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REVIEW ARTICLE

Diagnostic value of visceral adiposity index in chronic kidney disease: a meta-analysis

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Abstract

Aims Several studies have revealed inconsistencies about the predictive properties of visceral adiposity index (VAI) in identifying chronic kidney disease (CKD). To date, it is unclear whether the VAI is a valuable diagnostic tool for CKD. This study intended to evaluate the predictive properties of the VAI in identifying CKD.

Methods The PubMed, Embase, Web of Science, and Cochrane databases were searched for all studies that met our criteria from the earliest available article until November 2022. Articles were assessed for quality using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2). The heterogeneity was explored with the Cochran Q test and I^2 test. Publication bias was detected using Deek's Funnel plot. Review Manager 5.3, Meta-disc 1.4, and STATA 15.0 were used for our study.

Results Seven studies involving 65,504 participants met our selection criteria and were therefore included in the analysis. Pooled sensitivity (Sen), specificity (Spe), positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic odds ratio (DOR) and area under the curve (AUC) were 0.67 (95%CI: 0.54–0.77), 0.75 (95%CI: 0.65–0.83), 2.7 (95%CI: 1.7–4.2), 0.44 (95%CI: 0.29–0.66), 6 (95%CI:3.00–14.00) and 0.77 (95%CI: 0.74–0.81), respectively. Subgroup analysis indicated that mean age of subjects was the potential source of heterogeneity. The Fagan diagram found that the predictive properties of CKD were 73% when the pretest probability was set to 50%.

Conclusions The VAI is a valuable agent in predicting CKD and may be helpful in the detection of CKD. More studies are needed for further validation.

Keywords Meta-analysis · Visceral adiposity index (VAI) · Chronic kidney disease (CKD)

Introduction

Chronic kidney disease (CKD) is an increasingly prominent health concern, with a prevalence of 11.6% in adults aged ≥ 45 years in the United States, and 10.8% in China [1, 2]. The early identifier of CKD is critical for its prognosis, and the clinical diagnosis of CKD mainly based on glomerular filtration rate (GFR) or albuminuria, but GFR or albuminuria needs to be measured repeatedly for more than three months [3]. CKD is relatively difficult for diagnosis, particularly in early stages [4]. Some renal functions have been damaged before symptoms appear, so it is a research issue to rely on biomedical laboratory indicators to diagnose CKD [4].

Obesity is closely related to CKD, and obesity-related subclinical inflammation and oxidative stress might directly contribute to renal damage [5, 6]. In addition, obesity-induced insulin resistance can lead to podocyte damage [7]. Several studies have confirmed that fat accumulation

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products are independent risk indicators for the prediction and diagnosis of CKD [8–10]. Data from human body constitutes these indicators, which reflect the level of fat metabolism. The visceral adiposity index (VAI), first developed by Amato and colleagues in 2009, is a mathematical method that consists of body mass index, waist circumference, triglycerides and high-density lipoprotein [11]. The VAI is a reliable agent of interior fat accumulation and dysfunction. The VAI has been linked with several metabolic diseases, including hypertension, prehypertension, type-2 diabetes, hyperuricemia, cardiovascular disease, and dementia [12–17].

The diagnostic value of the VAI is very attractive because laboratory indicators are cheap and routine, and the calculation is simple. A great many of studies have evaluated the diagnostic ability of the VAI in identifying CKD [8–10, 18–20], with several showing that the VAI is superior in comparison with other laboratory indicators[8, 19, 20]. Despite the benefit shown by these studies, the diagnostic properties of the VAI remain controversial. Besides, some limitations, such as insufficient sample size, subject variations, may affect the diagnostic value of different study. Therefore, the main purpose of current study is to perform a meta-analysis of diagnostic tests for predicting the accuracy of the VAI in identifying CKD.

Methods

This study was carried out following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines [21].

Search strategy

A comprehensive bibliographic search was conducted using the PubMed, Embase, Cochrane, and Web of Science databases. All literatures published until November 7, 2022 were included in this review. The search strategy involved following key words: "visceral adiposity index," "visceral fat indexes," "visceral adipose index," "VAI," "VFI," "chronic kidney diseases," "chronic renal insufficiencies," "chronic renal diseases," "CKD," and "diagnosis."

Selection criteria

The inclusion criteria were as follows: (1) studies evaluated the relationship between VAI and CKD, and provided available data (the true-positive value (TP), false-positive value (FP), false-negative value (FN), and true-negative value (TN)) or studies have enough information to produce these data, (2) studies whose subjects were diagnosed with CKD based on a urinary albumin/creatinine ratio (UACR) of ≥ 30 mg/g or an estimated GFR (eGFR) of ≤ 60 ml/min/1.73 m^2, and (3) studies published or translated into English.

The exclusion criteria were as follows: (1) Repetitive literature, animal research, review or case report, (2) studies without definite diagnostic criteria for CKD, and (3) studies without enough information to generate diagnosis related data.

Data extraction

The following data were extracted from each article: first author's last name, year of publication, country, sample size, average age, diagnostic criteria for CKD, diagnostic data (TP, FP, FN, TN).

Quality assessment

Two independent reviewers (TT F and QL Z) assessed the articles. The disagreements were resolved by a third investigator (H Z). The Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) criteria was used to assess these studies' quality [22]. QUADAS-2 included nine questions, each question was answered as low risk, high risk, or unclear risk of bias. Review Manager 5.3 software was used to visualize the risk of bias in the included studies.

Statistical analysis

Meta-Disc 1.4 and STAT 15.0 software were used for analysis. The diagnostic value of VAI in patients with CKD was assessed by the pooled sensitivity (Sen), specificity (Spe), positive likelihood ratio (PLR), negative likelihood ratio (NLR), diagnostic odds ratio (DOR) and 95% confidence interval (CI), based on bivariate generalized linear mixed modelling. The area under the comprehensive receiver operating characteristic (SROC) curve was estimated. Threshold effect was tested using Spearman correlation analysis. Statistical heterogeneity was evaluated using the Cochran-Q test and I^2 test. If there was significant heterogeneity ($I^2 > 50\%$, $P < 0.05$), the data were pooled by random effect model, otherwise, fixed effect model was used. We also used meta-regression and subgroup analysis to explore potential variability among groups, and subgroup was grouped according to country, gender, average age, and diagnostic criteria for CKD. Publication bias was assessed using Deek's funnel plot. Diagnostic ability of the VAI was evaluated by a Fagan plot. $P < 0.05$ was considered significant.

Results

Search results

A total of 3,894 articles were collected, of which 3,113 were found to be duplicate records and were thus excluded. In addition, 699 articles were eliminated due to inclusion and exclusion criteria. Finally, 82 full-text articles were assessed for eligibility, among which, 64 records irrelevant to diagnostic test were excluded, 11 studies were removed due to insufficient data. Finally, 7 articles that met all of our selection criteria were included in this meta-analysis [8–10, 18–20, 23] (Table 1). The full search strategy is provided in Fig. 1.

Study characteristics and quality assessment

The characteristics of the screened studies are listed in Table 1. These studies were published between 2018 and 2022 and involved 65,504 participants. Six articles were

Table 1 Main characteristics of studies

Study	Country/ Region	Mean age	Diagnostic methods	Sample size	Cut off	Sen	Spe	TP	FP	FN	TN
Chen 2018	Taiwan	39[a]; 38[b]	eGFR	23,570	2.96	67.7%	65.1%	157	8145	75	15,193
Chen(a) 2020	China	63.9 ± 12.6	eGFR + UACR	1002	1.21	72.9%	43.4%	124	471	46	361
Chen(b) 2020	China	63.6 ± 13.4	eGFR + UACR	1718	1.88	54.1%	68.6%	145	455	123	995
Chen(a) 2021	Taiwan	64	eGFR + UACR	141	2.86	32.0	91.0	10	10	21	100
Chen(b) 2021	Taiwan	62	eGFR + UACR	259	2.03	48.0	74.0	24	54	26	155
Dong(a) 2018	China	56.48 ± 13.13	eGFR	13,410	13.60	37.8%	71.8%	258	3588	424	9140
Dong(b) 2018	China	56.48 ± 13.13	eGFR	16,106	9.60	42.0%	71.7%	375	4313	519	10,899
Seong 2021	South Korea	69.37 ± 9.50[a] 71.21 ± 9.42[b]	eGFR	4947	1.40	60.5%	59.9%	101	1917	66	2863
Wan(a) 2020	China	68.89 ± 8.94	eGFR + UACR	1949	–	63.6%	52.5%	300	702	171	776
Wan(b) 2020	China	68.85 ± 8.97	eGFR + UACR	1875	–	57.8%	68.7%	244	455	178	998
Li(1)(a) 2022	China	49.64 ± 13.78	eGFR	214	1.51	86.8%	91.2%	149	4	23	38
Li(1)(b) 2022	China	51.96 ± 12.46	eGFR	70	1.81	98.1%	72.7%	58	3	1	8
Li(2)(a) 2022	China	49.64 ± 13.78	eGFR	148	2.35	83.5%	86.1%	66	1	13	68
Li(2)(b) 2022	China	51.96 ± 12.46	eGFR	95	3.11	84.6%	83.8%	22	11	4	58

CKD chronic kidney disease; *UACR* urinary albumin/creatinine ratio; *eGFR* estimated glomerular filtration rate; *Sen*, sensitivity; *Spe* specificity; *TP* true positive value; *FP* false positive value; *FN* false negative value; *TN* true negative value

[a]Male; [b]Female. (a), male; (b), female; (1), chronic kidney disease combined with type 2 diabetes mellitus; (2), chronic kidney disease not combined with type 2 diabetes mellitus

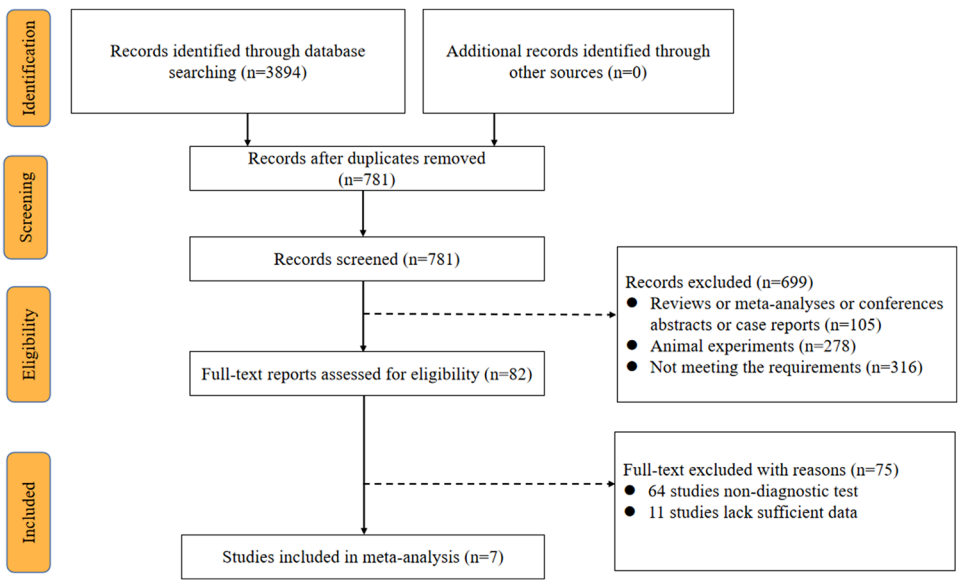

Fig. 1 Systematic review flow chart

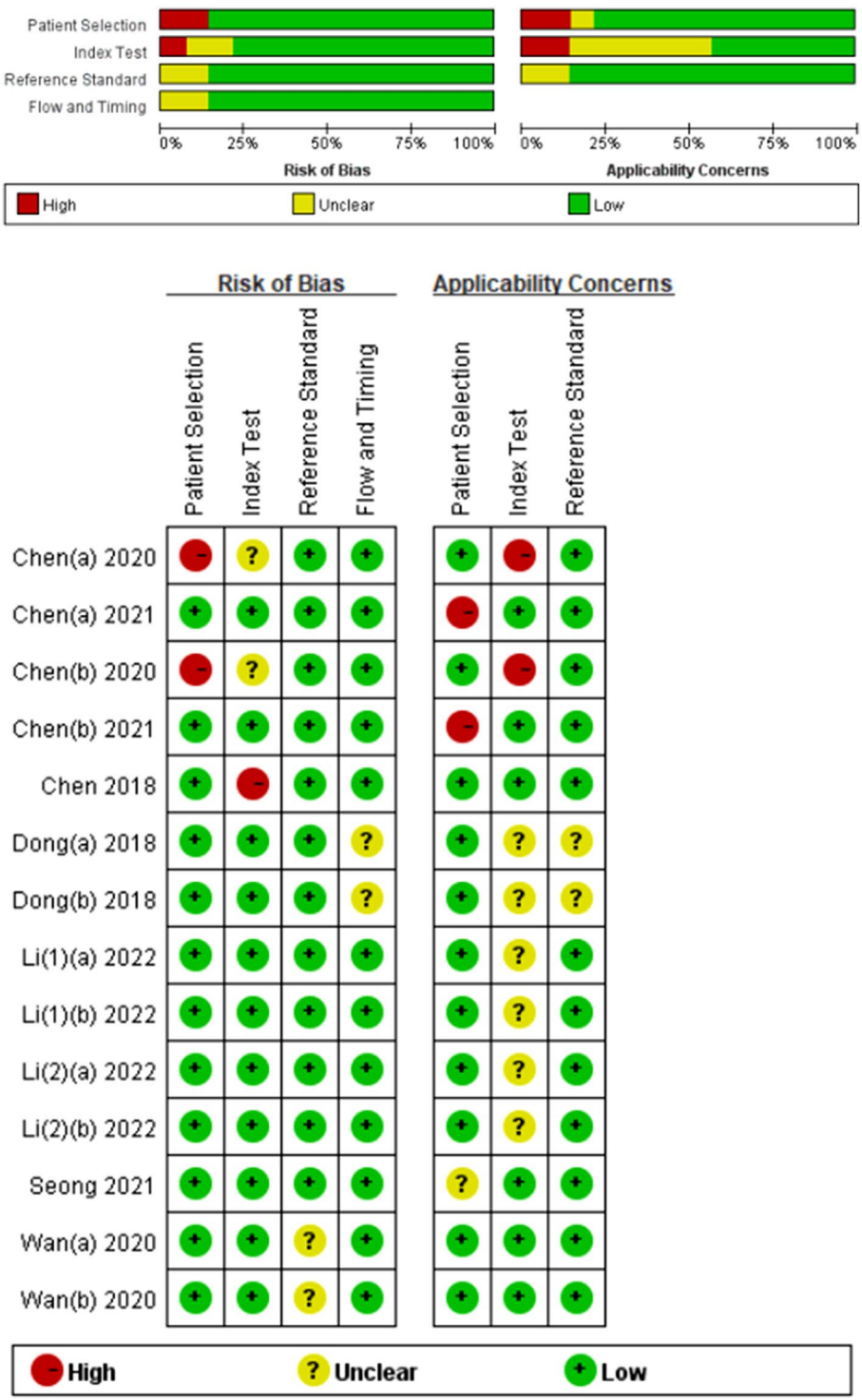

Fig. 2 Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) criteria for the included studies

from China (four were from Chinese mainland [9, 10, 18, 23], two from Taiwan [8, 19]), and one from South Korea [20]. Four articles adopted eGFR to diagnose CKD [8, 9, 20, 23], three articles diagnosed CKD by eGFR or UACR [10, 18, 19]. The subjects of three articles were younger than 60 years old [8, 9, 23], four articles were 60 years old or older [10, 18–20]. One article produced four groups diagnostic data (TP, FP, FN, TN) based on type of chronic kidney disease and gender. This article was divided into four studies, and pooled with other articles [23]. Four articles produced two groups diagnostic data (TP, FP, FN, TN), respectively, based on gender, and each article was divided into two studies, and pooled with other articles [9, 10, 18, 19]. All articles were evaluated by QUADAS-2, and the

Table 2 Diagnostic values of VAI for predicting CKD

Parameter	Estimate	95%CI	I^2(%)	*P*
Sen	0.67	0.54–0.77	97.4	0.000
Spe	0.75	0.65–0.83	99.7	0.000
PLR	2.7	1.70–4.20	98.7	0.000
NLR	0.44	0.29–0.66	98.6	0.000
DOR	6.0	3.00–14.00	98.5	0.000
AUC	0.77	0.74–0.81	–	–

Sen sensitivity; *Spe* specificity; *PLR* positive likelihood ratio; *NLR* negative likelihood ratio; *DOR* diagnostic odds ratio, *AUC*, area under the curve

quality evaluation is shown in Fig. 2. The included studies were of moderate to high quality. Ultimately, 14 studies from 7 articles were included in the meta-analysis (Table 1).

Test of heterogeneity

Spearman rank correlation analysis between the logarithm of sensitivity and 1-specificity was −0.064 ($P=0.829$), implied no diagnostic threshold effects. There was no "shoulder-arm" distribution by drawing the SROC curve, showing that there was no threshold effect. The I^2 heterogeneity of Sen, Spe, PLR, NLR, DOR was 97.4%, 99.7%, 98.7%, 98.6% and 98.5%, respectively, ($P=0.0001$ each). So random effect model was used in this meta-analysis.

Diagnostic values of VAI for predicting CKD

The pooled Sen and Spe were 0.67 (95%CI: 0.54–0.77) and 0.75 (95%CI: 0.65–0.83), respectively. The pooled PLR and NLR were 2.7 (95%CI: 1.7–4.2) and 0.44 (95%CI: 0.29–0.66), respectively. The pooled DOR was 6 (95%CI:3.00–14.00). The corresponding AUC was 0.77 (95%CI: 0.74–0.81) (Table 2, Fig. 3, 4, 5, 6).

Subgroup analysis and meta-regression analysis

In this study, subgroup analyses and meta-regression analysis were conducted to explore the heterogeneity. Subgroup analyses were based on country, average age of subjects, diagnostic for CKD. The Sen, Spe, PLR, NLR, DOR of VAI for predicting CKD in subjects less than 60 years old were better than those 60 years old or more. Meta-regression analysis showed that mean age of subjects and diagnostic methods of CKD were a potential source of heterogeneity ($P<0.05$) (Table 3, Fig. 7).

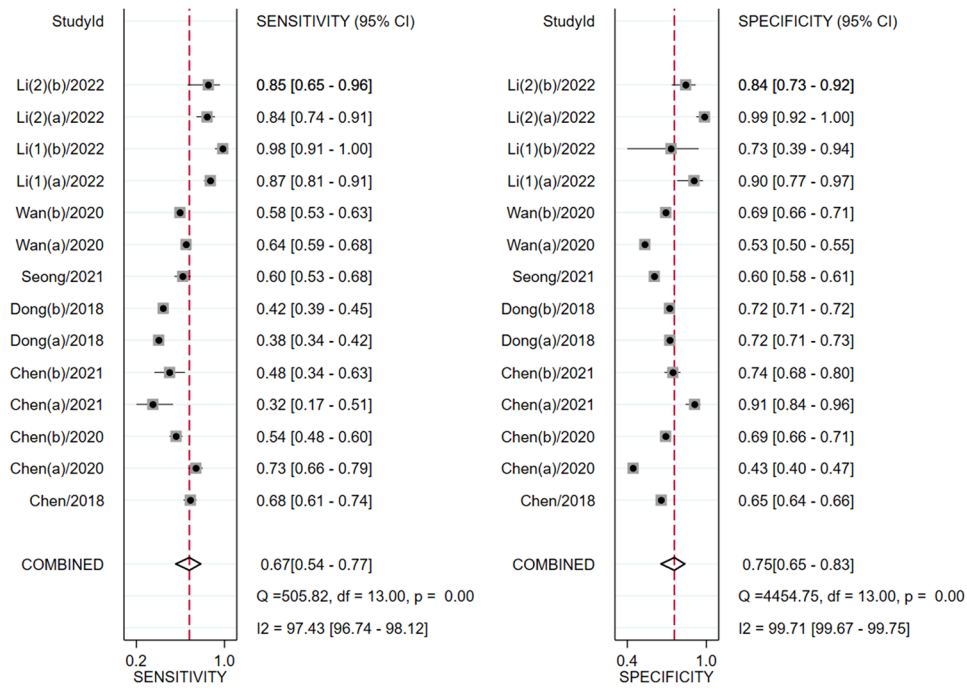

Fig. 3 Forest plot assessing the pooled sensitivity and specificity of VAI for predicting CKD. Notes: **a**, male; **b**, female. (1), CKD combined with T2DM; (2), CKD not combined with T2DM

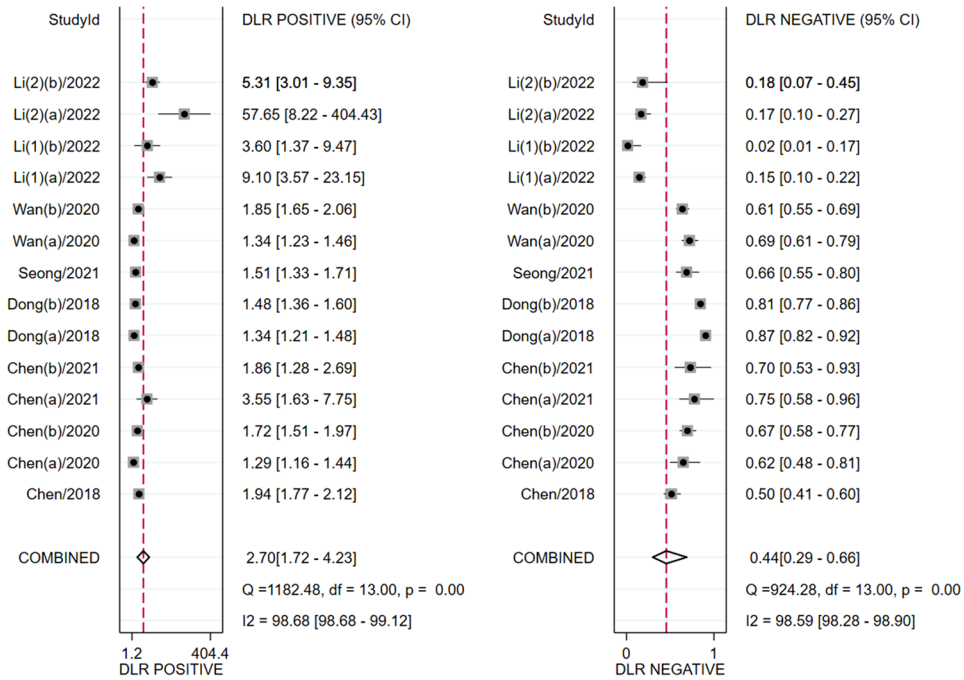

Fig. 4 Forest plot assessing the pooled positive and negative likelihood ratios of VAI for predicting CKD

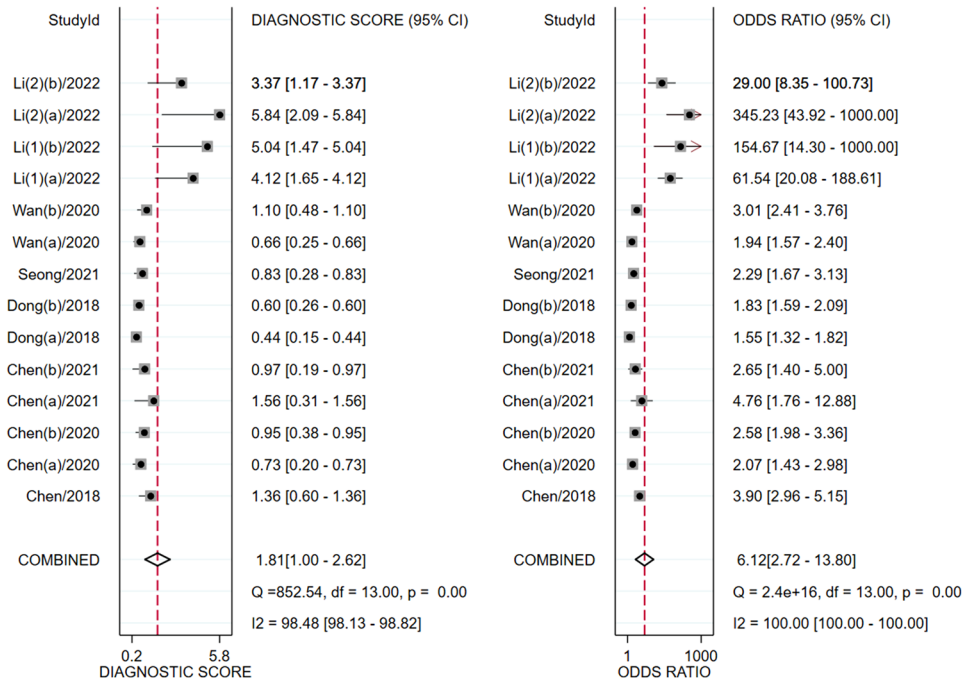

Fig. 5 Forest plot assessing the diagnostic odds ratio of VAI for predicting CKD

Sensitivity analysis and publication bias

The results did not significant alter after sensitivity analyses by eliminating studies one by one, indicating that the results were stable. Deek's funnel plot was drawn to test publication bias. The results showed that *P*-value was 0.000 (< 0.05), suggesting that there was an obvious publication bias in our meta-analysis (Fig. 8).

Clinical application value

We could draw Fagan plot for clinical application analysis. The prior probability was 50%, and the post-test probability of VAI for predicting CKD was 73%, and 31% of LR-negative, suggesting that VAI was a valuable diagnostic tool for CKD (Fig. 9).

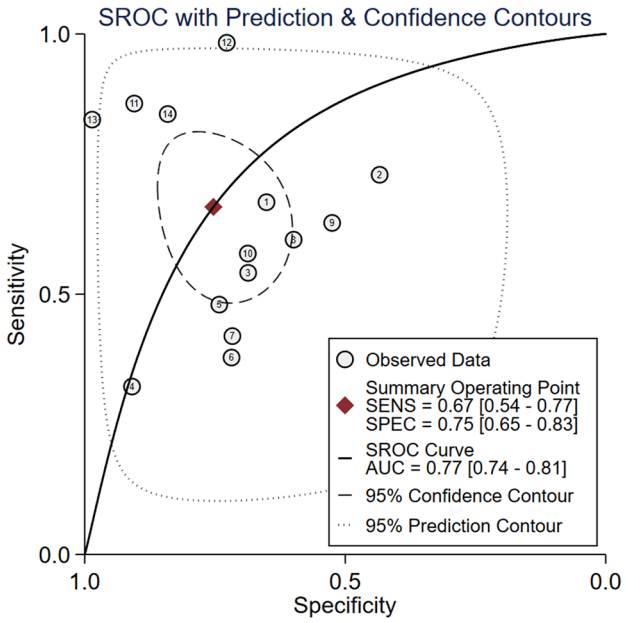

Fig. 6 Summary receiver operating curve of the diagnosis performance of VAI for predicting CKD

Discussion

CKD is one of the increasingly severe global public health concerns. As the current diagnostic indicators of CKD, proteinuria and serum creatinine are easily disturbed by patients' physiological conditions. In addition, biopsy of CKD is not suitable for patients with contraindications, is also traumatic, and is insensitive to early progression [24]. Therefore, effective and convenient diagnostic methods have become important. In recent years, various new tests for CKD have emerged rapidly. Among a variety of examination methods, VAI, as a new method to detect visceral fat, has attracted extensive attention because of its role in patients with CKD [8], but there were inconsistencies in its diagnostic value.

In our meta-analysis, we found that VAI had medium diagnostic values for predicting CKD, the pooled Sen was 0.67 (95%CI: 0.54–0.77) and Spe was 0.75 (95%CI: 0.65–0.83), and AUC was 0.77 (95%CI: 0.74–0.81). A higher DOR value indicates a better diagnostic ability. The pooled DOR was 6 (95%CI:3.00–14.00), indicating diagnostic ability was not high. The pooled PLR was 2.7, suggesting that the probability of CKD was increased by 2.7-fold with the positive VAI. The pooled NLR was 0.44, indicating that probability could be 44% if VAI was negative. According to the criteria, PLR > 10 and NLR < 0.1 meant high accuracy, but our result did not up to par, suggesting the clinical value of VAI was limited.

The potential mechanisms linking VAI to CKD are still unclear. Visceral adipose tissue triggers an inflammatory response through free fatty acids (FFA) [25, 26]. Mitochondria plays a highly significant role in the metabolism of FFA and is critical factors in lipotoxicity [27]. Adipokines may cause kidney damage by mediating endothelial dysfunction, guiding oxidative stress and inflammation [27, 28]. In addition, altered adipokine levels may spoil the glomerular

Table 3 Subgroup and Meta-regression analysis of VAI for predicting CKD

Subgroup	Number of studies	Sen(95%CI)	Spe(95%CI)	PLR(95%CI)	NLP(95%CI)	DOR(95%CI)	^{2}	*P*	I^2(%)
Country/Region							1.91	0.38	0
China	10	0.72(0.56–0.84)	0.76(0.63–0.86)	3.0(1.70–5.50)	0.37(0.21–0.66)	8.0(3.00–25.00)			
Non-China(Taiwan, South Korea)	4	0.53(0.38–0.67)	0.74(0.59–0.85)	2.1(1.50–2.80)	0.63(0.52–0.77)	3.0(2.00–5.00)			
Gender							1.14	0.56	0
Male	6	0.65(0.46–0.81)	0.77(0.59–0.88)	2.8(1.40–5.80)	0.45(0.26–0.79)	6.0(2.00–21.00)			
Female	6	0.71(0.44–0.88)	0.74(0.69–0.78)	2.7(1.80–4.10)	0.40(0.18–0.89)	7.0(2.00–22.00)			
Mean age							5.23	0.07	62
< 60	7	0.77(0.56–0.90)	0.79(0.71–0.85)	3.7(2.30–5.90)	0.29(0.13–0.64)	13.0(4.00–43.00)			
≥ 60	7	0.56(0.47–0.65)	0.68(0.54–0.79)	1.7(1.40–2.20)	0.65(0.62–0.68)	3.0(2.00–3.00)			
Diagnostic methods of CKD							3.045	0.18	42
eGFR	8	0.75(0.56–0.88)	0.77(0.69–0.84)	3.3(2.10–5.20)	0.32(0.16–0.64)	10.0(3.00–31.00)			
eGFR + UACR	6	0.55(0.45–0.65)	0.69(0.54–0.81)	1.8(1.30–2.30)	0.65(0.62–0.69)	3.0(2.00–4.00)			

95%CI, confidence intervals

Sen sensitivity; *Spe* specificity; *PLR* positive likelihood ratio; *NLR* negative likelihood ratio; *DOR* diagnostic odds ratio; *CKD* chronic kidney disease; *UACR* urinary albumin/creatinine ratio; *eGFR* estimated glomerular filtration rate

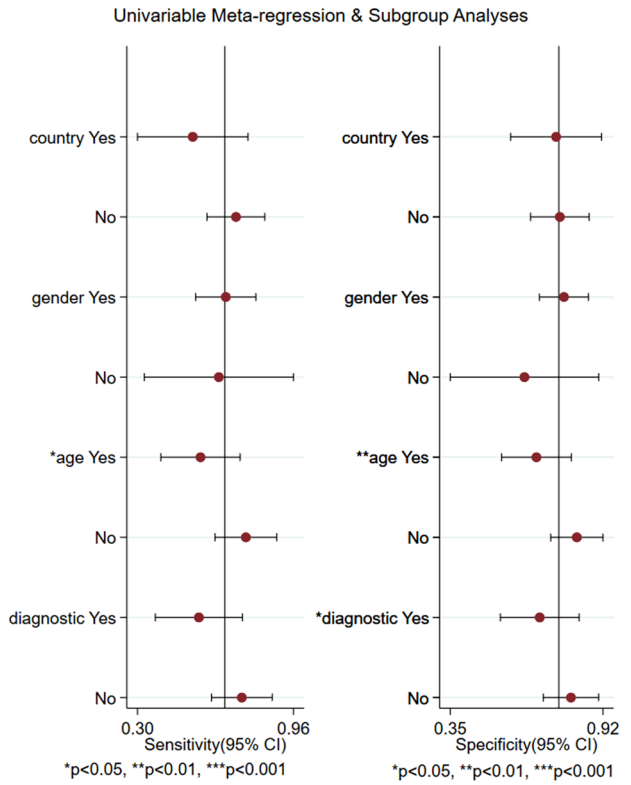

Fig. 7 Meta-regression analysis of VAI for predicting CKD

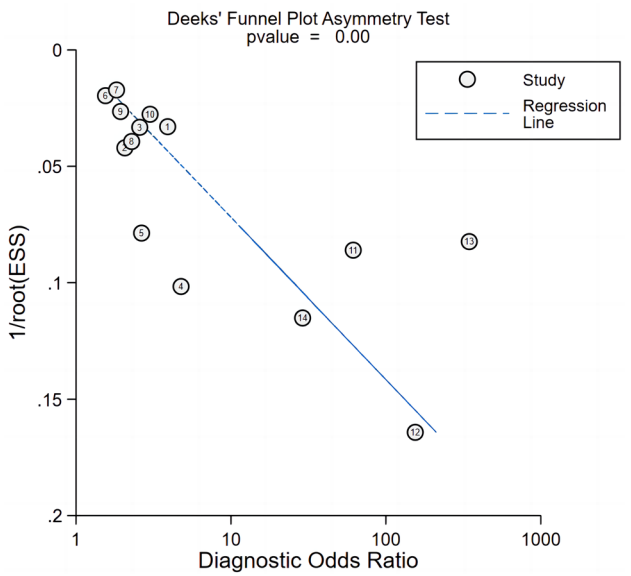

Fig. 8 Deek's funnel plot assessing the publication bias of included studies

filtration barrier, resulting in decreased GFRs [29]. In conclusion, these findings show that obesity may cause CKD by various mechanisms.

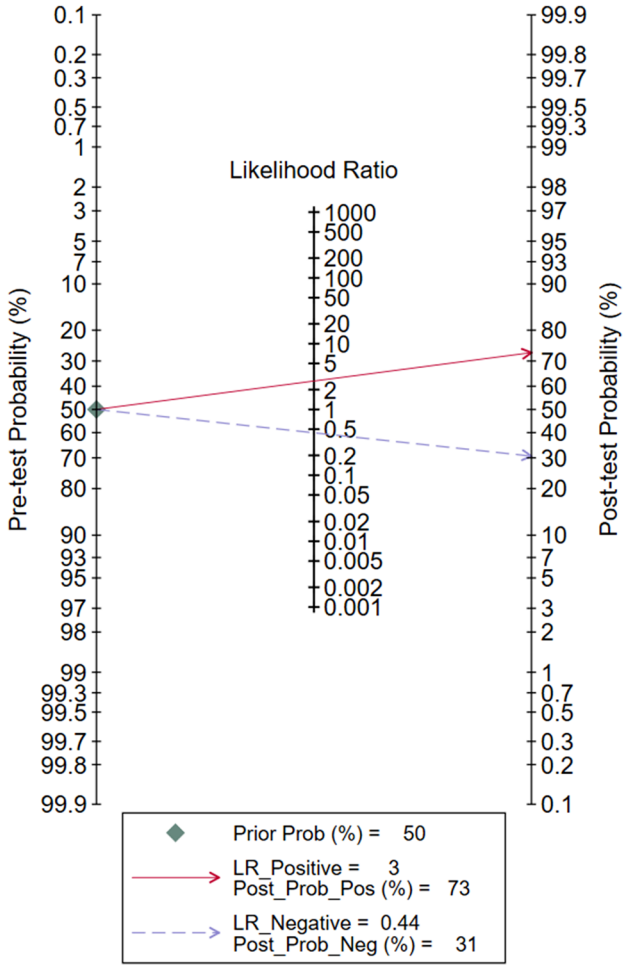

Fig. 9 Fagan diagram evaluating the overall diagnostic value of VAI for predicting CKD

The diagnostic values of VAI for predicting metabolic-associated fatty liver disease (MAFLD) have already been proven. Yi et al. [30] found that the combined Sen, Spe, PLR, NLR, DOR, AUC were 0.70, 0.67, 2.08, 0.39, 5.81, 0.79, respectively, and the VAI might be a valuable tool in the diagnosis of MAFLD. Bijari et al. [31]. considered that VAI had a moderate-to-high diagnostic value for metabolic syndrome (MetS), with Sen, Spe, AUC were 78%, 79%, 0.847, respectively. Chen et al. [8]. examined the role of VAI in CKD diagnosis and the Sen, Spe, AUC were 67.7%, 65.1%, 0.694, respectively, suggesting VAI might be a convenient tool for early detection of CKD in Taiwan. However, Dong et al. [9] showed that percentage body fat (PBF) was a more sensitive predictor for detecting CKD than other adiposity indices the VAI. PBF had a significantly higher AUC in both male and female groups (AUC for males: 0.593; AUC for females: 0.617) than VAI (AUC for males: 0.548; AUC for females: 0.577).

Subgroup analyses and meta-regression analysis were conducted to explore the heterogeneity, and found that mean age of subjects was a potential source of heterogeneity ($P < 0.05$). Subjects younger than 60 years old had a significantly higher Sen, Spe, PLR, NLR, DOR (0.75, 0.76, 3.1, 0.33, 10) than those 60 years old or more (Sen: 0.63; Spe: 0.72; PLR: 2.3; NLR: 0.51; DOR: 4). There were inconsistencies in diagnostic value of VAI for different age. Hu et al. [32] recognized the relationship between abdominal obesity and increasing age. His research showed that the prevalence of obesity was highest in men aged 45–54 years, while it was highest in women aged 55–64 years. Different from Hu et al.' s study, Ahn et al. [33] found the VAI had better diagnostic ability in subjects younger than 65 years. Ageing is related to an increase in abdominal white adipose tissue (AT) and fat deposition in skeletal muscle, which significantly affect insulin sensitivity [34]. As an important component of MetS, insulin resistance is common in older adults [1]. The common cause of insulin resistance and MetS is abdominal obesity [35].

Limitations of the study

This study has several limitations that must be considered when interpreting its results. First, our studies may have potential heterogeneity and publication bias, so the results should be interpreted with caution. Second, all participants originated from Asian population, while most studies were from Chinese population, our study may have a population selection bias. Third, subjects in our studies may have comorbidities, which may affect the diagnostic power of VAI for CKD. Finally, inconsistent the VAI thresholds for CKD diagnosis may have influenced the final results.

Conclusion

In conclusions, our analysis shows that the VAI is a valuable predictor in diagnosing CKD and is feasible for clinical applications. This study will contribute to sifting patients with CKD with simple anthropometric index and provide basis for early diagnosis of CKD. Significant heterogeneity in the pooled estimates may have limited the reliability of our conclusions. Therefore, further large-scale studies are needed to confirm our findings.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00592-023-02048-5.

Authors' contributions All authors contributed to data analysis, drafting or revising the article, gave final approval of the version to be published, and agree to be accountable for all aspects of the work.

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Data availability The original contributions presented in the study are included in the article/supplementary material.

Declarations

Conflict of interests The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethical approval All author: this manuscript has not been published in whole or in part elsewhere; the manuscript is not currently being considered for publication in another journal; all authors have been personally and actively involved in substantive work leading to the manuscript, and will hold themselves jointly and individually responsible for its content.

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