic nephropathy based on texture features was</td>
</tr>
</tbody>
</table>
established. The average unit cost in the logistic regression model was 0.98, the 95% confidence interval for the predictive efficacy was 0.9486–1.0, specificity 0.97 and precision 0.93, particularly. ROC curves also revealed that the model could distinguish with high sensitivity of at least 92%.

Zhao, K et al., 2023
China
This study was registered at the Chinese Clinical Trial Registry Center (registration number: ChiCTR-RRC-17012687). Sixty-seven DKD patients were prospectively randomly enrolled and underwent clinical examination and diffusion-weighted magnetic resonance imaging (DW-MRI).

ADC
cortex presented superior performance in discriminating DKD with normal and declined estimated glomerular filtration rate (eGFR) over ADC medulla, ΔADC and renal compartment volumes with an AUC of 0.904 (sensitivity of 83% and specificity of 91%) and was moderately correlated with the clinical biomarkers eGFR and proteinuria (P<0.05). The Cox survival analysis demonstrated that ADC cortex rather than ΔADC is a predictor of renal outcomes with a hazard ratio of 3.4 (95% CI: 1.1–10.2, P<0.05) independent of baseline eGFR and proteinuria.

Mo, X et al., 2023
China
A retrospective study of 174 diabetic patients (training cohort, n = 123; validation cohort, n = 51) who underwent renal MRI scans was included. They were assigned to normal function (n = 71), mild or moderate impairment (n = 69), and severe impairment groups (n = 34) according to renal function.

The models based on LC-K and All-K achieved the nonsignificantly highest accuracy in the classification of renal function (all p values > 0.05). The optimal model yielded high performance in classifying the normal function, mild or moderate impairment, and severe impairment, with an area under the curve of 0.938 (95% confidence interval [CI] 0.935–0.940), 0.919 (95%CI 0.916–0.922), and 0.959 (95%CI 0.956–0.962) in the training
<table>
<thead>
<tr>
<th>Authors</th>
<th>Country</th>
<th>Study Description</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feng, YZ et al., 2021</td>
<td>China</td>
<td>A total of 48 patients with hyperuricemia (HU) and 22 age-matched healthy control subjects (HC) were enrolled in the study. For each participant, three different functional magnetic resonance imaging (fMRI) sequences were acquired and analyzed, including intravoxel incoherent motion imaging (IVIM), diffusion tensor imaging (DTI), and blood-oxygen-level-dependent MRI (BOLD).</td>
<td>Ten parametric values of the HU group were significantly lower than those of the HC group among the 14 fMRI parameters ($P &lt; 0.05$). The cortical D, D*, and $f$ values and medullary D and R2* values had significant differences between the AH and GA groups ($P &lt; 0.05$). Combining the cortical D and $f$ values and medullary R2* value gave the best diagnostic efficacy, yielding an AUC, sensitivity, and specificity of $0.967 \pm 0.022$, 91.67%, and 95.83%, respectively.</td>
</tr>
<tr>
<td>He, L et al., 2022</td>
<td>China</td>
<td>CKD patients ($n = 186$) were recruited and underwent diagnosis of renal diffusion tensor imaging findings generated by MRI (DTI-MRI) or DTI-GBMRI to identify the pathological characteristics and depict renal efficiency. The cortical RBFs and estimated glomerular filtration rate were compared in CKD patients undergone DTI-GBMRI ($n = 92$) or DTI-MRI ($n = 94$).</td>
<td>Gadolinium enhanced the diagnosis generated by DTI-MRI in renal fibrosis, renal damage, and estimated glomerular filtration rate. The superiority in sensitivity and accuracy of the DTI-GBMRI method in assessing renal function and evaluating renal impairment was observed in CKD patients compared with DTI-MRI. Outcomes demonstrated that DTI-GBMRI had higher accuracy, sensitivity, and specificity than DTI-MRI in diagnosing patients with CKD.</td>
</tr>
<tr>
<td>Goyal, A et al., 2018</td>
<td>India</td>
<td>One hundred and twenty adult patients underwent MDCT (40-row and 128-row scanners), MRI (at 1.5 T), and DWI (at b-</td>
<td>AUC for MDCT (0.834) and MRI (0.841) in the classification of benign and malignant lesions were within corresponding 95% confidence</td>
</tr>
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</table>
values of 0 and 500 s/mm²) for characterization of 225 renal lesions. There were 65 malignant neoplasms (44 RCCs), 25 benign neoplasms, 25 abscesses, 45 pseudotumors, 15 hemorrhagic cysts, and 50 benign cysts. interval (CI) \( (P = 0.88) \) whereas MRI + DWI had significantly better performance \( \text{AUC} 0.968, P = 0.0002 \) and 0.0004, respectively). Both CT and MRI had low specificity (66.9% and 68.8%, respectively), which increased substantially with DWI (93.8%) owing to correct diagnosis of pseudotumors. MRI was superior to CT in diagnosing necrotic RCC and hemorrhagic cysts. MRI + DWI had the highest accuracy (94.2%) in assigning the definitive diagnosis and 97.6% lesions were diagnosed with very high confidence, significantly better than CT and MRI. Both CT and MRI had the same accuracy (86.1%) in RCC staging and evaluation of intravascular thrombi.

<table>
<thead>
<tr>
<th>Makvandi, k et al., 2022(^1)</th>
<th>Sweden</th>
<th>In the cross-sectional part of this prospective observational study, 38 subjects ages 18–79 years with type 2 diabetes and DKD [estimated glomerular filtration rate ( \text{eGFR} ) 15–60 mL/min/1.73 m(^2)] and 20 age- and gender-matched healthy volunteers (HVs) underwent mpMRI. Repeat mpMRI was performed on 23 DKD subjects and 10 HVs.</th>
<th>92</th>
<th>Several MRI biomarkers differentiated diabetic from healthy kidneys and distinct GFR stages (G3 versus G4/G5); mean arterial flow (MAF) was the strongest predictor (sensitivity 0.94 and 1.0, specificity 1.00 and 0.69; ( P = .04 ) and .004, respectively). Parameters significantly correlating with mGFR were specific measures of kidney haemodynamics, oxygenation, microstructure and macrostructure, with MAF being the strongest univariate predictor ( (r = 0.92; P &lt; .0001) ).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hara, Y et al., 2022(^1)</td>
<td>Japan</td>
<td>MRI images were acquired using a 3.0 Tesla superconducting unit (Skyra, Siemens Healthcare, Erlangen,</td>
<td>166</td>
<td>The T1-weighted in-phase (IP)/opposed-phase (OP)/water-only (WO) images showed good reproducibility in the inter-observer</td>
</tr>
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</table>
Germany) with a spine coil and an 18-channel phased-array body coil. The standard dedicated MRI protocol consisted of the following sequences: Dixon-based T1WI with the 3D gradient-echo method, DWI with multiple b-factors, and T2*WI with multiple gradient-echoes obtained in the coronal plane.

reproducibility analysis, with mean interclass correlation coefficient (ICC) values of 0.767, 0.774, and 0.781, respectively.
DISCUSSION

Chronic kidney disease (CKD) has become a paramount concern for health worldwide, impacting millions of people globally, with a global prevalence estimated to be between 10.5% and 13.1%. CKD is identified by the gradual inefficiency of kidney functioning demonstrated by an estimated glomerular filtration rate (eGFR) of 60 milliliters per minute per 1.73 m², the existence of kidney damage-related symptoms for more than 90 days, or both. It is characterized by the lowering of renal functioning with time, which increases the risks of dialysis, hospitalization, cardiovascular morbidity, and death. Timely diagnosis of CKD offers a vital opportunity to avert complications and postpone the progressive loss of renal function.¹⁹,²⁰

Interest has turned recently to the use and potential of MRI and the detailed structural and functional readouts it can provide to non-invasively assess and quantify pathophysiological changes in CKD. As one of the foremost imaging techniques to aid medical diagnoses, MRI is the method of choice for diseased (and normal) soft tissue because the contrast can be “tailored” using multiple “weighting” or “sensitization” techniques. Thus, MRI can distinguish between tissue types and organs despite their very similar water content. The contrast generated by these sensitization techniques reflects aspects of the physicochemical environment of the water molecules in the tissue. Tissue properties, such as tissue microstructure, composition, metabolism, function, and gross morphology, can be assessed with quantitative imaging biomarkers.²¹,²²

Current methods to assess CKD (e.g. serum creatinine, albuminuria and ultrasound) are insensitive to early kidney damage, do not usually provide insight into the aetiology of underlying kidney disease and do not reliably allow individual patient stratification in terms of prognosis or therapy decisions. Kidney biopsy is the only current method to assess renal microstructure, but it has several disadvantages, including its invasive...
nature and susceptibility to sampling bias. The clinical need for more specific diagnostic and prognostic tools is seen across the patient pathway and improved biomarkers that can determine the aetiology of kidney disease or characterize the dominant pathophysiological process in individual patients are urgently required. Recent developments in functional and quantitative renal magnetic resonance imaging (MRI) techniques show great potential to address these challenges. There are now several techniques to generate MRI biomarkers, which can measure biophysical tissue properties that have been linked to fibrosis, inflammation, tissue oedema, perfusion, filtration and tissue oxygenation.23,24

Magnetic resonance imaging (MRI) provides powerful tools for noninvasive assessment of renal function. Arterial spin labeling (ASL) uses endogenous blood as a tracer to measure renal perfusion. Blood oxygenation-level-dependent (BOLD) MRI probes renal oxygenation level by taking advantage of the paramagnetic property of deoxyhemoglobin, which increases the effective transverse relaxation rate $R_z^*$. Diffusion MRI measures tissue apparent diffusion coefficient (ADC), which is considered to be lowered by renal fibrosis. In the current issue of American Journal of Nephrology, Prasad and colleagues evaluated the utility of these MRI techniques in assessment of renal function assessment and prediction of CKD progression in patients with diabetes and stage 3 CKD, an early stage CKD with important clinical implications.25,26

**CONCLUSION**

In conclusion, MRI biomarkers may be able to pick up early signs of disease progression that have not yet led to a discernible effect on markers in blood and urine. In addition, MRI biomarkers are unique among diagnostic tools in that they characterize the entire kidney in high-spatial detail, are able to detect cortico-medullary and left-right changes separately, do not use ionizing radiation and can assess the degree of functional heterogeneity across the kidney. MRI is the only
technique able to study the renal medulla \textit{in vivo}, an area that may play an important role in the pathogenesis of CKD and AKI.

REFERENCES


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