A systematic review of handgrip strength measurement in clinical and epidemiological studies of kidney disease: towards a standardized approach

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Supplementary material

Supplementary material 1. Full search strategies

Supplementary material 2. Summary of handgrip strength measurement protocols

Supplementary material 3. Link to file containing all extracted data

In chronic kidney disease (CKD), handgrip strength (HGS) is recommended as a surrogate measure of protein-energy status and functional status. However, it is not routinely used due to inconsistencies such as the optimal timing of the HGS measurement and unclear guidance regarding technique. We aimed to determine the extent of variation in the protocols and methods of HGS assessment. We aimed to identify clinical and epidemiological studies conducted in CKD that reported on the use of HGS as an outcome. A systematic literature search identified n=129 studies with a total participant population of n=35,192. We identified large variations in all aspects of the methodology including body and arm position, repetitions, rest time, timing, familiarization, and how scores were calculated. The heterogeneous methodologies employed reinforce the need to standardize HGS measurement. After reviewing previously employed methodology in the literature, we propose a comprehensive HGS assessment protocol for use in CKD.

Key words

Handgrip strength; chronic kidney disease, systematic review

Introduction

Chronic kidney disease (CKD) is characterized by reductions in physical function and strength that has a detrimental effect on quality of life (QoL) and is associated with morbidity and mortality [1]. Handgrip strength (HGS) has emerged as a simple and reliable method to evaluate muscle function [2] and in studies of the general population [3-5], older adults [6], and clinical conditions [2, 7, 8], low HGS has emerged as an independent predictor for poor cognition, mobility, and mortality. Handgrip strength forms a prominent role in the detection of muscle weakness as part of the frailty and sarcopenia phenotype [9] and the possibility of modifying HGS through interventions, such as exercise, make it a popular amenable outcome measure [10].

Given its low cost and ease of assessment, HGS is widely used in clinical and epidemiological studies involving patients with CKD as a method of nutritional and functional assessment [11, 12]. In patients with non-dialysis dependent CKD, HGS is an independent predictor of mortality [13-16] and dialysis initiation [15, 16], whilst in dialysis patients, HGS is associated with nutritional status [12, 17]. A recent meta-analysis found the summary risk ratio of all-cause mortality associated with a 1-kg unit increase in HGS was 0.95 (0.93-0.97) [18]. Nonetheless, some studies suggest HGS is relatively preserved compared with lower limb strength [19] and has no association with body composition or nutritional status in peritoneal dialysis (PD) patients [20].

The 2020 'KDOQI Clinical Practice Guideline for Nutrition in CKD' recommend that in adults with CKD 1-5D, HGS is used as a surrogate measure of protein-energy status and functional status [21, 22]. The cited rationale is based on the relationship of HGS with nutritional status (e.g., malnutrition inflammation score [23, 24]) and inflammatory markers [25]). Nevertheless, whilst HGS is widely used in clinical studies, it is not routinely implemented in practice. Reasons for this lack of application are partly due to inconsistencies in guidance such as the optimal timing of the measurement (e.g., pre- or post- hemodialysis (HD) session, non-dialysis day) and equivocal information regarding technique [11, 21].

The lack of standardization of this routine and recommended measure is somewhat worrying as even small inconsistency in technique and protocol may result in invalid measurement and risk of error rendering its value inadequate. In order to propose a standardized protocol and measurement procedure for the assessment of HGS in CKD we conducted a systematic review to evaluate the current literature on HGS methodology. We aimed to determine the degree of protocol variation in HGS assessment, before using this information to propose a standardized method for future measurement in CKD.

Methods and materials

A systematic literature search was undertaken per the PRISMA statement [26]. The protocol was prospectively registered on PROSPERO (CRD42020206097).

Eligibility criteria

We aimed to identify clinical and epidemiological studies conducted in CKD that reported the use of HGS as an outcome measure. All types of studies were included, including interventional trials of any component. Studies using handgrip-based training to elicit a response (e.g., changes in blood pressure) were excluded. Review studies, abstracts, animal trials, and non-English articles were excluded. To aid data synthesis and to focus on contemporary methodology, we limited studies to those conducted in the last five years (i.e., 1st January 2016 to the date of search). Adult participants with a diagnosis of CKD were included (i.e., CKD1-5 including those on dialysis and kidney transplant recipients (KTRs)).

Types of outcome measures

The primary outcome was HGS and its use in any form. We were specifically interested in the variation in HGS protocol and methodology. No secondary outcomes were assessed.

Information sources

The following databases were searched: National Centre for Biotechnology Information (NCBI) PubMed [which includes the Medical Literature Analysis and Retrieval System Online (MEDLINE)], Excerpta Medica database (EMBASE), and the Cochrane Central Register of Controlled Trials (CENTRAL).

Search strategy

The following MESH search terms were used to search all databases: ‘Kidney’; ‘Kidney Diseases‘; ‘Kidney Transplantation‘; ‘Dialysis’; ‘Peritoneal Dialysis’; ‘Renal Dialysis’. In addition, non-MeSH terms ‘Handgrip’ and ‘Handgrip strength’, along with MeSH Descriptors ‘Pinch strength’ and ‘Muscle strength dynamometer’ were used. Full search strategies for each database can be found in **supplementary material 1**. A flow of information through the different phases of the search can be found in the PRISMA diagram, **Figure 1**.

Data collection process and data items

Following a preliminary pilot search in NCBI PubMed, a bespoke data extraction form was created. Prior to data extraction, this form was piloted by all the researchers on three papers selected at random. Following this pilot, the extraction form was amended. Each article was reviewed by an independent member of the team. If means were presented for different groups, pooled values were calculated [27]. Due to the nature of the review, risk of bias was not assessed.

The following information was extracted: 1) study; and 2) patient characteristics. Based on Roberts et al. [28] and Shiratori et al. [29], the following were extracted: 1) equipment type; 2) measurement protocol (e.g., hand size and nail length, hand dominance, jewellery removal, acquisition time); 3) HGS data; 4) body position (i.e., wrist/forearm, elbow, shoulder, posture); 5) effort and encouragement; 6) interval (rest) between measurements; 7) time of day; 8) training of assessors; 9) clinimetric properties; and 10) familiarization/practice tests. We also extracted, where appropriate, information pertaining to CKD: 1) the timing of the measurement (e.g., pre- or post-HD session, non-dialysis day); 2) any confounding effects of other conditions; 3) type of access (e.g., central venous catheter or a fistula/graft); 4) any information regarding fluid gain or ultrafiltration rate; and 5) any contraindications noted prior to testing.

Results

A PRISMA diagram can be found in **Figure 1** whilst a summary of included studies can be found in **supplementary material 2**. A link to the full data file can be found in **supplementary material 3**.

Summary of study characteristics

In summary, n=129 studies were eligible for inclusion with a total population of n=35,192. Study samples ranged from n=14 to 18,765. The median study sample size was n=90. Thirty (23%) studies assessed only non-dialysis dependent CKD1-5, n=80 (62%) in dialysis only [of which, n=52 (41%) were conducted in HD], and n=11 (9%) in KTRs. Studies were conducted in 28 countries with Brazil (n=20 studies) and the UK (n=10) undertaking the most. Ninety-three studies (73%) had observational designs and n=24 (19%) were experimental.

Summary of participant characteristics

The mean age was 59.5 (range: 36.2 to 77.3) years. Ethnicity was poorly reported with n=105 studies providing no data. In studies that did, 54% of patients were White. Males made up an average of 62% of each study population. Where eGFR was reported the average was 38.5 (range: 16.9 to 68.5) ml.min.1.73^2. Mean body mass index as 25.7 (range: 20.3 to 29.4) kg/m^2. Mean albumin was 39.0 (range: 26.3 to 63.0) mg/g and hemoglobin was 112.1 (range: 61.5 to 132.0) g/L. The reported prevalence of hypertension was 65.3%, 35.4% had diabetes, and 27.8% had cardiovascular disease (CVD).

Handgrip strength data

The majority of studies (n=75, 59%) did not report HGS data. When stated, the mean HGS was 26.4 (range: 9.5 to 55.0) kg. Most studies (n=88, 69%) measured HGS in kilograms (kg). Ten studies used kilogram-force (kgf). One study used kg/m^2 [30]. Two studies reported pounds (lbs) [31, 32] whilst another reported Newtons (N) [33]. Twenty-five studies did not report units.

Cut-off criteria used to define low muscle strength

In studies using HGS as a measure of sarcopenia or to define low strength, n=6 studies used the Asian Working Group for Sarcopenia (AWGS) cut-offs, whilst n=20 used variations of the European Working Group on Sarcopenia in Older People (EWGSOP) (n=15 used the older EWGSOP cut-off, n=5 used the revised EWGSOP cut-off).

Handgrip strength protocols

Equipment

The most frequently used dynamometer was Jamar® (n=55, 43%). The Jamar® Plus was specified in n=8 studies. The model of Jamar® was not specified in n=43 of the studies. The second most frequently used dynamometer make was Takei® (n=22, 17%). The most commonly reported model was the Takei® GRIP-D (n=8). Other makes of dynamometer included Yamar® (n=7), Saehan® (n=6), and CAMRY® (n=5). The type of dynamometer was poorly reported with n=11 studies simply specifying a digital model was used with n=20 stating the instrument was hydraulic.

Contraindication prior to testing

In one study, patients were excluded if they could not complete the test [34], whilst in another patients were excluded if they showed signs of hand ischemia [31].

Body position

Thirty (23%) studies specified that HGS was performed while sitting, whilst n=14 were conducted standing. Two were conducted whilst supine [35, 36] and one [37] stated patients could either sit or stand. Eighty-two (64%) studies did not report position. A 90° elbow flexion was specified in n=24 studies (n=17 of which were sitting, n=7 did not report position). Two studies stated the elbow was fully extended (180°), one standing [38] and the other sitting [39]. The remaining n=103 studies did not report position. Fourteen studies stated the forearm was placed in a neutral position. Specific wrist position was specified in two studies: one study [40] reported the wrist was between 0-15°ulnar deviation, and 0-30° dorsiflexion in another [41]. The shoulder position was stated in n=23 (18%) studies. Most of these studies (n=19) reported that the shoulders were adducted, n=3 stated the arms were abducted [30, 42, 43], whilst n=1 stated the shoulders were in a neutral position [44].

Hand selection

Forty-one (32%) studies tested both hands, whilst n=59 (46%) tested HGS in one hand only. The remaining studies did not report which hand was used. The dominant hand was tested in n=34 (27%) studies. Dominance was not stated in the other studies that used only one hand. In those with a fistula, n=36 studies reported that HGS was assessed in the non-fistula arm. One study assessed HGS in both hands of HD patients [45].

Instructions effort or encouragement

Twenty studies (16%) explicitly stated they gave participants verbal instruction to 'exert maximal force' or a variation of such. The majority of studies (n=103) did not report if encouragement was given.

Contraction time

Only n=4 studies [44, 46-48] reported an explicit contraction time where patients were asked to exert maximal effort for 5 seconds.

Warm-up and familiarization testing

A warm-up consisting of submaximal handgrip contractions was used by one study [44]. Whilst in another, patients were asked to shake their hand three times [49]. In two studies [50, 51], the first trial was discarded as a 'warm-up'. Eleven studies incorporated a form of familiarization with the equipment which involved patients being instructed and shown how to use the equipment. The remaining n=118 (92%) did not report the use of familiarization.

Assessment repetitions

Most studies (n=86, 67%) performed three assessments in each hand. Three studies performed one assessment, n=11 performed two, n=2 performed four assessments, and n=1 performed six assessments. The remaining n=26 (20%) studies did not report the repetitions used. Only one trial specified that hands were tested alternatively (i.e., right, left, etc.) [52].

Rest time

Thirty (30%) studies reported rest time: 10-20 seconds was used by n=2 studies; 15 seconds by n=2 studies; 20 seconds by n=1 study; 30-seconds by n=8 studies; 90-seconds by n=1 study;

3-minutes by n=1 study; and 5-minutes by n=5 studies. ‘At least’ 10 and 30 seconds was used by n=3 studies, whilst n=2 studies reported giving ‘at least’ 5-minutes rest. The most frequently reported rest time was 1-minute, used by n=14 (11%) studies. Rest time was not reported in the remaining n=90 studies (70%).

Calculating a score

The most frequent method to generate a score was to use the maximal score (n=67, 52%), followed by the average of all trials performed in that hand (n=29, 23%). Four studies used the average of the maximal score from each hand, whilst n=2 reported the median value. The other n=27 (21%) did not report how they calculated HGS score. One study combined the HGS of both hands to report a combined kg value [53].

Testing time

Forty of the studies involving patients undergoing dialysis reported information on the time of day assessments took place (relative to dialysis schedule). Six studies (5%) assessed HGS *after* dialysis. Specific details were provided in several studies, such as that assessment should take place *at least 18-24 hours* following last session [38], another stating testing should take place *at least 24-hours after* [54], and another *at least 30 minutes after* [55]. Marini et al. [56] reported that assessment should take place *after the middle dialysis session* of the week to avoid alteration in hydration status.

Eighteen studies reported assessments *before dialysis*, with Bogataj et al. [57] stating this should be at *least 30-minutes before*. Five studies reported performing HGS *during* dialysis, particularly during the mid-week session [42, 58] and within the first hour of dialysis [37, 59].

The remaining n=6 studies stated performing HGS on a non-dialysis day, with n=3 of these performing assessments in the afternoon [60-62]. In PD, testing was done during PD clinic visits, although type of clinic was not reported [59].

Training of assessor

No specific details of how the assessor was trained were mentioned in any study.

Adverse outcomes

No adverse events were reported specifically related to the HGS assessment.

Discussion

Despite HGS being recommended in CKD [21], little attention has been paid to the significance of standardization of the test protocol itself. Such standardization is important to improve the accuracy and consistency of the test since differences can affect the reproducibility and the comparison across studies. This review examined 129 studies with over 35,000 participants across the CKD spectrum. We identified large variations in all aspects of the HGS methodology reported. Here we discuss these findings in context before making recommendations towards a standardized approach in **Table 1** with a checklist on reporting HGS protocols in **Table 2.**

Variations of the Jamar® dynamometer were the most widely used instruments. In the 1990's, the American Society of Hand Therapists (ASHT) recommended the Jamar® dynamometer leading to its widespread use [63]. Jamar® is now widely accepted as the gold standard by which other dynamometers are evaluated [28] and research has shown excellent inter-instrument reliability exists between Jamar® and other commonly used dynamometers (e.g., Baseline, MicroFET); this suggests they could be used interchangeably [64]. The other most frequently reported dynamometer was from Takei®, specifically the D-Grip. Study in healthy volunteers from Brazil showed significant differences between the Jamar® and Takei® dynamometers which could be due to the influence of the handle shapes; Jamar® has a superior anatomical shape [65]. However, both dynamometers have been shown comparable in patients with cystic fibrosis [66] and healthy young adults [65]. To our knowledge, no study has compared devices in a CKD population. It is important to note that both the Jamar® and Takei® devices may not be the most appropriate for those with very poor HGS as both dynamometers are unable to detect forces <5kg [67, 68]. In a sample of n=209 adult HD patients, 5% of patients scored <5kg. Regardless of dynamometer make and model, appropriate calibration as per the manufacturer's instructions should be performed and follow-up testing should be performed using the same instrument.

The recent KDOQI guidelines [21, 22] highlighted future research should determine the standardization of the arm position, evaluation period, and choice of arm side. We noted considerable variation in the body position during the assessment. Firstly, studies reported a mixture of sitting and standing positions. It has previously been shown that no significant difference in HGS occurs when either sitting or standing [69, 70], although results are not *entirely* equivocal [71]. Nonetheless, given that any differences in posture are likely to have minimal effect on the readings, like Horner et al. [37] from our review, we suggest patients should be either sat or stood depending on their capacity. This may be particular pertinent to patients with poor balance or mobility.

Few studies reported the handle settings for the instrument. Jiang et al. [72] stated that in patients with CKD4-5, the "handle was adjusted to ensure fingers were properly rested on the handle." For the Jamar® dynamometer, there are five handle positions available, however the second position is the most reliable [73] and recommended by the ASHT [63, 74, 75]. However, the Southampton protocol is broader, suggesting the handle should be adjusted so the thumb is around one side of the handle and the fingers are around the other [28]. It should be specified that HGS using the Jamar® second position is reduced in those with fingernails extending >1cm beyond the fingertip, and for position one, HGS is reduced with fingernails projecting 0.5cm [76].

Most studies in the review reported an elbow flexion of 90°. Higher grip strength has been reported with the elbow in 90° flexion rather than fully extended [77, 78], although findings are equivocal [79]. Our review showed the majority of studies reported an adducted shoulder position (i.e., arms down by the side, 0°). Su et al. found the highest mean HGS score was recorded when the shoulder was positioned at 180° of flexion (i.e., overhead) with the elbow in full extension, whereas (the position commonly reported this review) 90° elbow flexion with a shoulder flexion of 0° produced the lowest HGS score [80]. Conversely, other studies have reported no differences when shoulder joints varied between 90° and 180° [78] or 0 and 180° shoulder flexion [81]. Given the complex nature of shoulder movement and risk of injury in a population characterized by deconditioning and poor mobility [82], we suggest HGS should safely be performed with the elbow in 90° flexion and the shoulder adducted (0°).

Regarding the wrist position, most studies reported that the forearm was placed in a neutral position. Although Hasheminejad et al. [40] stated the wrist was between 0-15° ulnar deviation and Taşoğlu et al. [41] reported of 0-30° dorsiflexion. Previous work has suggested that a minimum of 25° of wrist extension was required for optimum grip strength [83]. Handgrip strength measured with the wrist in a neutral position was significantly higher than that in the wrist ulnar deviation [78]. In another study, the HGS was higher when the wrist was positioned in neutral [81]. The ASHT recommends the forearm in neutral and wrist between 0 and 30° of dorsiflexion [63].

It is well known there are differences of around 10% in HGS between the dominant and non-dominant hands [29]. In those on dialysis with a fistula, most studies reported that HGS was assessed in the *non-fistula* arm. A review by Leal et al. [84] suggested that measuring HGS on the fistula arm could result in problems such as a risk of bleeding if the arm is overexerted. Nonetheless, studies [45, 67, 85, 86] have measured HGS on the fistula arm, although this generally occurs before connection and just after disconnection (after bleeding stopped) to limit the impact on the fistula itself. Studies have shown HGS is generally lower in the access arm. El-Katab et al. [67] found a significant difference of 2.4kg (15%) between the fistula and non-fistula arm. Similarly, Omichi et al. [45] reported HGS was lower in the fistula access arm compared to the non-access arm (a difference of 3.9kg (21%) in right arm, and 1.1kg (7%) in left arm) in HD patients, i.e., HGS was greater in the left arm for those dialyzing with right arm vascular access and vice versa. Whilst this suggests that the presence of a fistula may impact HGS compared to the contralateral arm, it is important to note that such data may be confounded by the surgical practice to form the fistula in the *non-dominant* arm. As such it seems desirable to make measurements *in the non-fistula arm* to improve reliability and safety.

Only 16% of studies explicitly stated they gave participants verbal instruction to ‘exert maximal force’ or a variation of such. Different instructions and verbal encouragement, even the volume of said instruction [78], can affect performance [70, 75, 87]. The contraction time per HGS trial was poorly described with only four studies reporting an explicit contraction time of 5 seconds. The ASHT protocol states the acquisition time should be at least 3 seconds. There is limited research into the differences in sustained isometric contractions of the hand. Kamimura and Ikuta [88] showed in healthy students that there were no differences in peak strength values between a 6-second and 10-second test. Moreover, peak HGS occurred after 1 second in both tests. As such, an acquisition time of at least 3 seconds is likely to be sufficient.

One of the largest sources of variation between studies was the method used to generate a HGS score. The majority of studies (67%) performed three assessments in each hand as per other studies in the literature [28, 75]. Most studies used the highest value for analysis, however other ways of recording HGS included the mean, median, or the sum of values obtained. It has been suggested the *mean of three attempts* has the highest test-retest reliability and consistency [29], and that the mean of three trials is more accurate than one trial or the highest score of three trials [77]. Contrariwise, it has been stated that muscle fatigability might increase with each subsequent attempt and that one trial is sufficient [89]. A study in 66 participants with forearm injuries observed that the values generated for three methods (one trial, mean, and highest) produced comparable results [90]. Given the high prevalence of fatigue and poor muscle function in CKD, we suggest that taking the *maximal score from three attempts* should be used, as fatigability will not influence the mean. However, one trial should be sufficient if short on time. We observed variation in the units presented. Most studies reported HGS in kg, a SI unit, however other values (e.g., kgf) were used. Whilst units may be converted to kg, the use of non-standard units make comparisons difficult.

The rest time reported between each trial varied substantially, between 10 seconds and 5 minutes. The most frequently reported rest time was 1 minute. The resting interval between trials can influence strength performance because this variable is directly related to muscle fatigue. Shiratori et al. [29] recommended a rest period of *at least 1 minute* to counteract the effects of fatigue, whilst the ASHT protocol states the rest time should be *at least 15 seconds*. To minimize the total time for the test, hands can be tested alternately (i.e., right, left, etc.)

such as performed in D'Alessandro et al. [52] and stated in the Southampton protocol [28]. Only a small number of studies (n=4) specified any form of warm-up, whilst only n=11 studies incorporated some form of familiarization. In two studies [50, 51], the first trial was discarded as a 'warm-up'. There is limited research exploring the effect of including practice or familiarization testing, although as described above, given the reliability of performing just one trial [90], it appears that they may not be required.

The KDOQI workgroup recommended further research on the timing of the HGS measurement (e.g., pre- or post-HD session, non-dialysis day) [21, 22]. We found that n=18 studies reported assessments *before* dialysis, with Bogataj et al. [57] stating this should be at least 30-minutes before. A recent study in 101 HD patients showed a significant decline (~4kg, 41%) in HGS *after* dialysis compared to values *before* [85]. However, Leal et al. [84] showed no difference pre-post dialysis session. Hall et al. [91] suggested performing HGS testing *before* a HD session to avoid limiting participation due to post-dialysis complications (e.g., cramps or hypotension). However, considerations pre-dialysis includes fluid overload and hypertension and should be determined before undergoing HGS testing. Delaneye et al. [85] assessed HGS *before* HD connection and just *after* disconnection (after bleeding stopped). Five studies reported performing HGS *during* dialysis, particularly during the mid-week session [42, 58] and *within* the first hour [37, 59]. There is limited evidence on how HGS results could be influenced by the dialysis session itself (and events that can occur such as hypotension) [85]. The remaining studies stated assessment should take place on a *non-dialysis* day. Hall et al. [91] reported that in 37 community-dwelling older adults receiving HD good agreement between 'short physical performance battery' scores on dialysis days and non-dialysis days, although it remains unknown if agreement upholds for HGS. As such, assessment of HGS *before* a dialysis session, or on a *non-dialysis day* if possible, is preferential. As with other physical function assessments [92, 93], to limit the variability in physiologic status and dialysis fatigue, HGS should be assessed before the participant's *mid-week dialysis session*.

No adverse events were reported specifically related to the HGS assessment and only one study reported a contraindication relevant to the hand. Kmentova et al. stated that patients should be excluded if they showed clinical signs of hand ischemia [31]. There are few reported contraindications to HGS in the literature, although testing is generally contraindicated before full healing following a fracture, ligament repair, tendon laceration, or tendon transfer of the forearm, wrist, or hand [94]. Isometric exercise, including HGS testing [95], is associated with acute hemodynamic changes consisting of increases in systolic, diastolic, and arterial pressure, as well as increased heart rate and cardiac output [96]. Caution should be applied to those with uncontrolled hypertension or CVD.

Strengths and limitations

To our knowledge, there is no other systematic review of literature that comprises a detailed description of the methods of HGS in observational and experimental studies in CKD. We were able to include a large number of studies (n=129) encompassing over 35,000 participants. Given the large number of studies assessing HGS, we limited our review to English articles conducted in the last 5 years to provide an overview of contemporary research. The aim of the present review was to gather information regarding HGS methods, hence, we did not evaluate the quality of the studies included.

Gaps in the literature

Along with determining cut-off values correlated with measures of nutritional status, assessing the reliability and validity, and exploring the association with other markers of function (as recommended by the KDOQI workgroup [21, 22]), other areas for research include: directly comparing devices; investigating how HGS could be influenced by the dialysis session; and explore differences in HGS between dialysis and non-dialysis days. One component that was not extracted in the current review was the use of feedback - a variable not well documented [29]. Jung et al. [97] found providing real-time visual feedback increased HGS by 7-10%. Therefore, further research is needed to determine the role of visual and verbal feedback in CKD.

Conclusion and practical applications

The diverse methodologies employed in CKD research reinforce the need to standardize HGS measurement. After reviewing previously employed methodology in the literature, we have proposed a comprehensive HGS assessment protocol for use in CKD **(Table 1).** Researchers should always include a detailed description of the methodology employed; a proposed checklist can be found in **Table 2**. Any differences in protocols can influence the HGS results and, consequently, affect the comparability between the studies. A collective approach is not only important for research purposes but also for clinical practice.

References

1. MacKinnon HJ, Wilkinson TJ, Clarke AL, Gould DW, O'Sullivan TF, Xenophontos S, et al. The association of physical function and physical activity with all-cause mortality and adverse clinical outcomes in nondialysis chronic kidney disease: a systematic review. *Ther Adv Chronic Dis*. 2018; 9(11):209-226.

2. McGrath R. Are we maximizing the utility of handgrip strength assessments for evaluating muscle function? *Aging Clin Exp Res*. 2020. Epub ahead of print.

3. Celis-Morales CA, Welsh P, Lyall DM, Steell L, Petermann F, Anderson J, et al. Associations of grip strength with cardiovascular, respiratory, and cancer outcomes and all cause mortality: prospective cohort study of half a million UK Biobank participants. *BMJ*. 2018; 361:k1651.

4. Yates T, Zaccardi F, Dhalwani NN, Davies MJ, Bakrania K, Celis-Morales CA, et al. Association of walking pace and handgrip strength with all-cause, cardiovascular, and cancer mortality: a UK Biobank observational study. *Eur Heart J*. 2017; 38(43):3232-3240.

5. Zaccardi F, Davies MJ, Khunti K, Yates T. Comparative Relevance of Physical Fitness and Adiposity on Life Expectancy: A UK Biobank Observational Study. *Mayo Clin Proc*. 2019; 94(6):985-994.

6. Rijk JM, Roos PR, Deckx L, van den Akker M, Buntinx F. Prognostic value of handgrip strength in people aged 60 years and older: A systematic review and meta-analysis. *Geriatr Gerontol Int*. 2016; 16(1):5-20.

7. Hamasaki H, Kawashima Y, Katsuyama H, Sako A, Goto A, Yanai H. Association of handgrip strength with hospitalization, cardiovascular events, and mortality in Japanese patients with type 2 diabetes. *Sci Rep*. 2017; 7(1):7041.

8. Kilgour RD, Vigano A, Trutschnigg B, Lucar E, Borod M, Morais JA. Handgrip strength predicts survival and is associated with markers of clinical and functional outcomes in advanced cancer patients. *Support Care Cancer.* 2013; 21(12):3261-70.

9. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T; Writing Group for the European Working Group on Sarcopenia in Older People 2 (EWGSOP2), and the Extended Group for EWGSOP2. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing.* 2019; 48(4):601.

10. Labott BK, Bucht H, Morat M, Morat T, Donath L. Effects of Exercise Training on Handgrip Strength in Older Adults: A Meta-Analytical Review. *Gerontology*. 2019; 65(6):686-698.

11. Viramontes-Hörner D, Taal MW. Nutritional status assessment: a neglected biomarker in persons with end-stage kidney disease. *Curr Opin Nephrol Hypertens*. 2020; 29(6):547-554.

12. Leal VO, Mafra D, Fouque D, Anjos LA. Use of handgrip strength in the assessment of the muscle function of chronic kidney disease patients on dialysis: a systematic review. *Nephrol Dial Transplant*. 2011; 26(4):1354-60.

13. Pereira RA, Cordeiro AC, Avesani CM, Carrero JJ, Lindholm B, Amparo FC, et al. Sarcopenia in chronic kidney disease on conservative therapy: prevalence and association with mortality. *Nephrol Dial Transplant.* 2015; 30(10):1718-25.

14. Morishita S, Tsubaki A, Shirai N. Physical function was related to mortality in patients with chronic kidney disease and dialysis. *Hemodial Int*. 2017; 21(4):483-489.

15. Chang YT, Wu HL, Guo HR, Cheng YY, Tseng CC, Wang MC, Lin CY, Sung JM. Handgrip strength is an independent predictor of renal outcomes in patients with chronic kidney diseases. *Nephrol Dial Transplant.* 2011; 26(11):3588-95.

16. Wilkinson TJ, Miksza J, Baker LA, Lightfoot CJ, Watson E, Yates T, et al. Sarcopenia, Chronic Kidney Disease and Risk of Mortality: Findings From 426,839 Individuals in The UK Biobank. *Nephrol Dial Transplant*. 2020; 35(3): gfaa140.MO023.

17. Vogt BP, Borges MCC, Goés CR, Caramori JCT. Handgrip strength is an independent predictor of all-cause mortality in maintenance dialysis patients. *Clin Nutr.* 2016; 35(6):1429-1433.

18. Hwang SH, Lee DH, Min J, Jeon JY. Handgrip Strength as a Predictor of All-Cause Mortality in Patients with Chronic Kidney Disease Undergoing Dialysis: A Meta-Analysis of Prospective Cohort Studies. *J Ren Nutr.* 2019; 29(6):471-479.

19. Roshanravan B, Robinson-Cohen C, Patel KV, Ayers E, Littman AJ, de Boer IH, et al. Association between physical performance and all-cause mortality in CKD. *J Am Soc Nephrol.* 2013; 24(5):822-30.

20. Konings CJ, Kooman JP, Schonck M, van Kreel B, Heidendal GA, Cheriex EC, et al. Influence of fluid status on techniques used to assess body composition in peritoneal dialysis patients. *Perit Dial Int.* 2003; 23(2):184-90.

21. Ikizler TA, Burrowes JD, Byham-Gray LD, Campbell KL, Carrero JJ, Chan W, et al. KDOQI Clinical Practice Guideline for Nutrition in CKD: 2020 Update. *Am J Kidney Dis.* 2020; 76(3):S1-S107.

22. Kistler BM, Moore LW, Benner D, Biruete A, Boaz M, Brunori G, et al. The International Society of Renal Nutrition and Metabolism Commentary on the National Kidney Foundation and Academy of Nutrition and Dietetics KDOQI Clinical Practice Guideline for Nutrition in Chronic Kidney Disease. *J Ren Nutr.* 2020; S1051-2276(20)30134-5

23. Silva LF, Matos CM, Lopes GB, Martins MT, Martins MS, Arias LU, Pisoni RL, Lopes AA. Handgrip strength as a simple indicator of possible malnutrition and inflammation in men and women on maintenance hemodialysis. *J Ren Nutr.* 2011; 21(3):235-45.

24. Amparo FC, Cordeiro AC, Carrero JJ, Cuppari L, Lindholm B, Amodeo C, et al. Malnutrition-inflammation score is associated with handgrip strength in nondialysis-dependent chronic kidney disease patients. *J Ren Nutr.* 2013; 23(4):283-7.

25. Isoyama N, Qureshi AR, Avesani CM, Lindholm B, Bàràny P, Heimbürger O, et al. Comparative associations of muscle mass and muscle strength with mortality in dialysis patients. *Clin J Am Soc Nephrol.* 2014; 9(10):1720-8.

26. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med.* 2009; 6(7):e1000100.

27. Cumpston M, Li T, Page MJ, Chandler J, Welch VA, Higgins JP, et al. Updated guidance for trusted systematic reviews: a new edition of the Cochrane Handbook for Systematic Reviews of Interventions. *Cochrane Database Syst Rev.* 2019; 10:ED000142.

28. Roberts HC, Denison HJ, Martin HJ, Patel HP, Syddall H, Cooper C, et al. A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardised approach. *Age Ageing.* 2011; 40(4):423-9.

29. Shiratori AP, Iop Rda R, Borges Júnior NG, Domenech SC, Gevaerd Mda S. Evaluation protocols of hand grip strength in individuals with rheumatoid arthritis: a systematic review. *Rev Bras Reumatol.* 2014; 54(2):140-7.

30. Kim C, Kim JK, Lee HS, Kim SG, Song YR. Longitudinal changes in body composition are associated with all-cause mortality in patients on peritoneal dialysis. *Clin Nutr.* 2020; S0261-5614(20)30208-9.

31. Kmentova T, Valerianova A, Kovarova L, Lachmanova J, Hladinova Z, Malik J. Decrease of muscle strength in vascular access hand due to silent ischaemia. *J Vasc Access.* 2018; 19(6):573-577.

32. Kovarova L, Valerianova A, Kmentova T, Lachmanova J, Hladinova Z, Malik J. Low Cerebral Oxygenation Is Associated with Cognitive Impairment in Chronic Hemodialysis Patients. *Nephron.* 2018; 139(2):113-119.

33. Tian X, Chen Y, Yang ZK, Qu Z, Dong J. Novel Equations for Estimating Lean Body Mass in Patients With Chronic Kidney Disease. *J Ren Nutr.* 2018; 28(3):156-164.

34. 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(7):1104-1108.

35. Neves DV, Lanchote VL, Moysés Neto M, Cardeal da Costa JA, Vieira CP, Coelho EB. Influence of chronic kidney disease and haemodialysis treatment on pharmacokinetics of nebivolol enantiomers*. Br J Clin Pharmacol.* 2016; 82(1):83-91.

36. Hanauer Schaab E, Lanchote VL, Balthazar Nardotto GH, Marques Pereira MP, Dantas M, Paiva CE, et al. Effect of Lercanidipine on the Pharmacokinetics-Pharmacodynamics of Carvedilol Enantiomers in Patients With Chronic Kidney Disease. *J Clin Pharmacol*. 2020; 60(1):75-85.

37. Viramontes Hörner D, Selby NM, Taal MW. The Association of Nutritional Factors and Skin Autofluorescence in Persons Receiving Hemodialysis. *J Ren Nutr.* 2019; 29(2):149-155.

38. Frih B, Jaafar H, Mkacher W, Ben Salah Z, Hammami M, Frih A. The Effect of Interdialytic Combined Resistance and Aerobic Exercise Training on Health Related Outcomes in Chronic Hemodialysis Patients: The Tunisian Randomized Controlled Study. *Front Physiol.* 2017; 8:288.

39. Kuki A, Tanaka K, Kushiyama A, Tanaka Y, Motonishi S, Sugano Y. Association of gait speed and grip strength with risk of cardiovascular events in patients on haemodialysis: a prospective study. *BMC Nephrol.* 2019; 20(1):196.

40. Hasheminejad N, Namdari M, Mahmoodi MR, Bahrampour A, Azmandian J. Association of Handgrip Strength With Malnutrition-Inflammation Score as an Assessment of Nutritional Status in Hemodialysis Patients. *Iran J Kidney Dis.* 2016; 10(1):30-5.

41. Taşoğlu Ö, Bayrakci N, Sezgin Özcan D, Özkayar N, Taşoğlu İ, Özgirgin N. A functional tool demonstrating the physical function decline independentof age in patients with predialysis chronic kidney disease. *Turk J Med Sci.* 2017; 47(1):91-97.

42. Lai S, Muscaritoli M, Andreozzi P, Sgreccia A, De Leo S, Mazzaferro S, et al. Sarcopenia and cardiovascular risk indices in patients with chronic kidney disease on conservative and replacement therapy. *Nutrition.* 2019; 62:108-114.

43. Martinez L, Esteve V, Yeste M, Artigas V, Llagostera S. Neuromuscular electrostimulation: a new therapeutic option to improve radio-cephalic arteriovenous fistula maturation in end-stage chronic kidney disease patients. *Int Urol Nephrol.* 2017; 49(9):1645-1652.

44. Macagnan FE, Baroni BM, Cristofoli ÉZ, Godoy M, Schardong J, Plentz RDM. Acute effect of photobiomodulation therapy on handgrip strength of chronic kidney disease patients during hemodialysis. *Lasers Med Sci.* 2019; 34(4):835-840.

45. Omichi Y, Srivareerat M, Panorchan K, Greenhall GH, Gupta S, Davenport A. Measurement of Muscle Strength in Haemodialysis Patients by Pinch and Hand Grip Strength and Comparison to Lean Body Mass Measured by Multifrequency Bio-Electrical Impedance. *Ann Nutr Metab.* 2016; 68(4):268-75.

46. Vanden Wyngaert K, Celie B, Calders P, Eloot S, Holvoet E, Van Biesen W, et al. Markers of protein-energy wasting and physical performance in haemodialysis patients: A cross-sectional study. *PLoS One.* 2020; 15(7):e0236816.

47. Vanden Wyngaert K, Van Craenenbroeck AH, Eloot S, Calders P, Celie B, Holvoet E, et al. Associations between the measures of physical function, risk of falls and the quality of life in haemodialysis patients: a cross-sectional study. *BMC Nephrol. 2020*; 21(1):7.

48. Delanaye P, Bataille S, Quinonez K, Buckinx F, Warling X, Krzesinski JM, et al. Myostatin and Insulin-Like Growth Factor 1 Are Biomarkers of Muscle Strength, Muscle Mass, and Mortality in Patients on Hemodialysis. *J Ren Nutr.* 2019; 29(6):511-520.

49. Ling LL, Chan YM, Mat Daud Z'. Serum potassium and handgrip strength as predictors of sleep quality among hemodialysis patients in Malaysia. *Asia Pac J Clin Nutr.* 2019; 28(2):401-410.

50. Kittiskulnam P, Carrero JJ, Chertow GM, Kaysen GA, Delgado C, Johansen KL. Sarcopenia among patients receiving hemodialysis: weighing the evidence. J Cachexia Sarcopenia Muscle. 2017; 8(1):57-68.

51. Kittiskulnam P, Srijaruneruang S, Chulakadabba A, Thokanit NS, Praditpornsilpa K, Tungsanga K, et al. Impact of Serum Bicarbonate Levels on Muscle Mass and Kidney Function in Pre-Dialysis Chronic Kidney Disease Patients. *Am J Nephrol.* 2020; 51(1):24-34.

52. D'Alessandro C, Piccoli GB, Barsotti M, Tassi S, Giannese D, Morganti R et al. Prevalence and Correlates of Sarcopenia among Elderly CKD Outpatients on Tertiary Care. Nutrients. 2018; 10(12):1951.

53. Rosa CSDC, Nishimoto DY, Souza GDE, Ramirez AP, Carletti CO, Daibem CGL, et al. Effect of continuous progressive resistance training during hemodialysis on body composition, physical function and quality of life in end-stage renal disease patients: a randomized controlled trial. *Clin Rehabil.* 2018; 32(7):899-908.

54. Vieira PJ, Silva LR, Maldamer VZ, Cipriano G Jr, Chiappa AM, Schuster R, et al. Skeletal muscle metaboreflex in patients with chronic renal failure. *Clin Physiol Funct Imaging*. 2017; 37(2):229-234.

55. Yunita Sari CM; Suhardjono, Nainggolan G, H Marbun MB, Abdullah M. Correlation between central arterial stiffness and handgrip strength in chronic hemodialysis patients. *Saudi J Kidney Dis Transpl.* 2019; 30(4):891-897.

56. Marini AC, Motobu RD, Freitas ATV, Laviano A, Pimentel GD. Pre-sarcopenia in patients undergoing hemodialysis: Prevalence and association with biochemical parameters. *Clin Nutr ESPEN.* 2018; 28:236-238.

57. Bogataj Š, Pajek M, Buturović Ponikvar J, Pajek J. Outcome Expectations for Exercise and Decisional Balance Questionnaires Predict Adherence and Efficacy of Exercise Programs in Dialysis Patients. *Int J Environ Res Public Health. 2020*; 17(9):3175.

58. Silva DM, Queiroz NP, Freitas ATVS, Passarelli M, Corgosinho FC, Peixoto MDRG. Serum advanced glycation end products are not associated with muscle strength in hemodialysis patients. *Eur J Clin Nutr.* 2019; 73(4):617-623.

59. Viramontes Hörner D, Selby NM, Taal MW. Skin autofluorescence and malnutrition as predictors of mortality in persons receiving dialysis: a prospective cohort study. *J Hum Nutr Diet. 2020*; 33(6):852-861.

60. Bučar Pajek M, Čuk I, Pajek J. Vascular Access Effects on Motor Performance and Anthropometric Indices of Upper Extremities. *Ther Apher Dial.* 2016; 20(3):295-301.

61. Bučar Pajek M, Leskošek B, Vivoda T, Svilan K, Čuk I, Pajek J. Integrative Examination of Motor Abilities in Dialysis Patients and Selection of Tests for a Standardized Physical Function Assessment. *Ther Apher Dial.* 2016; 20(3):286-94.

62. Bučar Pajek M, Pajek J. Characterization of deficits across the spectrum of motor abilities in dialysis patients and the impact of sarcopenic overweight and obesity. *Clin Nutr.* 2018; 37(3):870-877.

63. Fess E. Clinical assessment recommendations. Chicago: American Society of Hand Therapists; 1992.

64. Mathiowetz V. Comparison of Rolyan and Jamar dynamometers for measuring grip strength. *Occup Ther Int.* 2002; 9(3):201-9.

65. Amaral JF, Mancini M, Novo Júnior JM. Comparison of three hand dynamometers in relation to the accuracy and precision of the measurements. *Rev Bras Fisioter.* 2012; 16(3):216-24.

66. Proud D, Rezaie M, Lau D, Ketchell RI, Duckers J. 344 Which grip device to grip? A comparison of hand grip strength dynamometers in adult patients with cystic fibrosis. *J Cyst Fibros*. 2017; 1;16:S151.

67. El-Katab S, Omichi Y, Srivareerat M, Davenport A. Pinch grip strength as an alternative assessment to hand grip strength for assessing muscle strength in patients with chronic kidney disease treated by haemodialysis: a prospective audit. *J Hum Nutr Diet.* 2016; 29(1):48-51.

68. Hogrel JY. Grip strength measured by high precision dynamometry in healthy subjects from 5 to 80 years. *BMC Musculoskelet Disord.* 2015; 16:139.

69. El-Sais WM, Mohammad WS. Influence of different testing postures on hand grip strength. *Eur Sci J.* 2014; 10(36).

70. Watanabe T, Owashi K, Kanauchi Y, Mura N, Takahara M, Ogino T. The short-term reliability of grip strength measurement and the effects of posture and grip span. *J Hand Surg Am*. 2005; 30(3):603-9.

71. Balogun JA, Akinloye AA, Adenlola SA. Grip strength as a function of age, height, body weight and Quetelet index. *Physio Ther Prac.* 1991; 7(2):111-9.

72. Jiang K, Slee A, Davenport A. Body composition and weakness of hand grip strength and pinch strength in patients with chronic kidney disease from different ethnic backgrounds. *J Hum Nutr Diet.* 2020. Epub ahead of print.

73. Trampisch US, Franke J, Jedamzik N, Hinrichs T, Platen P. Optimal Jamar dynamometer handle position to assess maximal isometric hand grip strength in epidemiological studies. *J Hand Surg Am.* 2012; 37(11):2368-73.

74. Fess E, Moran C. Clinical assessment recommendations. 1st ed. Indianapolis: American Society of Hand Therapists; 1981.

75. Sousa-Santos AR, Amaral TF. Differences in handgrip strength protocols to identify sarcopenia and frailty - a systematic review. *BMC Geriatr.* 2017; 17(1):238.

76. Jansen CW, Patterson R, Viegas SF. Effects of fingernail length on finger and hand performance*. J Hand Ther.* 2000; 13(3):211-7.

77. Mathiowetz V, Rennells C, Donahoe L. Effect of elbow position on grip and key pinch strength. *J Hand Surg Am.* 1985; 10(5):694-7.

78. De S, Sengupta P, Maity P, Pal A, Dhara PC. Effect of body posture on hand grip strength in adult Bengalee population. *J Ex Sci Physio.* 2011; 7(2):79-88.

79. Balogun JA, Akomolafe CT, Amusa LO. Grip strength: effects of testing posture and elbow position. *Arch Phys Med Rehabil.* 1991; 72(5):280-3.

80. Su CY, Lin JH, Chien TH, Cheng KF, Sung YT. Grip strength in different positions of elbow and shoulder. *Arch Phys Med Rehabil.* 1994; 75(7):812-5.

81. Parvatikar VB, Mukkannavar PB. Comparative study of grip strength in different positions of shoulder and elbow with wrist in neutral and extension positions. *J Ex Sci Physio*. 2009; 5(2):67.

82. Wu KT, Chou WY, Ko JY, Siu KK, Yang YJ. Inferior outcome of rotator cuff repair in chronic hemodialytic patients. *BMC Musculoskelet Disord.* 2019; 20(1):209.

83. O'Driscoll SW, Horii E, Ness R, Cahalan TD, Richards RR, An KN. The relationship between wrist position, grasp size, and grip strength. *J Hand Surg Am.* 1992; 17(1):169-77.

84. Leal VO, Mafra D, Fouque D, Anjos LA. Use of handgrip strength in the assessment of the muscle function of chronic kidney disease patients on dialysis: a systematic review. *Nephrol Dial Transplant.* 2011; 26(4):1354-60.

85. Delanaye P, Quinonez K, Buckinx F, Krzesinski JM, Bruyère O. Hand grip strength measurement in haemodialysis patients: before or after the session? *Clin Kidney J.* 2018; 11(4):555-558.

86. 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.* 2008; 27(4):557-64.

87. Walsh OT, CHT L. Effect of Verbal Directions on Grip Strength Evaluated Using the Handheld Dynamometer. *Department of Occupational Therapy Faculty Papers.* Paper 66. Available at: https://jdc.jefferson.edu/otfp/66

88. Kamimura T, Ikuta Y. Evaluation of grip strength with a sustained maximal isometric contraction for 6 and 10 seconds. *J Rehabil Med.* 2001; 33(5):225-9.

89. Abizanda P, Navarro JL, García-Tomás MI, López-Jiménez E, Martínez-Sánchez E, Paterna G. Validity and usefulness of hand-held dynamometry for measuring muscle strength in community-dwelling older persons. *Arch Gerontol Geriatr.* 2012; 54(1):21-7.

90. Coldham F, Lewis J, Lee H. The reliability of one vs. three grip trials in symptomatic and asymptomatic subjects. *J Hand Ther.* 2006; 19(3):318-26.

91. Hall RK, Rutledge J, Luciano A, Hall K, Pieper CF, Colón-Emeric C. Physical Function Assessment in Older Hemodialysis Patients. *Kidney Med.* 2020; 2(4):425-431.

92. Painter P, Marcus R. Physical function and gait speed in patients with chronic kidney disease. *Nephrol Nurs J.* 2013; 40(6):529-38,

93. Bennett PN, Fraser S, Barnard R, Haines T, Ockerby C, Street M, et al. Effects of an intradialytic resistance training programme on physical function: a prospective stepped-wedge randomized controlled trial. *Nephrol Dial Transplant.* 2016; 31(8):1302-9.

94. Cooper C. Fundamentals of Hand Therapy-E-Book: Clinical Reasoning and Treatment Guidelines for Common Diagnoses of the Upper Extremity. 2014: Elsevier Health Sciences.

95. Tanaka S, Sugiura T, Yamashita S, Dohi Y, Kimura G, Ohte N. Differential response of central blood pressure to isometric and isotonic exercises. *Sci Rep.* 2014; 4:5439.

96. Chrysant SG. Current evidence on the hemodynamic and blood pressure effects of isometric exercise in normotensive and hypertensive persons. *J Clin Hypertens (Greenwich).* 2010; 12(9):721-6.

97. Jung MC, Hallbeck MS. Quantification of the effects of instruction type, verbal encouragement, and visual feedback on static and peak handgrip strength. Int J Ind Ergo. 2004; 34(5): 367-374.

98. Bohannon RW. Minimal clinically important difference for grip strength: a systematic review. *J Phys Ther Sci.* 2019; 31(1):75-78.

Figure 1. PRISMA diagram

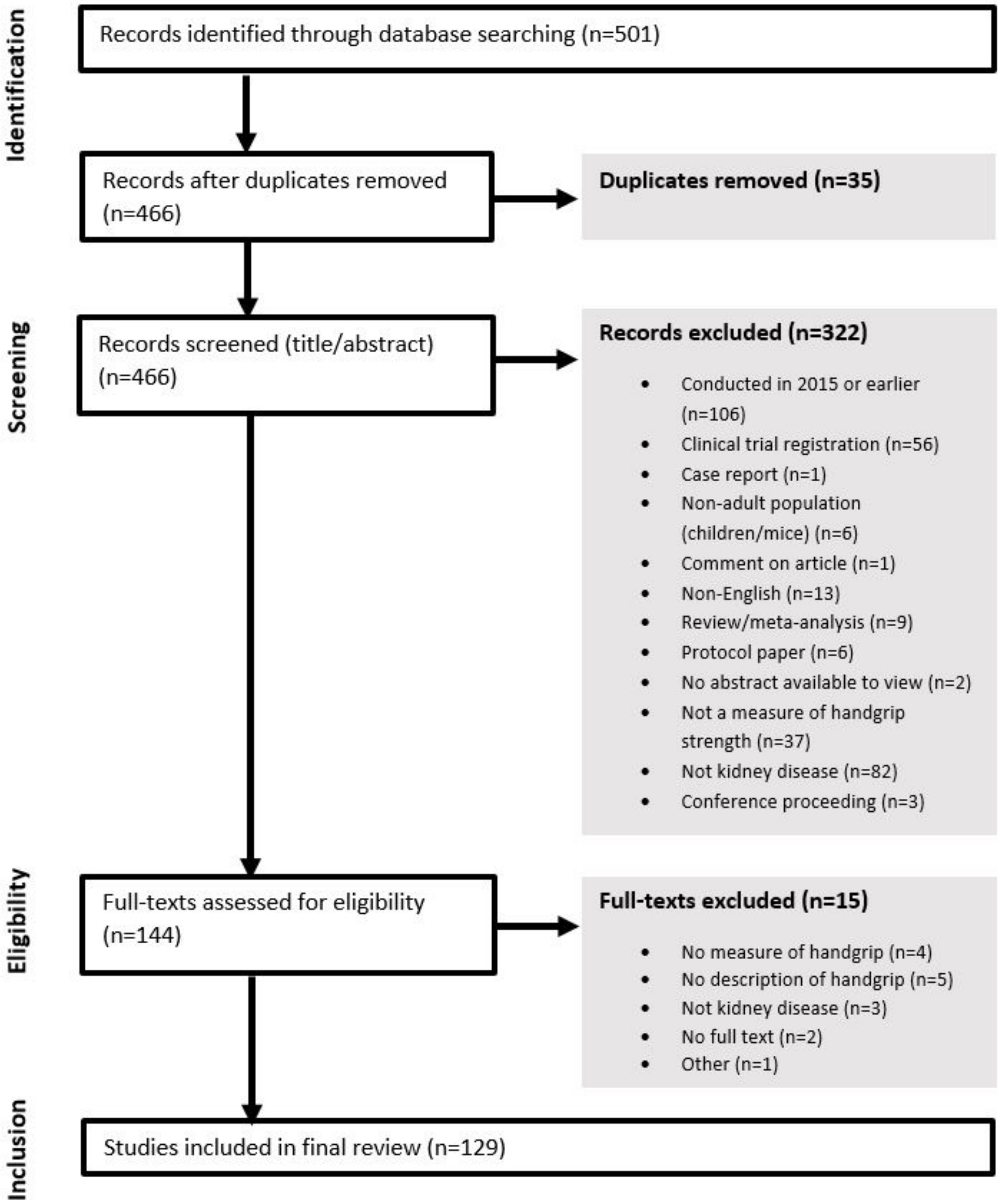

Table 1. Recommended protocol for measuring handgrip strength in people with CKD

1. Participants should be seated in a straight-backed chair with the feet flat on the floor. Use the same chair for every measurement if possible. If the patient cannot be seated, assessment whilst standing is suitable.
2. The shoulders should be adducted (0°) and neutrally rotated with the elbow flexed at 90°.
3. The forearm should be placed in a neutral rotation, and the wrist between 0° and 30° extension and between 0° and 15° ulnar deviation.
4. The arm should *not be supported* by the patient, examiner, or by an armrest.
5. The dynamometer should be presented vertically and in line with the forearm to maintain the standard forearm and wrist positions.

Figure 2A. Seating positron with shoulders adducted, elbow flexed at 90°, and forearm in neural position

6. Position the hand so that the thumb is around one side of the handle and the four fingers are around the other side. The instrument should feel comfortable in the hand.

7. Alter the position of the handle if necessary - on a Jamar® instrument, the second-hand position should be used. Rarely, a small-handed person or a large-handed person may require the handle to be at the first or third position setting.

Figure 2B. Dynamometer presented vertically in line with forearm. Hand is positioned with the thumb is around one side of the handle and the four fingers are around the other side.

8. In patients who have a fistula, use the *non-fistula* arm.
9. In regard to the dialysis session, assessing HGS *before* the dialysis session (and before connection to the machine) is preferable.
10. To limit the variability in physiologic status and dialysis fatigue, HGS should be assessed before the participant's *mid-week dialysis session.*
11. Encourage the participant to squeeze as long and as tightly as possible using a set of standardised instructions: *'I want you to hold the handle like this and squeeze as hard as you can'.* The examiner then demonstrates and then gives the dynamometer to the patient. After the patient is positioned appropriately, the examiner says*, 'Are you*

ready? Squeeze as hard as you can'. As the patient begins to squeeze, the examiner says*, 'Harder!... Harder!... Relax'.*

12. Grip force should be applied smoothly, without rapid wrenching or jerking motion.
13. No visual or auditory feedback should be provided; thus, the dynamometer's dial should be turned away from patients so they cannot see the display.
14. The contraction time should be *at least* 3 seconds, and no more than 6 seconds. The patient should exhale during the grip.
15. Read grip strength in kilograms (kg) from the outside dial and record the result to the nearest 1 kg on the data entry form.
16. For some devices, the minimal reading is 5 kg (check instrument instructions). If an individual cannot reach the minimal value, record this to the devices minimal detectable score.
17. Rest for at least 1 minute (between hands) and repeat measurement on the other hand *if appropriate*.
18. Do two further measurements (for each hand alternating sides *if appropriate, i.e., no fistula access*) to give *three readings* in total for each side.
19. If limited on time, one measurement from the dominant hand (or non-fistula arm) is sufficient.
20. The *highest value* should be used in statistical analyses.
21. Record hand dominance in all patients, even if both hands were not used, i.e., right, left or ambidextrous (people who can genuinely write with both hands).
22. The minimal important difference in a dialysis patient is estimated to be 3.4 kg, whilst a clinical important difference is estimated to be 5-6.5 kg [98].
23. Deviations in the procedure are strongly discouraged; however, when it is impossible to fully implement this protocol, namely due to the individuals' health conditions, any variation should be reported.

Table 2. Checklist for handgrip strength reporting

- ☐ Dynamometer characteristics (brand, model, resolution, calibration, and handle position)
- ☐ Posture (standing or sitting)
- ☐ Arm position (including shoulder, elbow, and wrist positions)
- ☐ Inclusion of access arm (if appropriate)
- ☐ Number of trials performed
- ☐ How the score was derived
- ☐ Acquisition (time taken to record HGS) and rest time between intervals
- ☐ The applied instructions
- ☐ Any cut-off points to identify low hand grip strength
- ☐ Time of day tested (including in relation to dialysis if appropriate)