REVIEW

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Diagnosis, prevalence, and outcomes of sarcopenia in kidney transplantation recipients: A systematic review and meta-analysis

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Abstract

The prevalence of sarcopenia and its clinical predictors and clinical impact vary among kidney transplant recipients (KTRs), in part because of different diagnostic criteria. This study aimed to assess the reported diagnosis criteria of sarcopenia and compare them in terms of prevalence, clinical predictors, and impact of sarcopenia. The Medline, Embase, and Cochrane Library were searched for the full-length reports published until 28 January 2022. The subgroup analysis, meta-regression, and sensitivity analysis were performed and heterogeneity was assessed using the I^2. A total of 681 studies were retrieved, among which only 23 studies (including 2535 subjects, 59.7% men, mean age 49.8 years) were eventually included in the final analysis. The pooled prevalence in these included studies was 26% [95% confidence interval (95% CI): 20–34%, I^2 = 93.45%], including 22% (95% CI: 14–32%, I^2 = 88.76%) in men and 27% (95% CI: 14–41%, I^2 = 90.56%) in women (P = 0.554 between subgroups). The prevalence of sarcopenia diagnosed using low muscle mass was 34% (95% CI: 21–48%, I^2 = 95.28%), and the prevalence of using low muscle mass in combination with low muscle strength and/or low physical performance was 21% (95% CI: 15–28%, I^2 = 90.37%) (P = 0.08 between subgroups). In meta-regression analyses, the mean age (regression coefficient: 1.001, 95% CI: 0.991–1.011) and percentage male (regression coefficient: 0.846, 95% CI: 0.367–1.950) could not predict the effect size. Lower body mass index (odds ratio (OR): 0.57, 95% CI: 0.39–0.84, I^2 = 61.5%), female sex (OR: 0.31, 95% CI: 0.16–0.61, I^2 = 0.0%), and higher age (OR: 1.08, 95% CI: 1.05–1.10, I^2 = 10.1%) were significantly associated with a higher risk for sarcopenia in KTRs, but phase angle (OR: 0.81, 95% CI: 0.16–4.26, I^2 = 84.5%) was not associated with sarcopenia in KTRs. Sarcopenia was not associated with rejections (risk ratio (RR): 0.67, 95% CI: 0.23–1.92, I^2 = 12.1%), infections (RR: 1.03, 95% CI: 0.34–3.12, I^2 = 87.4%), delayed graft functions (RR: 0.81, 95% CI: 0.46–1.43, I^2 = 0.0%), and death (RR: 0.95, 95% CI: 0.32–2.82, I^2 = 0.0%) in KRTs. Sarcopenia was found to be very common in KRTs. However, we have not found that sarcopenia had a negative impact on clinical health after kidney transplantation. Large study cohorts and multicentre longitudinal studies in the future are urgently needed to explore the prevalence and prognosis of sarcopenia in kidney transplant patients.

Keywords Diagnosis; Prevalence; Sarcopenia; Kidney transplantation

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Introduction

Kidney transplantation (KT) improves survival and quality of life in end-stage kidney disease (ESKD) patients and is less expensive than numerous rounds of dialysis, thus making KT a preferred form of renal replacement therapy.[1] The 2020 Kidney Disease: Improving Global Outcomes Clinical Practice Guideline recommends that all patients with chronic kidney disease (CKD) stages G4-G5 who are expected to progress to ESRD should be informed of considering for KT.[2] A recent study found that the prevalence of sarcopenia in CKD patients ranges from 4% to 42%.[3] Another meta-analysis found a 28.5% prevalence of sarcopenia in CKD patients with dialysis.[4] Harada *et al*. suggested that a theoretically successful KT could improve metabolic disorder, activity, and appetite in CKD patients and restore body composition to a healthy state. However, they found that successful KT changed only part of the body composition and, interestingly, decreased muscle mass.[5] Some studies have reported that after KT the prevalence of sarcopenia in KT recipients (KTRs) ranges from 3.7% to 72.1%, and some studies have found that the prevalence of sarcopenia is increased compared with that before KT.[6–8] The current study identified some causes of sarcopenia in CKD patients, such as increased inflammation, oxidative stress, and uraemic toxins (due to anorexia, acidosis, and anaemia) that can lead to impaired protein assimilation and increased muscle atrophy.[9,10] The shock of KT, decreased postoperative activity, and immunosuppressive drugs, including corticosteroids, specific metabolic abnormalities associated with calcineurin inhibitors may contribute to the development of sarcopenia after KT, which may partially explain the findings in some studies that the prevalence of sarcopenia after KT is higher than that before KT.[11–13] It has been shown that muscle mass is inversely related to mortality and graft loss in KTRs, and patients having a higher muscle mass might have better survival outcomes after KT.[14,15] Therefore, it is important to assess muscle mass during the screening for eligibility for receiving KT.

In current studies on sarcopenia in KTRs, there is a huge difference in the rate of prevalence of sarcopenia, which is reportedly between 3.7%[7] and 72.1%,[6] possibly due to the inclusion of different diagnostic criteria and/or sample sizes. Common diagnostic criteria of sarcopenia in KTRs follow the European Working Group on Sarcopenia in Older People (EWGSOP)[16,17] and the Asian Working Group for Sarcopenia (AWGS).[18,19] However, the clinical predictors of sarcopenia and its impacts on outcomes in KTRs remain unclear. Thus, this review aimed to evaluate the studies of literature on KTRs to identify the most commonly practiced diagnostic criteria of sarcopenia, its prevalence, clinical predictors, and outcomes.

Methodology

This study was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and was registered in PROSPERO (ID: CRD42022315040).[20]

Search strategy

The Medline, Embase, and Cochrane Library were searched via Ovid SP until 28 January 2022, using the strategy as described in *Table* S1. Manual searching for the reference lists of eligible studies was performed. There was no language restriction.

Inclusion and exclusion criteria

All studies reporting sarcopenia in all ages with all types of KTRs were included, and the diagnosis of sarcopenia was defined according to the criteria provided in the article's methodology. The criteria for exclusion of studies were as follows: (i) no data on diagnosis and prevalence of sarcopenia; (ii) reviews, comments, conference abstracts, editorials, notes, letters, consensus and guidelines, and case reports or animal studies; and (iii) duplicate studies.

Outcomes

The major outcomes of the study were (i) identification of frequently applied diagnostic criteria and prevalence rate of sarcopenia; (ii) determination of clinical predictors of sarcopenia; and (iii) comparative analysis between KTRs with or without sarcopenia, concerning (a) quality of life, from all types of questionnaires; (b) physical activity level; (c) kidney transplantation records, for example, complications, infections, hospital readmission, rejection and delayed graft function; (d) inflammation biomarkers, for example, white cell count and C-reactive protein (CRP) level, and (e) all-cause mortality.

Study selection

Two authors (J. Z. and M. Z.) independently screened all articles by their titles and abstract contents after duplicate removal and then separately assessed only the full-text articles following the inclusion and exclusion criteria. A third author (H. G.) examined and made the final decision on the studies included.

Data extraction and quality assessment

A preformatted sheet was used to extract data from eligible studies by two authors (J. Z. and Q. Z.) independently, and a third author (H. G.) reviewed and finalized the data. Extracted data included the following information: first author name, region, year, study design method, sex, sample size, age, male (%), the diagnostic criteria and prevalence rate of sarcopenia, kidney transplantation data, the clinical predictors of sarcopenia, and outcomes.

The methodological quality of the cross-sectional and case–control/cohort studies was evaluated based on the National Institutes of Health Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.[21] And a tool was used to assess the risk of bias in prevalence studies.[22] Each study was evaluated independently by two authors, and any disagreement was resolved by discussion with a third reviewer.

Statistical analyses

A meta-analysis was used to calculate the weight of prevalence, the clinical predictors, and outcomes of sarcopenia in KTRs. Among studies evaluating sarcopenia following different diagnostic criteria, we aggregated those prevalence closest to the EWGSOP-2019 recommendations.[17] For studies reporting the prevalence of sarcopenia in both men and women, we summarized the prevalence by sex. We extracted the odds ratios (ORs) and 95% confidence intervals (95% CIs) of the predictors of sarcopenia from multivariate analyses for meta-analysis. All values were reported as point estimates with 95% CI in parentheses. Dichotomous variables were tested using both risk ratios (RRs) and ORs. Continuous variables were tested using both mean difference (MD) and standard mean difference (SMD). A $P < 0.05$ was considered statistically significant.

Heterogeneity was assessed using the I^2. I^2 values of 25%, 50%, and 75% were indicated to be low, moderate, and high levels of heterogeneity, respectively.[23] A fixed-effects model (Mantel–Haenszel method) was used when there was no heterogeneity among the studies.[24] A random-effects model (DerSimonian and Laird method) was used if heterogeneity existed.[25]

Subgroup analysis was performed according to definitions (1 vs. >1 diagnostic criteria) of sarcopenia (EWGSOP, AWGS, and others), evaluated via chi-square (χ^2) test, and then meta-regression was performed including the average age and sex (percentage male). We conducted a sensitivity analysis test to assess the robustness of summary estimates by excluding unfit studies one by one. Egger bias test[26] and Begg–Mazumdar Kendall's tau[27] were used to evaluate the publication bias. We used the trim-and-fill approach if there was any publication bias.[28] The meta-analysis was performed with STATA 12.0 (StataCorp, College Station, TX, USA).

Results

Figure 1 shows the details of the literature selection. A total of 681 studies were retrieved, among which 43 studies were found with the full text. Out of these, 20 studies were excluded for reasons detailed in *Table* S2. Finally, 23[6–8,29–48] studies were included, involving 2535 KTRs with 59.7% of male subjects. Of these, nine studies were from Europe, seven were from Asia, five were from South America, one was from North America, and one was from Oceania. The characteristics of the included studies are shown in *Table* 1. The included studies were observational, including 13 cross-sectional design, 7 prospective studies, and 3 reported retrospective data. The overall quality of included studies was moderate (*Table* S3). Among the included studies, 8 studies were with a moderate risk of bias, and 15 studies had a low risk of bias in the assessment of the risk of bias in prevalence (*Table* S4).

Diagnosis of sarcopenia

The diagnostic criteria used to assess sarcopenia are summarized in *Table* 1. Ten studies[6,8,29–31,34–37,48] used low muscle mass (LMM) as the sole diagnostic criterion, whereas 13 studies[7,32,33,38–47] used LMM in combination with low muscle strength (LMS) and/or low physical performance (LPP). The different cut-off thresholds used to define sarcopenia for each of the included studies are listed in *Table* 2.[49–57] LMM was measured via dual-energy X-ray absorptiometry (six studies),[7,31,34,39,42,45] bioelectrical impedance analysis (10 studies),[8,32,33,38,40,41,43,44,46,47] and computed tomography (CT, six studies).[6,29,30,35–37] LMS was measured by HGS (14 studies).[7,33,38–48] LPP was measured by GS, including 4mGS (four studies),[33,40,42,43] 6mGS (two studies),[32,39] and 10mGS (two studies).[41,45] The EWGSOP[16,17] (14 studies)[7,32–34,38–40,42–44,46–48] and AWGS[18,19] (4 studies)[31,32,41,45] recommended thresholds were common. A comparison of the main guidelines used to detect sarcopenia in KRTs is shown in *Table* S5.

Sarcopenia prevalence

The pooled prevalence in the included studies was 26% (95% CI: 20–34%, I^2 = 93.45%, $P < 0.001$; *Figure* 2). Eleven studies and 11 studies provided data on the prevalence of sarcopenia in males and females, respectively, and the pooled prevalence was 22% (95% CI: 14–32%, I^2 = 88.76%, $P < 0.001$) and 27% (95% CI: 14–41%, I^2 = 90.56%, $P < 0.001$),

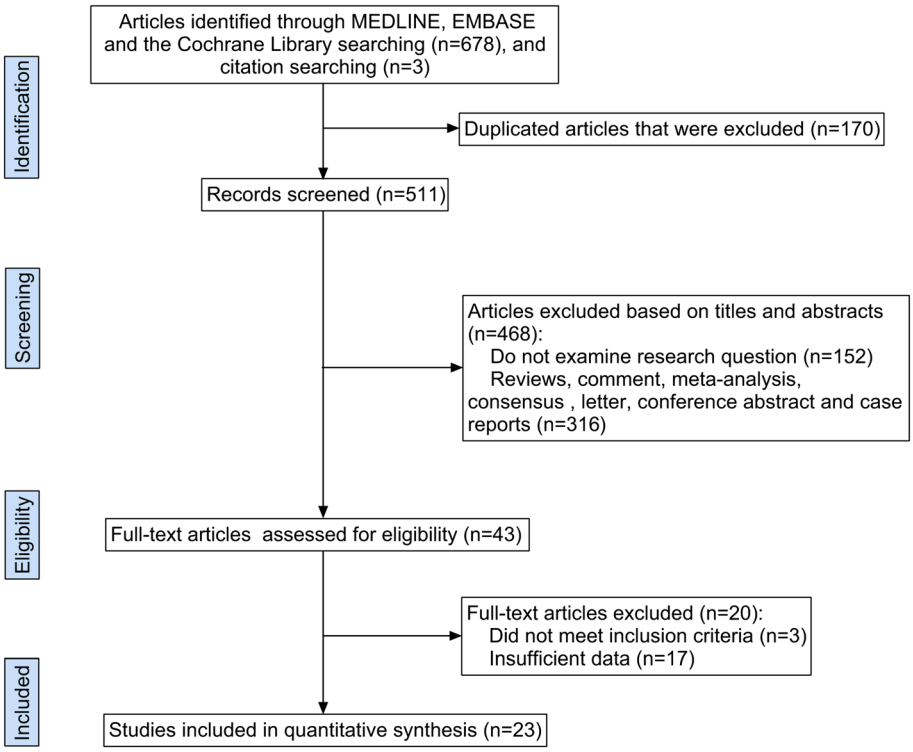

Figure 1 Flow diagram of study selection process.

respectively. The difference was not statistically significant (P = 0.554) (*Figure* S1).

Subgroup analysis, meta-regression, and sensitivity analysis

The prevalence of sarcopenia diagnosed using LMM was 34% (95% CI: 21–48%, I^2 = 95.28%, $P < 0.001$), which was higher than that of the combination of LMM and LMS and/or LPP (21%, 95% CI: 15–28%, I^2 = 90.37%, $P < 0.001$). But the difference was not statistically significant (P = 0.08, *Figure* S2). Rates of sarcopenia defined by AWGS, EWGSOP, and other methods were 21% (95% CI: 9–36%, I^2 = 89.44%, $P < 0.001$), 23% (95% CI 17–30%, I^2 = 89.28%, $P < 0.001$), and 36% (95% CI: 15–59%, I^2 = 97.10%, $P < 0.001$), respectively. However, there were no statistically significant differences (P = 0.526, *Figure* S3). In meta-regression analyses, the mean age (regression coefficient: 1.001, 95% CI: 0.991–1.011, P = 0.775) and the percentage of male subjects (regression coefficient: 0.846, 95% CI: 0.367–1.950, P = 0.681) could not predict the effect size (*Figures* S4 and S5). Sensitivity analysis showed that omitting any of the included studies did not significantly affect the risk of bias in the prevalence of sarcopenia (*Figure* S6).

Clinical predictors of sarcopenia

Thirteen studies provided data on the clinical predictors of sarcopenia in KTRs. Higher body mass index (BMI) (OR: 0.82, 95% CI: 0.68–0.99, I^2 = 61.5%, $P < 0.001$, three studies), male gender (OR: 0.31, 95% CI: 0.16–0.61, I^2 = 0.0%, P = 0.584, two studies) was significantly associated with a lower risk for sarcopenia in KTRs, whereas age (OR: 1.08, 95% CI: 1.05–1.10, I^2 = 10.1%, P = 0.329, three studies) was significantly associated with a higher risk. Phase angle (OR: 0.81, 95% CI: 0.16–4.26, I^2 = 84.5%, P = 0.011, two studies) was not significantly associated with risk for sarcopenia in KTRs (*Figure* 3). Due to the lack of sufficient data to perform a quantitative meta-analysis, the results of the remaining review of clinical predictors of sarcopenia are summarized in *Table* S6. Additionally, the results of a review of clinical predictors of HGS are summarized in *Table* S7.

Clinical outcomes of sarcopenia

Studies that reported the clinical outcomes in median and interquartile ranges (IQR) were included in *Table* 3. KTRs with sarcopenia had the worse quality of life (measured by SF-26)[44] and lower physical activity levels.[42,44] Sarcopenia was not associated with rejections (RR: 0.67, 95% CI: 0.23–1.92,

Table 1 Studies included characteristics

Study, year, country	Study design	Male (%)	Sample size	Age [mean ± SD or median (IQR)]	Living donor (%)	Dialysis time (month)	Diagnostic criteria of sarcopenia	Criteria (assessment method to detect sarcopenia)	Prevalence of sarcopenia		
									Female (%)	Male (%)	Total (%)
Wong *et al*. 2022[29] Australia	Retrospective	71.4	63	57 (48.5–63.5)	71.4	-	Others*	LMM (CT)	77.8	44.4	54.0
Morel *et al*. 2021[30] France	Retrospective cohort	61.5	200	54.8 ± 13.8	13.0	2.2	Others*	LMM (CT)	3.9	5.7	5.0
Mazzola *et al*. 2021[6] France	Prospective cohort	25.8	31	58 (53–63)	-	-	Others*	LMM (CT)	89.5	58.3	72.1
Koito *et al*. 2021[31] Japan	Cross-sectional	72.5	40	52.1 ± 11.7	-	21.6	AWGS (2019)	LMM (DXA)	51.7	45.5	50.0
Khoo *et al*. 2021[32] Taiwan	Cross-sectional	48.4	95	45.2 ± 10.9	-	-	AWGS (2019) EWGSOP (2019)	LMM (BIA) LMS (HGS) LPP (6mGS)	10.2	13.0	11.6
dos Reis *et al*. 2021[33] Brazil	Cross-sectional	68.0	125	48 ± 12	39.1	48	EWGSOP (2019)	LMM (BIA) LMS (HGS) LPP (4mGS)	10.0	22.4	18.4
Dienemann *et al*. 2021[34] Germany	Prospective cohort	51.7	60	46 (20–60)	45.0	28.8	Others*	LMM (DXA)	-	-	11.7
Deliege *et al*. 2021[35] France	Retrospective	58.2	122	66 ± 4.3	5.7	30.9	EWGSOP (2019)	LMM (CT)	29.4	22.5	25.4
Chen Y., *et al*. 2021[36] China	Prospective	55.0	40	25 (17–39)	-	-	Others*	LMM (CT)	-	-	47.5
Chen X., *et al*. 2021[37] Maryland	Prospective cohort	59.3	275	55.5 ± 12.5	-	-	Others*	LMM (CT)	-	-	39.6
Woloszyk *et al*. 2020[38] Poland	Prospective cohort	58.9	95	50.8 ± 13.4	-	-	EWGSOP (2010 or 2019)	LMM (BIA) LMS (HGS)	-	-	31.6
Nanmoku *et al*. 2020[8] Japan	Prospective	62.5	80	44.6 ± 13.2	-	20.5	EWGSOP (2010)	LMM (BIA)	-	-	38.8
Martins *et al*. 2020[39] Brazil	Cross-sectional	57.8	83	48.8 ± 12.1	45.8	-	EWGSOP (2010)	LMM (DXA) LMS (HGS) LPP (6mGS)	-	-	19.3
Limirio *et al*. 2020[40] Brazil	Cross-sectional	68.5	127	47.6 ± 11.5	-	55.4	EWGSOP (2019)	LMM (BIA) LMS (HGS) LPP (4mGS)	-	-	18.9
Kosoku *et al*. 2020[41] Japan	Cross-sectional	58.1	210	55 (45–66)	82.9	45	AWGS (2014)	LMM (BIA) LMS (HGS) LPP (10mGS)	18.2	6.6	11.4
Bellafronte *et al*. 2020[7] Spain	Cross-sectional	59.3	81	49 ± 8	-	79	EWGSOP (2019)	LMM (DXA) LMS (HGS)	-	-	3.7
Menna Barreto *et al*. 2019[42] Brazil	Cross-sectional	57.3	185	50 (18–65)	-	36	EWGSOP (2019)	LMM (DXA) LMS (HGS) LPP (4mGS)	11.4	11.3	11.4
Dos Reis *et al*. 2019[43] Brazil	Cross-sectional	68.2	129	47.8 ± 11.8	37.2	-	EWGSOP (2010)	LMM (BIA) LMS (HGS) LPP (4mGS)	-	-	49.6
Chan *et al*. 2019[44] United Kingdom	Prospective	56.3	128	49 ± 15	-	24	EWGSOP (2010)	LMM (BIA) LMS (HGS)	-	-	28.9
Yanishi *et al*. 2018[45] Japan	Cross-sectional	72.4	58	46.6 ± 12.7	-	33.6	AWGS (2014)	LMM (DXA) LMS (HGS) LPP (10mGS)	25.0	19.0	20.7
Malgorzewicz *et al*. 2018[46] Poland	Cross-sectional	52.9	70	49.89 ± 13.4	-	-	EWGSOP (2010 or 2019)	LMM (BIA) LMS (HGS)	-	-	33.3
Dierkes *et al*. 2018[47] Norway	Cross-sectional	70.8	72	60 (49, 67)	-	-	EWGSOP (2010)	LMM (BIA) LMS (HGS)	-	-	31.9
Ozkayar *et al*. 2014[48] Turkey	Cross-sectional	59.0	166	37.9 ± 11.9	-	-	EWGSOP (2010)	LMS (HGS)	22.4	17.6	20.5

Abbreviations: AWGS, Asian Working Group for Sarcopenia; BIA, bioelectrical impedance analysis; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; EWGSOP, European Working Group on Sarcopenia in Older People; GS, gait speed; HGS, handgrip strength; IQR, interquartile range; KT, kidney transplant; LMM, lower muscle mass; LMS, lower muscle strength; LPP, lower physical performance; SD, standard deviation.
*Diagnostic criteria of sarcopenia other than EWGSOP (2010 or 2019) and AWGS (2014 or 2019).

Table 2 Criteria and cut-off points used to detect sarcopenia in included studies

Criteria		References
Lower muscle mass		
DXA	1. EWGSOP (2010) ASMI: <7.26 kg/m^2 for men and <5.5 kg/m^2 for women.	Martins *et al*. 2020[39]
	2. EWGSOP (2019) ALM: <20 kg for men and <15 kg for women.	Bellafronte *et al*. 2020[7]
	3. EWGSOP (2019) SMI/height^2: <7.26 kg/m^2 for men and <5.5 kg/m^2 for women.	Menna Barreto *et al*. 2019[42]
	4. AWGS (2014) SMI: <7.0 kg/m^2 for men and <5.4 kg/m^2 for women.	Yanishi *et al*. 2018[45]
	5. AWGS (2019) SMI: <7.0 kg/m^2 for men and <5.4 kg/m^2 for women.	Koito *et al*. 2021[31]
	6. Batsis *et al*. (2013)[43] ALMI: <2 SD below young adult mean.	Dienemann *et al*. 2021[34]
BIA	1. EWGSOP (2010) Wieskotten *et al*. LTI < gender- and age- specific cutoffs from a reference.	Chan *et al*. 2019[44]
	2. EWGSOP (2010) SMI: <8.87 kg/m^2 for men and <6.42 kg/m^2 for women.	Dierkes *et al*. 2018[47]
	3. EWGSOP (2010) Janssen *et al*. 2002 MMI: <10.76 kg/m^2 for men and <6.76 kg/m^2 for women.	Dos Reis *et al*. 2019[43]
	4. EWGSOP (2019) ASMI: <7.0 kg/m^2 for men and <5.5 kg/m^2 for women.	dos Reis *et al*. 2021[33] and Limirio *et al*. 2020[40]
	5. EWGSOP (2010 or 2019) Beaudart *et al*. (2018)[44] LTI: <14 kg/m^2 for both genders.	Woloszyk *et al*. 2020[38] and Malgorzewicz *et al*. 2018[46]
	6. AWGS (2014) SMI: <7.0 kg/m^2 for men and 5.7 kg/m^2 for women.	Nanmoku *et al*. 2020[8] and Kosoku *et al*. 2020[41]
	7. Jin *et al*. (2019)[45] SMI: <16.5 kg/m^2 in men and <14.2 kg/m^2 in women.	Khoo *et al*. 2021[32]
CT	1. Thoresen *et al*. (2012)[46] the total psoas area below 1561 mm^2 in men and 1464 mm^2 in women.	Mazzola *et al*. 2021[6]
	2. Shachar *et al*. (2016)[47] SMI: <55.4 kg/m^2 in men and <41.0 kg/m^2 in women.	Chen, Y. *et al*. 2021[36]
	3. Montgomery *et al*. (2019)[48] SMI: <50 kg/m^2 in men and <39 kg/m^2 in women.	Chen, X. *et al*. 2021[37]
	4. Derstine *et al*. (2018)[49] SMI: <44.6 kg/m^2 in men and <34.0 kg/m^2 in women.	Deliege *et al*. 2021[35]
	5. Martin *et al*. (2018)[50] SMI: <41 cm^2/m^2 in women, <43 cm^2/m^2 in men with a BMI < 25 kg/m^2 and < 53 cm^2/m^2 in men with a BMI > 25 kg/m^2.	Wong *et al*. 2022[29]
	6. SMI: < the lower limit of the prediction interval for 95% of healthy subjects.	Morel *et al*. 2021[30]
Lower muscle strength		
HGS	1. EWGSOP (2010) Laurentani *et al*. (2003)[51] HGS: <30 kg for men and <20 kg for women.	Martins *et al*. 2020,[39] Dos Reis *et al*. 2019,[43] Chan *et al*. 2019,[44] Dierkes *et al*. 2018[47] and Ozkayar *et al*. 2014[48]
	2. EWGSOP (2019) HGS: <27 kg for men and <16 kg for women.	dos Reis *et al*. 2021,[33] Limirio *et al*. 2020,[40] Bellafronte *et al*. 2020[7] and Menna Barreto *et al*. 2019[42]
	3. AWGS (2019) HGS: <28 kg for men and <18 kg for women.	Khoo *et al*. 2021[32]
	4. EWGSOP (2010 or 2019) Beaudart *et al*. (2018)[44] HGS: <46 kg for men and <26 kg for women.	Woloszyk *et al*. 2020[38] and Malgorzewicz *et al*. 2018[46]
	5. AWGS (2014) HGS: <26 kg for men and <18 kg for women.	Kosoku *et al*. 2020[41] and Yanishi *et al*. 2018[45]
Lower physical performance		
4mGS	1. EWGSOP (2019) GS: <0.8 m/s (both genders).	dos Reis *et al*. 2021,[33] Limirio *et al*. 2020,[40] and Menna Barreto *et al*. 2019[42]
	2. EWGSOP (2010) GS: <0.8 m/s (both genders).	Dos Reis *et al*. 2019[43]
6mGS	1. AWGS (2019) GS: <1.0 m/s (both genders).	Khoo *et al*. 2021[32]
	2. EWGSOP (2010) GS: <0.8 m/s (both genders).	Martins *et al*. 2020[39]
10mGS	1. AWGS (2014) GS: <0.8 m/s (both genders).	Kosoku *et al*. 2020[41] and Yanishi *et al*. 2018[45]

Abbreviations: ALM, appendicular lean mass; ASMI, appendicular skeletal muscle index; AWGS, Asian Working Group for Sarcopenia; BIA, bioelectrical impedance analysis; BMI, body mass index; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; EWGSOP, European Working Group on Sarcopenia in Older People; GS, gait speed; HGS, handgrip strength; LTI, lean tissue index; MMI, muscle mass index; SD, standard deviation; SMI, skeletal muscle mass index.

I^2 = 12.1%, two studies), infections (RR: 1.03, 95% CI: 0.34–3.12, I^2 = 87.4%, two studies), delayed graft functions (RR: 0.81, 95% CI: 0.46–1.43, I^2 = 0.0%, three studies), and death (RR: 0.95, 95% CI: 0.32–2.82, I^2 = 0.0%, two studies) in KRTs (*Figure* 4).

Publication bias

There was no publication bias in the prevalence of sarcopenia in this study (Begg's test: P = 0.054; Egger's test: P = 0.093).

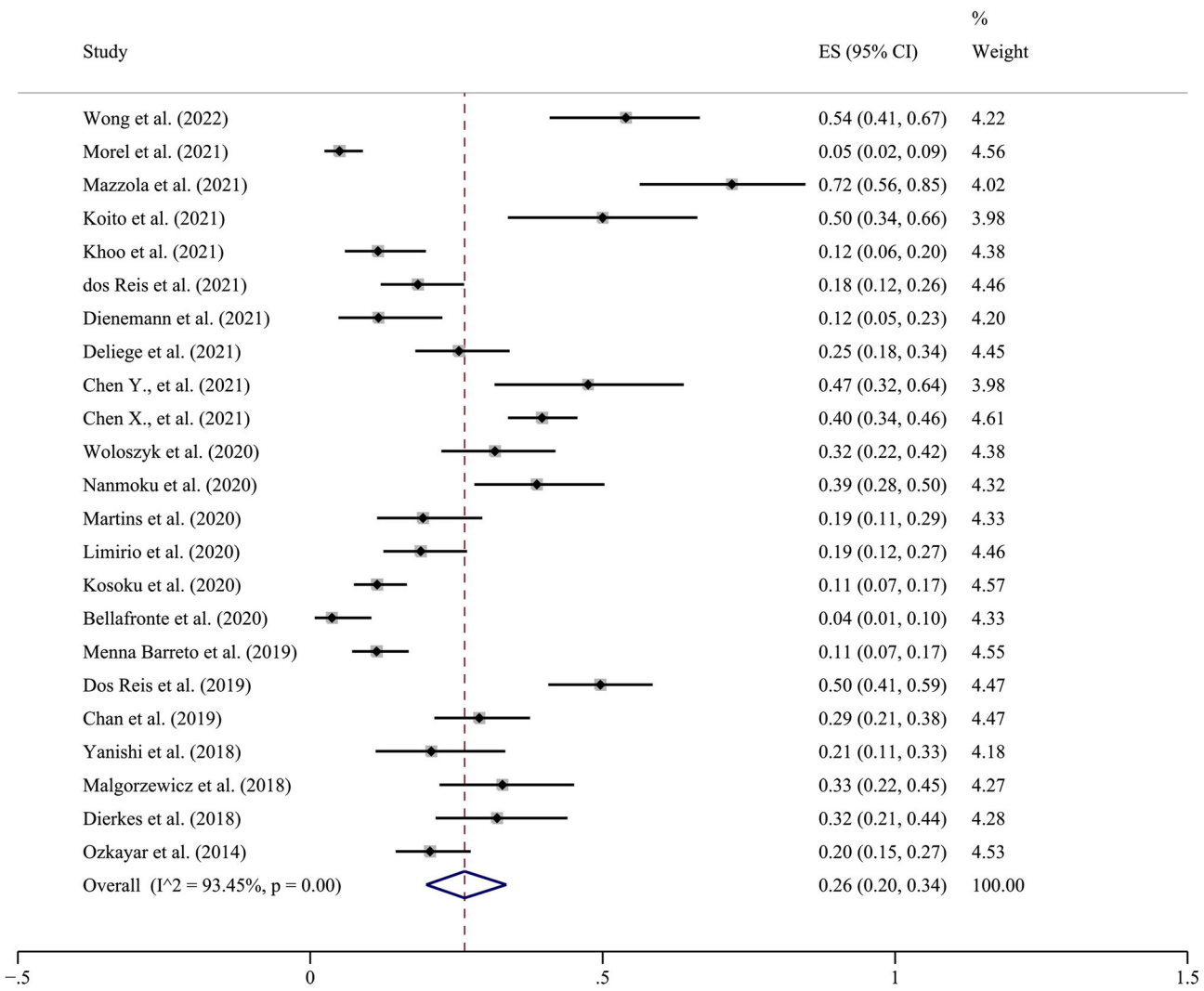

Figure 2 Prevalence of sarcopenia in kidney transplantation recipients. CI, confidence interval; ES, effect size (prevalence %). Random effects model used for analysis.

Discussion

KT improves the quality of life and life expectancy of ESRD patients and has higher economic benefits compared with dialysis in CKD patients.[1,58–62] Every year, the number of elderly candidates for KT has been increasing.[63] Current guidelines recommend the assessment of frailty for the prospective KT candidates, whereas sarcopenia is ignored.[2] However, these two geriatric syndromes have many overlapping causes and consequences that may have significant implications in this particular clinical setting.[64] Patients with sarcopenia/LMM can lead to transplant failure, increased mortality, and postoperative complications such as systemic infection after KT.[14,15,30,35] Recent findings suggest that the mechanism of sarcopenia in KT candidates could be (i) nephropathy-related causes: nutritional deficiency and concomitant malnutrition,[65] vitamin D deficiency,[66] metabolic acidosis,[67] insulin resistance,[68] low physical activity,[69] hyperparathyroidism,[70] uraemia,[10] and proteinuria[71]; and (ii) chronic low-grade inflammation that typical occurs in dialysis patients.[72] KT can correct or ameliorate some of the causes of sarcopenia, such as metabolic acidosis and chronic inflammation. But the post-transplant immunosuppressive drug usage, low physical activity, and poor renal function still can reduce muscle mass and function in KTR subjects.[64] Sarcopenic obesities are commonly diagnosed in KTR individuals and are associated with an increased risk of death, disability, cardiovascular diseases, and metabolic disorders.[73] This study summarized the prevalence, diagnostic criteria, clinical predictors, and outcomes of sarcopenia in KTRs.

We found that the overall prevalence of sarcopenia was 26% in KRTs, including 22% in men and 27% in women. A meta-analysis found that the prevalence of sarcopenia in ESRD patients undergoing dialysis was 28.5%.[4] Another

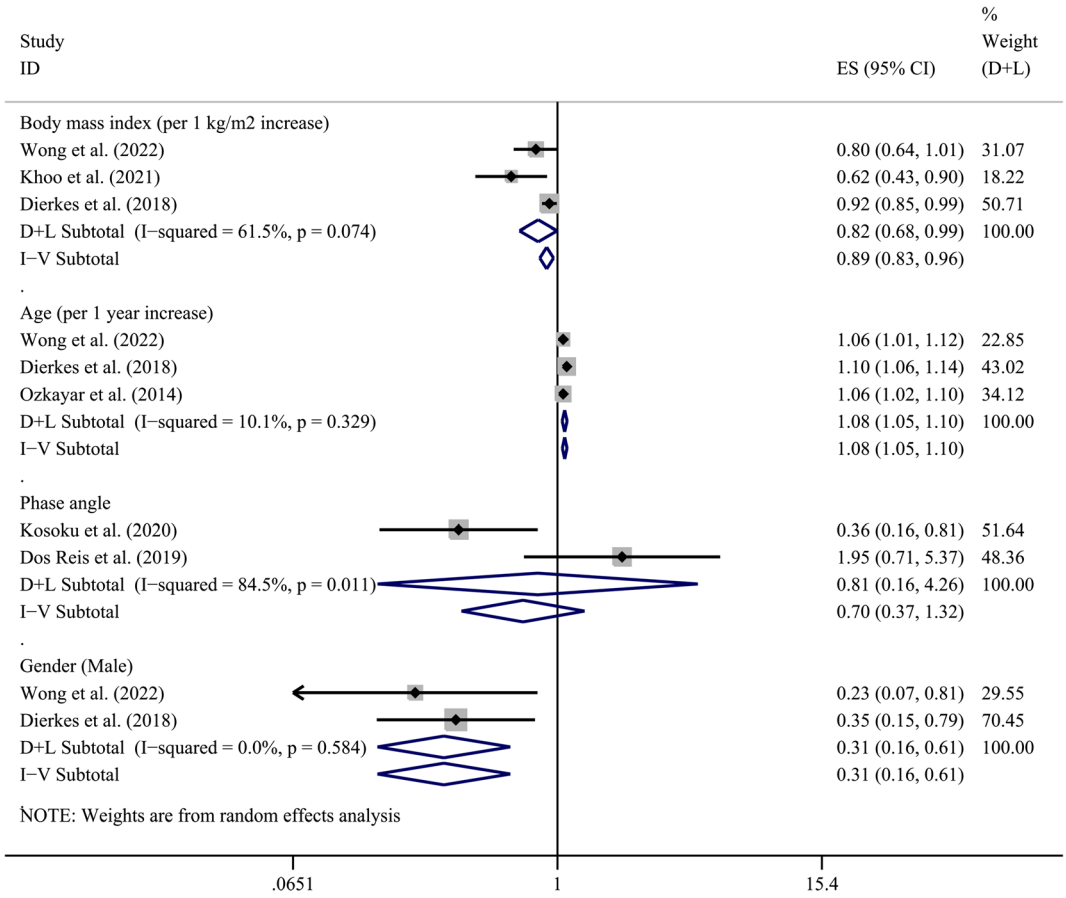

Figure 3 Clinical predictors of sarcopenia in kidney transplantation recipients. CI, confidence interval; ES, effect size (odds ratio).

Table 3 Clinical impact of the sarcopenia in different variables in KRTs

		Compared with KTRs without sarcopenia	
Categories	Variables	1 criterion	>1 criterion
Health-related quality of life	SF-36		Worse[44]
Physical activity level	Activity time	N.d.[33] (min/day)	Reduction[44] (h/week)
	Baecke questionnaire		Reduction[42]
Complications		N.d.[6]	
Postoperative ICU admission		N.d.[29]	
Early hospital readmission		N.d.[29]	
Inflammation	WCC, cells × 10^9/L	N.d.[29]	
	CRP (mg/L)	N.d.[29]	N.d.[38,41]

Abbreviations: CRP, C-reactive protein; ICU, intensive care unit; KTRs, kidney transplantation recipients; N.d., no significant difference; SF-36, Medical Outcomes Study Short Form-36 questionnaire; WCC, White cell count.

meta-analysis showed that in patients with CKD not yet on dialysis, the prevalence of sarcopenia was 34.5% in stages 2 and 3A of CKD and 65.5% in stages 3B, 4, or 5.[74] The prevalence of sarcopenia appears to be lower in CKD patients on dialysis or after KT, possibly due to a reduction in uraemic toxins and improved kidney function.[10] This can be further studied in the future. Meta-regression showed that the mean age and male percentage were not associated with the prevalence of sarcopenia, suggesting the importance of assessing sarcopenia even in male and younger KTRs. Diagnosis of sarcopenia includes either the LMM alone or combined criteria of LMM and LMS and/or LPP. The prevalence of sarcopenia assessed by LMM alone was 34% compared with 21% by LMM with LMS and/or LPP. As reported in dialysis patients and chronic obstructive pulmonary disease patients,[4,75] the combined criterion exhibited a lower positive rate than

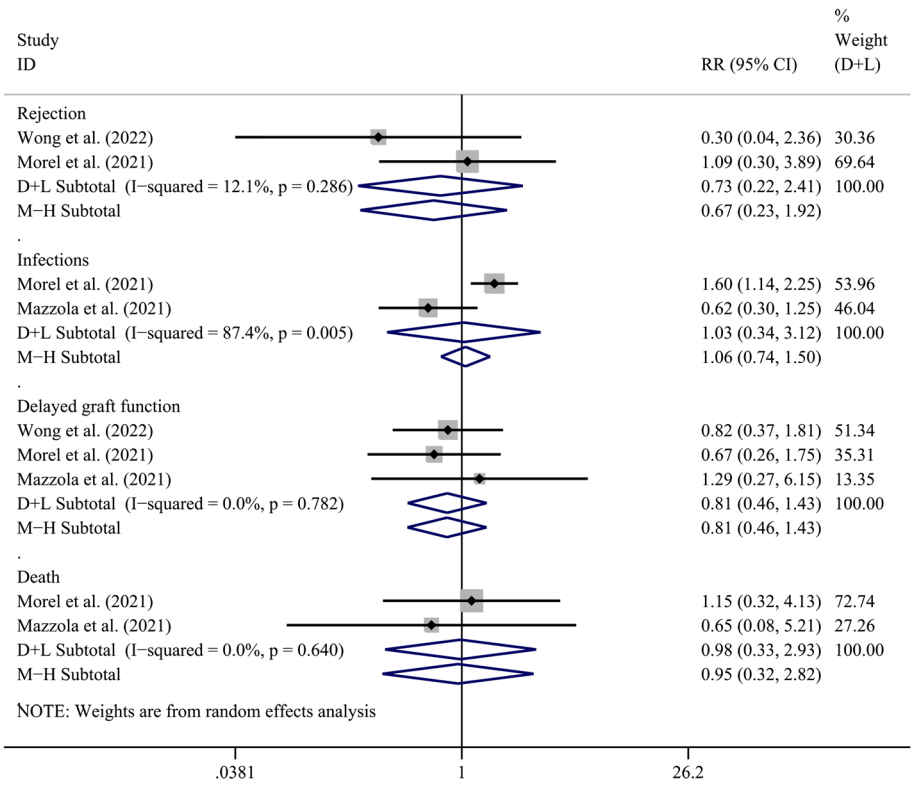

Figure 4 Clinical impact of sarcopenia in kidney transplantation recipients.

the LMM alone in the assessment of sarcopenia, but it improved the accuracy of the sarcopenia diagnosis, which is now internationally recognized as the standard assessment criterion. The prevalence of sarcopenia assessed by EWGSOP and AWGS was lower than that by other methods, which included LMM assessment by CT, may be a pre-requisite for presurgical anatomic mapping, and can be used to assess early and late-term post-transplant complications for KT patients,[29,76] but the resulting prevalence varies widely, ranging from 5.0%[30] to 72.1%[6] due to the use of different cut-off thresholds. It is recommended that future studies should use uniform CT cut-off thresholds to assess the LMM. For HGS and GS, the included studies used EWGSOP and AWGS diagnostic criteria, but the selection of cut-off thresholds and detection methods were uneven. It is recommended that future studies should count only the standardized cut-off thresholds and conduct consistent tests to diagnose sarcopenia.

Aging has been considered a risk factor for sarcopenia in KTRs. Previous studies have shown that advanced aging is the most important risk factor for sarcopenia.[77] However, average age did not affect the prevalence of sarcopenia in our meta-regression, suggesting that even young patients should be screened for sarcopenia. Malnutrition is an important risk factor for sarcopenia,[78] and BMI is one of the most commonly used and easily accessible indicators of nutritional status in clinical practice.[79] Many studies reported that BMI was the best predictor of sarcopenia.[41,45] We found that lower BMI is a risk factor for sarcopenia, which can be used to predict the risk of sarcopenia in KTRs. Studies have confirmed that overweight and obesity in KTRs are known problems.[80–82] Excessive fat deposition and muscle loss are common in patients after KT, a condition known as sarcopenic obesity.[83–86] The assessment of fat mass requires a combination of BMI and body composition or abdominal circumference.[5,87] Previous studies have shown that weight gain is often observed in the early post-transplant period, but this change in weight is not due to an increase in muscle mass, but rather an increase in fat mass. Conversely, muscle mass may decrease even further in the short term after KT.[88] Even within 2 years after KT, the increase in fat mass in KTRs was significantly greater than the increase in muscle mass.[34,89] Taken together, existing studies have found that an increase in BMI contributes to a lower risk of sarcopenia, whereas an increase in body fat mass can lead to muscle loss, helping to partially explain the 'obesity paradox'.[86] Therefore, KTRs should increase physical activity, perform muscle training and dietary control to increase BMI, and reduce body fat mass to prevent the development of sarcopenia.[89–91] In contrast to women, men were a protective factor for sarcopenia. However, meta-regression found that the percentage of male subjects was not associated with the prevalence of sarcopenia, suggesting that even men should be evaluated for

sarcopenia. Dos Reis *et al.*[43] showed that phase angle was only related to the HGS, but not to sarcopenia in KTRs, whereas Kosoku *et al.*[41] reported the opposite. The pooled results revealed that phase angle was not associated with sarcopenia, but this result should be generalized with caution due to the availability of a small number of studies. Furthermore, it has been reported that creatinine,[29] mean muscle attenuation of the total muscle,[29] inorganic phosphates (PO_4),[29] vascular reactivity index (VRI),[32] polyunsaturated fatty acid,[33] ω-3 fatty acids,[33] albumin,[8] and obesity[8] were protective against sarcopenia. Parathyroid hormone (PTH),[29] glucocorticoids,[34] fat mass index (FMI),[34] wound complications,[35] the combined endpoint of graft loss and/or death,[35] glomerulonephritis,[8] pre-transplantation sarcopenia,[8] physical health-related QoL,[44] mental health-related QoL,[44] and prescribed medications[47] were risk factors for sarcopenia. Regarding muscle strength, Chan *et al.*[44] found that lean tissue index, age, male sex, haemoglobin count, vitamin D level, physical activity level, and protein intake were the associated risk factors. Whereas Khoo *et al.*[32] showed that only VRI was related to the HGS.

Sarcopenia has a negative impact on clinical outcomes related to KTRs, including quality of life, physical activity levels, graft rejection, systemic infection, delayed graft function, and death. Oterdoom *et al*. found that muscle mass was negatively associated with KTRs death and graft loss.[14] Sterja *et al*. found a negative association between muscle mass and death among KTRs.[15] Deliege *et al*. showed that LMM was associated with the longer hospital stays after KT, higher rates of wound complications, and graft loss or death in the elderly male patients.[35] Wong *et al*. found that after adjusting for the age, sex, dialysis vintage, type of transplant, length of hospital stay for KT admission, delayed graft function, diabetes, and rejection within the first month of KT, the risk of readmission within 30 days after KT in sarcopenia patients was 7.22 times higher than in patients without sarcopenia (95% CI: 1.87–27.91).[29] Included studies showed mortality rates of 20%,[30] 10.2%,[35] and 10%[44] in sarcopenia patients after KT. Chan *et al*. reported that after adjustment for age, sex, ethnicity, smoking habit, and alcohol consumption, post-KT sarcopenia patients had a 1.94-fold (95% CI: 1.10–3.42) higher risk of death and acute hospitalization than those without sarcopenia.[44] However, due to the limited data provided by the included studies, this study could not clarify the relationship between them. In the future, larger cohorts and multicentre studies are needed to determine negative controls to explore the clinical effects of sarcopenia on KTRs and to set up an intervention group for sarcopenia, as well. And there is currently a void in this field. We were unable to demonstrate a relationship between sarcopenia and inflammatory biomarkers. Wong *et al*., Menna Barreto *et al*., and Kosoku *et al*. found no difference in the level of CRP and white blood cell count between sarcopenic and non-sarcopenic KT recipients.[29,41,42] Although we could not detect the involvement of any specific inflammatory factor related to sarcopenia, however, our study showed that sarcopenia could be associated with increased secretion of pro-inflammatory cytokines (e.g., tumour necrosis factor α and interleukin-6),[92] which seemed to be a valuable area for future research.

To our knowledge, this systematic review was the first to compare the diagnostic methods, prevalence, clinical predictors, and clinical impact of sarcopenia in KTRs. We provided a comparative analysis of commonly used diagnostic criteria for sarcopenia in the KT population and summarized the prevalence rates reported in the recent studies to provide a basis for future interventions. At the same time, we described the influencing factors of sarcopenia in KTRs. Given the aforementioned risk factors, early risk assessment and intervention should be prioritized to prevent the occurrence of sarcopenia, as well as to reduce its adverse impacts on the prognosis of KTRs. Finally, our study analysed the impact of sarcopenia on the prognosis of KT. Although the included studies were limited in number and the impact could not be accurately estimated, they still provide some fundamental clues for future investigations. We found that sarcopenia was highly associated with increased mortality and early readmission rates in KTRs. We thus recommend widespread early screening and guidance for the prevention and treatment of sarcopenia to improve outcomes and reduce the burden of family and social care on patients.

There are certain limitations to this study. First, the included studies had significant heterogeneity (I^2 = 93.45%), mainly in terms of diagnostic methods, measurement methods, diagnostic thresholds, and participants' characteristics, for which we performed the subgroup analysis, meta-regression, and sensitivity analysis to find the possible sources of heterogeneity. Second, for the clinical predictors and their impacts on sarcopenia after KT, the number of studies on some variables was limited, and so the application and promotion of the combined results were also restricted to a certain extent. Finally, we did not include meta-analyses of studies on the relationship between muscle mass, as reflected by creatinine levels, and prognosis in kidney transplant recipients, which was determined by inclusion criteria. Yanishi *et al.*[93] found that the creatinine/cystatin C ratio is suitable for evaluating muscle mass in KTRs. However, they did not explore its impact on the prognosis of KTRs. Future studies could use the creatinine/cystatin C ratio as one of the biomarkers reflecting muscle mass to predict transplant outcomes.

Conclusions

In conclusion, due to the high prevalence of sarcopenia among KTRs, it is important to screen and evaluate

sarcopenia at an early stage, and standardization of diagnostic criteria for sarcopenia in KTRs would be beneficial in the future. Large study cohorts and multicentre longitudinal studies are urgently needed to explore the prevalence and prognosis of sarcopenia in kidney transplant patients.

Conflict of interest

All authors have no conflicts of interest to disclose.[94]

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Online supplementary material

Additional supporting information may be found online in the Supporting Information section at the end of the article.

References

1. Tonelli M, Wiebe N, Knoll G, Bello A, Browne S, Jadhav D, et al. Systematic review: kidney transplantation compared with dialysis in clinically relevant outcomes. *Am J Transplant* 2011;**11**: 2093–2109.
2. Chadban SJ, Ahn C, Axelrod DA, Foster BJ, Kasiske BL, Kher V, et al. KDIGO Clinical Practice Guideline on the Evaluation and Management of Candidates for Kidney Transplantation. *Transplantation* 2020; **104**:S11–s103.
3. Chatzipetrou V, Bégin MJ, Hars M, Trombetti A. Sarcopenia in Chronic Kidney Disease: A Scoping Review of Prevalence, Risk Factors, Association with Outcomes, and Treatment. *Calcif Tissue Int* 2022;**110**: 1–31.
4. Shu X, Lin T, Wang H, Zhao Y, Jiang T, Peng X, et al. Diagnosis, prevalence, and mortality of sarcopenia in dialysis patients: a systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle* 2022;**13**: 145–158.
5. Harada H, Nakamura M, Hotta K, Iwami D, Seki T, Togashi M, et al. Percentages of water, muscle, and bone decrease and lipid increases in early period after successful kidney transplantation: A body composition analysis. *Transplant Proc* 2012;**44**:672–675.
6. Mazzola A, Brustia R, Magro B, Atif M, Ouali N, Tourret J, et al. Impact of sarcopenia on clinical outcomes of patients undergoing simultaneous liver and kidney transplantation: a cohort study. *Clin Res Hepatol Gastroenterol* 2021;**45**:101692.
7. Bellafronte NT, Sizoto GR, Vega-Piris L, Chiarello PG, Cuadrado GB. Bed-side measures for diagnosis of low muscle mass, sarcopenia, obesity, and sarcopenic obesity in patients with chronic kidney disease under non-dialysis-dependent, dialysis dependent and kidney transplant therapy. *PLoS ONE* 2020;**15**:e0242671.
8. Nanmoku K, Kawabata N, Kinoshita Y, Shinzato T, Kubo T, Shimizu T, et al. Deterioration of presarcopenia and its risk factors following kidney transplantation. *Clin Exp Nephrol* 2020;**24**:379–383.
9. Kim JK, Choi SR, Choi MJ, Kim SG, Lee YK, Noh JW, et al. Prevalence of and factors associated with sarcopenia in elderly patients with end-stage renal disease. *Clin Nutr (Edinburgh, Scotland)* 2014;**33**:64–68.
10. Watanabe H, Enoki Y, Maruyama T. Sarcopenia in Chronic Kidney Disease: Factors, Mechanisms, and Therapeutic Interventions. *Biol Pharm Bull* 2019;**42**: 1437–1445.
11. Muhlbacher F, Kapadia CR, Colpoys MF, Smith RJ, Wilmore DW. Effects of glucocorticoids on glutamine metabolism in skeletal muscle. *Am J Physiol* 1984;**247**:E75–E83.
12. Wolthers T, Grøfte T, Jørgensen JO, Vilstrup H. Growth hormone prevents prednisolone-induced increase in functional hepatic nitrogen clearance in normal man. *J Hepatol* 1997;**27**:789–795.
13. Lee CH, Kim GH. Electrolyte and Acid-base disturbances induced by clacineurin inhibitors. *Electrolyte Blood Press: E & BP* 2007; **5**:126–130.
14. Oterdoom LH, van Ree RM, de Vries AP, Gansevoort RT, Schouten JP, van Son WJ, et al. Urinary creatinine excretion reflecting muscle mass is a predictor of mortality and graft loss in renal transplant recipients. *Transplantation* 2008;**86**: 391–398.
15. Streja E, Molnar MZ, Kovesdy CP, Bunnapradist S, Jing J, Nissenson AR, et al. Associations of pretransplant weight and muscle mass with mortality in renal transplant recipients. *Clin J Am Soc Nephrol: CJASN* 2011;**6**:1463–1473.
16. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing* 2010;**39**:412–423.
17. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* 2019;**48**:16–31.
18. Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. *J Am Med Dir Assoc* 2014;**15**:95–101.
19. Chen LK, Woo J, Assantachai P, Auyeung TW, Chou MY, Iijima K, et al. Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment. *J Am Med Dir Assoc* 2020;**21**:300–7. e2.
20. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical research ed)* 2021; **372**:n71.
21. Quality assessment tool for observational cohort and cross-sectional studies. https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools
22. Hoy D, Brooks P, Woolf A, Blyth F, March L, Bain C, et al. Assessing risk of bias in prevalence studies: modification of an existing tool and evidence of interrater agreement. *J Clin Epidemiol* 2012;**65**:934–939.
23. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med* 2002;**21**:1539–1558.
24. Leonard T, Duffy JC. A Bayesian fixed effects analysis of the Mantel-Haenszel model applied to meta-analysis. *Stat Med* 2002;**21**:2295–2312.
25. DerSimonian R, Kacker R. Random-effects model for meta-analysis of clinical trials: an update. *Contemp Clin Trials* 2007;**28**: 105–114.
26. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ (Clinical research ed)* 1997;**315**:629–634.
27. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. *Biometrics* 1994;**50**: 1088–1101.
28. Duval S, Tweedie R. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. *Biometrics* 2000;**56**:455–463.
29. Wong L, Kent AB, Lee D, Roberts MA, McMahon LP. Low muscle mass and early hospital readmission post-kidney trans-

plantation. *Int Urol Nephrol* 2022;**54**: 1977–1986.
30. Morel A, Ouamri Y, Canouï-Poitrine F, Mulé S, Champy CM, Ingels A, et al. Myosteatosis as an independent risk factor for mortality after kidney allograft transplantation: a retrospective cohort study. *J Cachexia Sarcopenia Muscle* 2022;**13**:386–396.
31. Koito Y, Yanishi M, Kimura Y, Tsukaguchi H, Kinoshita H, Matsuda T. Serum Brain-Derived Neurotrophic Factor and Myostatin Levels Are Associated With Skeletal Muscle Mass in Kidney Transplant Recipients. *Transplant Proc* 2021;**53**: 1939–1944.
32. Khoo SB, Lin YL, Ho GJ, Lee MC, Hsu BG. Association of endothelial dysfunction with sarcopenia and muscle function in a relatively young cohort of kidney transplant recipients. *PeerJ* 2021;**9**:e12521.
33. dos Reis AS, Limirio LS, Santos HO, de Oliveira EP. Intake of polyunsaturated fatty acids and omega-3 are protective factors for sarcopenia in kidney transplant patients. *Nutrition* 2021;**81**:110929.
34. Dienemann T, Ziolkowski SL, Bender S, Goral S, Long J, Baker JF, et al. Changes in Body Composition, Muscle Strength, and Fat Distribution Following Kidney Transplantation. *Am J Kidney Dis* 2021;**78**: 816–825.
35. Deliège PG, Braconnier A, Chaix F, Renard Y, Petrache A, Guyot-Colosio C, et al. Skeletal Muscle Index as a Prognostic Marker for Kidney Transplantation in Older Patients. *J Ren Nutr* 2021;**31**:286–295.
36. Chen Y, Wang B, Xiao L, Li Y, Luo Y. Changes in Muscle Mass in Patients With Renal Transplants Based on Ultrasound: A Prospective Study. *J Ultrasound Med* 2021;**40**: 1637–1648.
37. Chen X, Shafaat O, Liu Y, King EA, Weiss CR, Xue QL, et al. Revision of frailty assessment in kidney transplant recipients: Replacing unintentional weight loss with CT-assessed sarcopenia in the physical frailty phenotype. *Am J Transplant* 2022; **22**:1145–1157.
38. Woloszyk P, Malgorzewicz S, Chamienia A, Debska-Slizien A. Obesity After Successful Kidney Transplantation. *Transplant Proc* 2020;**52**:2352–2356.
39. Martins CA, França AKTC, Dias RSC, Costa RCO, Lemos APL, Santos AMD, et al. Prevalence of sarcopenia in kidney transplants and their association with determinant factors of muscle homeostasis. *Rev Assoc Med Bras* 2020;**66**:1235–1240.
40. Limirio LS, Santos HO, dos Reis AS, de Oliveira EP. (Dis) Agreement between the first and the recent European consensus on definition and diagnosis for sarcopenia in kidney transplant patients. *Eur J Clin Nutr* 2020;**74**:1104–1108.
41. Kosoku A, Uchida J, Nishide S, Kabei K, Shimada H, Iwai T, et al. Association of sarcopenia with phase angle and body mass index in kidney transplant recipients. *Sci Rep* 2020;**10**:266.
42. Menna Barreto APM, Barreto Silva MI, Pontes K, Costa MSD, Rosina KTC, Souza E, et al. Sarcopenia and its components in adult renal transplant recipients: prevalence and association with body adiposity. *Br J Nutr* 2019;**122**:1386–1397.
43. Dos Reis AS, Santos HO, Limirio LS, de Oliveira EP. Phase Angle Is Associated With Handgrip Strength but Not With Sarcopenia in Kidney Transplantation Patients. *J Ren Nutr* 2019;**29**:196–204.
44. Chan W, Chin SH, Whittaker AC, Jones D, Kaur O, Bosch JA, et al. The Associations of Muscle Strength, Muscle Mass, and Adiposity With Clinical Outcomes and Quality of Life in Prevalent Kidney Transplant Recipients. *J Ren Nutr* 2019;**29**: 536–547.
45. Yanishi M, Kinoshita H, Tsukaguchi H, Kimura Y, Koito Y, Jino E, et al. Dual Energy X-ray Absorptiometry and Bioimpedance Analysis are Clinically Useful for Measuring Muscle Mass in Kidney Transplant Recipients With Sarcopenia. *Transplant Proc* 2018;**50**:150–154.
46. Malgorzewicz S, Woloszyk P, Chamienia A, Jankowska M, Debska-Slizien A. Obesity Risk Factors in Patients After Kidney Transplantation. *Transplant Proc* 2018;**50**: 1786–1789.
47. Dierkes J, Dahl H, Lervaag Welland N, Sandnes K, Sæle K, Sekse I, et al. High rates of central obesity and sarcopenia in CKD irrespective of renal replacement therapy - An observational cross-sectional study. *BMC Nephrol* 2018;**19**:259.
48. Ozkayar N, Altun B, Halil M, E. Kuyumcu M, Arik G, Yesil Y, et al. Evaluation of sarcopenia in renal transplant recipients. *Nephro-Urol Mon* 2014;**6**:e20055.
49. Batsis JA, Barre LK, Mackenzie TA, Pratt SI, Lopez-Jimenez F, Bartels SJ. Variation in the prevalence of sarcopenia and sarcopenic obesity in older adults associated with different research definitions: dual-energy X-ray absorptiometry data from the National Health and Nutrition Examination Survey 1999-2004. *J Am Geriatr Soc* 2013;**61**:974–980.
50. Beaudart C, Locquet M, Reginster JY, Delandsheere L, Petermans J, Bruyère O. Quality of life in sarcopenia measured with the SarQoL®: impact of the use of different diagnosis definitions. *Aging Clin Exp Res* 2018;**30**:307–313.
51. Jin M, du H, Zhang Y, Zhu H, Xu K, Yuan X, et al. Characteristics and reference values of fat mass index and fat free mass index by bioelectrical impedance analysis in an adult population. *Clin Nutr (Edinburgh, Scotland)* 2019;**38**:2325–2332.
52. Thoresen L, Frykholm G, Lydersen S, Ulveland H, Baracos V, Prado CM, et al. Nutritional status, cachexia and survival in patients with advanced colorectal carcinoma. Different assessment criteria for nutritional status provide unequal results. *Clin Nutr (Edinburgh, Scotland)* 2013;**32**:65–72.
53. Shachar SS, Williams GR, Muss HB, Nishijima TF. Prognostic value of sarcopenia in adults with solid tumours: A meta-analysis and systematic review. *Eur J Cancer (Oxford, England: 1990)* 2016;**57**: 58–67.
54. Montgomery J, Englesbe M. Sarcopenia in Liver Transplantation. *Curr Transplant Rep* 2019;**6**:7–15.
55. Derstine BA, Holcombe SA, Goulson RL, Ross BE, Wang NC, Sullivan JA, et al. Quantifying Sarcopenia Reference Values Using Lumbar and Thoracic Muscle Areas in a Healthy Population. *J Nutr Health Aging* 2017;**21**:180–185.
56. Martin L, Birdsell L, MacDonald N, Reiman T, Clandinin MT, McCargar LJ, et al. Cancer cachexia in the age of obesity: skeletal muscle depletion is a powerful prognostic factor, independent of body mass index. *J Clin Oncol* 2013;**31**:1539–1547.
57. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, di Iorio A, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol (Bethesda, Md: 1985)* 2003;**95**:1851–1860.
58. Gentile S, Beauger D, Speyer E, Jouve E, Dussol B, Jacquelinet C, et al. Factors associated with health-related quality of life in renal transplant recipients: results of a national survey in France. *Health Qual Life Outcomes* 2013;**11**:88.
59. Port FK, Wolfe RA, Mauger EA, Berling DP, Jiang K. Comparison of survival probabilities for dialysis patients vs cadaveric renal transplant recipients. *JAMA* 1993;**270**: 1339–1343.
60. Wolfe RA, Ashby VB, Milford EL, Ojo AO, Ettenger RE, Agodoa LY, et al. Comparison of mortality in all patients on dialysis, patients on dialysis awaiting transplantation, and recipients of a first cadaveric transplant. *N Engl J Med* 1999;**341**: 1725–1730.
61. Rabbat CG, Thorpe KE, Russell JD, Churchill DN. Comparison of mortality risk for dialysis patients and cadaveric first renal transplant recipients in Ontario. *Canada J Am Soc Nephrol* 2000;**11**:917–922.
62. Karopadi AN, Mason G, Rettore E, Ronco C. Cost of peritoneal dialysis and haemodialysis across the world. *Nephrol Dial Transplant* 2013;**28**:2553–2569.
63. Saran R, Robinson B, Abbott KC, Agodoa LYC, Bragg-Gresham J, Balkrishnan R, et al. US Renal Data System 2018 Annual Data Report: Epidemiology of Kidney Disease in the United States. *Am J Kidney Dis* 2019;**73**:A7–a8.
64. Gandolfini I, Regolisti G, Bazzocchi A, Maggiore U, Palmisano A, Piotti G, et al. Frailty and Sarcopenia in Older Patients Receiving Kidney Transplantation. *Front Nutr* 2019;**6**:169.
65. Kovesdy CP, Kopple JD, Kalantar-Zadeh K. Management of protein-energy wasting in non-dialysis-dependent chronic kidney disease: reconciling low protein intake with nutritional therapy. *Am J Clin Nutr* 2013; **97**:1163–1177.
66. Remuzzi A. Vitamin D, insulin resistance, and renal disease. *Kidney Int* 2007;**71**: 96–98.
67. Kraut JA, Madias NE. Consequences and therapy of the metabolic acidosis of chronic kidney disease. *Pediatr Nephrol (Berlin, Germany)* 2011;**26**:19–28.

68. Frost RA, Lang CH. Multifaceted role of insulin-like growth factors and mammalian target of rapamycin in skeletal muscle. *Endocrinol Metab Clin North Am* 2012;**41**: 297–322, vi.
69. Johansen KL, Chertow GM, Kutner NG, Dalrymple LS, Grimes BA, Kaysen GA. Low level of self-reported physical activity in ambulatory patients new to dialysis. *Kidney Int* 2010;**78**:1164–1170.
70. Kir S, Komaba H, Garcia AP, Economopoulos KP, Liu W, Lanske B, et al. PTH/PTHrP Receptor Mediates Cachexia in Models of Kidney Failure and Cancer. *Cell Metab* 2016;**23**:315–323.
71. Sabatino A, Regolisti G, Karupaiah T, Sahathevan S, Sadu Singh BK, Khor BH, et al. Protein-energy wasting and nutritional supplementation in patients with end-stage renal disease on hemodialysis. *Clin Nutr (Edinburgh, Scotland)* 2017;**36**: 663–671.
72. Fouque D, Kalantar-Zadeh K, Kopple J, Cano N, Chauveau P, Cuppari L, et al. A proposed nomenclature and diagnostic criteria for protein-energy wasting in acute and chronic kidney disease. *Kidney Int* 2008; **73**:391–398.
73. Rossi AP, Bianchi L, Volpato S, Bandinelli S, Guralnik J, Zamboni M, et al. Dynapenic Abdominal Obesity as a Predictor of Worsening Disability, Hospitalization, and Mortality in Older Adults: Results From the InCHIANTI Study. *J Gerontol A Biol Sci Med Sci* 2017;**72**:1098–1104.
74. Souza VA, Oliveira D, Barbosa SR, Corrêa J, Colugnati FAB, Mansur HN, et al. Sarcopenia in patients with chronic kidney disease not yet on dialysis: Analysis of the prevalence and associated factors. *PLoS ONE* 2017;**12**:e0176230.
75. Sepúlveda-Loyola W, Osadnik C, Phu S, Morita AA, Duque G, Probst VS. Diagnosis, prevalence, and clinical impact of sarcopenia in COPD: a systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle* 2020;**11**:1164–1176.
76. Vernuccio F, Gondalia R, Churchill S, Bashir MR, Marin D. CT evaluation of the renal donor and recipient. *Abdom Radiol (New York)* 2018;**43**:2574–2588.
77. Sayer AA, Robinson SM, Patel HP, Shavlakadze T, Cooper C, Grounds MD. New horizons in the pathogenesis, diagnosis and management of sarcopenia. *Age Ageing* 2013;**42**:145–150.
78. Landi F, Calvani R, Cesari M, Tosato M, Martone AM, Ortolani E, et al. Sarcopenia: An Overview on Current Definitions, Diagnosis and Treatment. *Curr Protein Pept Sci* 2018;**19**:633–638.
79. Allison DB, Zhu SK, Plankey M, Faith MS, Heo M. Differential associations of body mass index and adiposity with all-cause mortality among men in the first and second National Health and Nutrition Examination Surveys (NHANES I and NHANES II) follow-up studies. *Int J Obes Relat Metab Disord* 2002;**26**:410–416.
80. de Oliveira CM, Moura ÁE, Gonçalves L, Pinheiro LS, Pinheiro FM Jr, Esmeraldo RM. Post-transplantation weight gain: prevalence and the impact of steroid-free therapy. *Transplant Proc* 2014;**46**:1735–1740.
81. Wissing KM, Pipeleers L. Obesity, metabolic syndrome and diabetes mellitus after renal transplantation: prevention and treatment. *Transplant Rev (Orlando)* 2014;**28**:37–46.
82. Malgorzewicz S, Debska-Slizien A, Czajka B, Owczarzak A, Rutkowski B. Influence of Body Mass on Kidney Graft Function in Patients After Kidney Transplantation. *Transplant Proc* 2016;**48**:1472–1476.
83. van den Ham EC, Kooman JP, Christiaans MH, Leunissen KM, van Hooff JP. Post-transplantation weight gain is predominantly due to an increase in body fat mass. *Transplantation* 2000;**70**:241–242.
84. Zamboni M, Rubele S, Rossi AP. Sarcopenia and obesity. *Curr Opin Clin Nutr Metab Care* 2019;**22**:13–19.
85. Choi KM. Sarcopenia and sarcopenic obesity. *Korean J Intern Med* 2016;**31**: 1054–1060.
86. Schütz T, Hudjetz H, Roske AE, Katzorke C, Kreymann G, Budde K, et al. Weight gain in long-term survivors of kidney or liver transplantation--another paradigm of sarcopenic obesity? *Nutrition* 2012;**28**: 378–383.
87. Fukuoka Y, Narita T, Fujita H, Morii T, Sato T, Sassa MH, et al. Importance of physical evaluation using skeletal muscle mass index and body fat percentage to prevent sarcopenia in elderly Japanese diabetes patients. *J Diabetes Investig* 2019;**10**: 322–330.
88. Işiklar I, Akin O, Demirağ A, Niron EA. Effects of renal transplantation on body composition. *Transplant Proc* 1998;**30**:831–832.
89. Moreau K, Chauveau P, Martin S, El-Haggan W, Barthe N, Merville P, et al. Long-term evolution of body composition after renal transplantation: 5-year survey. *J Ren Nutr* 2006;**16**:291–299.
90. Karelis AD, Hebert MJ, Rabasa-Lhoret R, Rakel A. Impact of Resistance Training on Factors Involved in the Development of New-Onset Diabetes After Transplantation in Renal Transplant Recipients: an Open Randomized Pilot Study. *Can J Diabetes* 2016;**40**:382–388.
91. Lima PS, de Campos AS, de Faria Neto O, Ferreira TCA, Amorim CEN, Stone WJ, et al. Effects of Combined Resistance Plus Aerobic Training on Body Composition, Muscle Strength, Aerobic Capacity, and Renal Function in Kidney Transplantation Subjects. *J Strength Cond Res* 2021;**35**: 3243–3250.
92. Carrero JJ, Chmielewski M, Axelsson J, Snaedal S, Heimbürger O, Bárány P, et al. Muscle atrophy, inflammation and clinical outcome in incident and prevalent dialysis patients. *Clin Nutr (Edinburgh, Scotland)* 2008;**27**:557–564.
93. Yanishi M, Kinoshita H, Tsukaguchi H, Kimura Y, Koito Y, Sugi M, et al. The creatinine/cystatin C ratio provides effective evaluation of muscle mass in kidney transplant recipients. *Int Urol Nephrol* 2019;**51**: 79–83.
94. von Haehling S, Coats AJS, Anker SD. Ethical guidelines for publishing in the Journal of Cachexia, Sarcopenia and Muscle: update 2021. *J Cachexia Sarcopenia Muscle* 2021;**12**:2259–2261.