Handgrip Strength and Body Composition in Individuals with and without Kidney Disease

By

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CERTIFICATE OF APPROVAL

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This is to certify that the Master's thesis of

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Abstract

Background: Studies have shown that reduced handgrip strength. (HGS) is associated with malnutrition in patients with chronic kidney disease (CKD) as their glomerular filtration rate (GFR) declines. However, no study has determined if other factors associated with CKD, such as lean body mass (LBM), influence HGS scores and how these HGS scores compare to normative standards. If these factors can be determined, it could be possible to more accurately interpret HGS in patients with CKD and potentially identify and treat malnutrition at earlier stages in this population. This study will expand the understanding of HGS in patients with CKD and how HGS may be used to assess nutrition status.

Methods: The overall goal of this project was to describe HGS in individuals with CKD. To meet this goal, NHANES data was assessed to compare HGS in populations with healthy GFR to those with kidney disease (GFR≤60 mL/min). Factors that influence HGS, such as measurements of LBM, dietary intake and biochemical measurements, in individuals diagnosed with kidney disease and those without kidney disease were examined.

Results: Of the 4,901 participants that were included in this study, 141 were classified as having kidney disease in the case group with a GFR<60 mL/min and the remaining participants in the control group. We found that there was no significant difference in the proportion of male or female participants with kidney disease who had HGS below the Takei average. When looking at males and females together, 55% of the individuals with kidney disease, had below average HGS. There was a significant positive correlation ($p<0.0001$) between LBM and HGS in individuals with and without kidney disease. Even after controlling for height, there was still a significant positive correlation. ($p<0.0001$) between HGS and lean body mass index (LBMI) in

individuals with and without kidney disease. There was also a significant positive correlation ($p<0.0001$) between HGS and mid-upper arm circumference (MUAC) in individuals without kidney disease, but not significant ($p=0.1703$) in individuals with kidney disease. There was a significant negative correlation ($p<0.0001$) between HGS and serum phosphorus in those without kidney disease, but a non-significant negative correlation ($p=0.3187$) in individuals with kidney disease. There was a significant positive correlation ($p=0.0092$) between HGS and serum corrected calcium in individuals without kidney disease, but a non-significant negative correlation ($p=0.1145$) in those with kidney disease. There was a significant difference in the mean energy and protein intakes between participants with and without kidney disease. Highest intakes of energy and protein were in participants without kidney disease and decreased as kidney disease progressed and GFR declined.

Conclusion: In conclusion, lower HGS was associated with declining GFR, LBM, LBMI, MUAC, serum phosphorus, and renal diet adherence. While the renal diet is restrictive to help manage the complications of CKD, it was interesting to see the association between this diet and lower HGS. With further research and larger studies, it may be possible to identify appropriate HGS ranges that can be used to assess nutrition status and to allow for earlier detection of malnutrition.

Introduction

Protein energy malnutrition (PEM) is a common complication for patients with Chronic Kidney Disease (CKD), especially as they progress to end-stage renal disease (ESRD).[1] PEM is often characterized by muscle mass loss associated with inflammation and this muscle wasting is a major concern for patients with CKD.[1] Studies have shown that muscle wasting can be documented in 18-75% of patients with ESRD and has become a valuable predictor of morbidity and mortality.[2] Muscle wasting leads to reduced muscle strength, which is associated with loss of muscle function. Reduced muscle strength and function have been shown to have negative impacts on recovery after illness and overall quality of life.[3]

One of the methods used for determining muscle function in patients is handgrip strength (HGS). This method, in conjunction with other markers, such as subjective global assessment (SGA), malnutrition-inflammation score (MIS), dietary intake assessment, and anthropometry assessment, is a validated tool to assess nutritional status.[1] HGS is a quick, simple, non-invasive, and low-cost method to evaluate muscle strength.[2] Studies have shown that reduced HGS is associated with malnutrition in patients with CKD.[1] However, no study has determined if other indirect factors associated with CKD, such as lean body mass (LBM) and mid-upper arm circumference (MUAC), influence HGS scores, and how these HGS scores compare to normative standards. If these factors can be determined, it could be possible to more accurately interpret HGS in patients with CKD and potentially identify and treat malnutrition at earlier stages in this population.

Background

Nutrition and Chronic Kidney Disease

CKD can be a very complex disease that requires specialized management. Many complications can arise due to CKD and ESRD treatments. These complications include uremia, metabolic acidosis, hyperkalemia, hypervolemia, anemia, hyperphosphatemia, and abnormalities in serum calcium concentrations.[4] Management of CKD is focused on normalizing lab values, fluid balance, and prevention of malnutrition and incudes medications, possible dialysis treatments, and dietary modifications. These dietary modifications can be overwhelming for the patient and family members and inadequate adherence can lead to additional issues like PEM.

There are many factors of CKD that can contribute to PEM, including protein and energy metabolism disorders, infection, or other concurrent conditions like cardiovascular disease or diabetes. There are also factors like decreased appetite, nausea, vomiting, or taste changes.[1] Decreased muscle function in this population is typically related to metabolic stresses, such as nutrient losses into dialysate, acidemia, or hyperparathyroidism.[5]

Handgrip Strength

Used as one of the six diagnostic characteristics for malnutrition in adults, HGS is an assessment tool used to determine muscle function. HGS is a measurement of the “maximal voluntary force of the hand and arm” and is a validated method to assess nutrition status when used with other markers, such as serum albumin, SGA, MIS, dietary intake assessment, or

anthropometry assessment.[1,2] This method is also quick, simple, non-invasive, and low-cost.[2] Studies have shown that lower HGS is associated with malnutrition in patients with CKD.[1]

According to the American Society of Hand Therapists (ASHT), best practice recommends that the patient should be seated with the arm adducted at the side and the elbow should be flexed to 90 degrees with the forearm at neutral and the wrist at 15-30 degrees of extension (dorsiflexion) and 0-15 degrees of ulnar deviation.[6] Standard procedures suggest using the average of three repeated trials as the test score. If the patient experiences painful grip, a single trial may be allowed. Grip duration should be at least three seconds and until the dynamometer's dial drops followed by a rest period of at least 15 seconds between repetitions and alternating hands.[6] The patient should be provided a practice trial with standard instructions of procedure as described here. To interpret grip strength deficit, the test score should be compared to normative values provided with the dynamometer.[6]

Even though these best practices are provided by the ASHT, there is still inconsistency in protocols used to evaluate HGS, especially in the sarcopenic/frail population.[7] HGS is a reliable measure on its own for assessing muscle strength in this population, but several factors can influence the measurement, such as different posture, different positions of the elbow and wrist, the hand used to test, and the setting of the dynamometer.[7]

A common inconsistency in measuring HGS is the dynamometer that is used to perform the test. The Jamar hydraulic dynamometer is recommended by the ASHT and is the most widely used and tested dynamometer.[7] However, several different dynamometers are currently used across varied populations causing even further inaccuracies and inconsistencies if they are not regularly calibrated.[7] Amaral, et al. (2012) compared three hand dynamometers in relation

to the accuracy and precision of the measurements and found that the values of manual grip strength measured with the Takei instruments are different than the values for the Jamar dynamometer.[8] The Jamar dynamometer tends to record higher grip strength values than other dynamometers.[8]

An additional inconsistency in measuring HGS is the number of trials or repetitions that are performed in order to score/measure the grip strength. The best practice of the ASHT recommends the average of three trials is recommended.[6] This is supported by Mathiowetz, et al. (1984) who suggested that the mean of three trials is a more accurate measure than one trial or even the highest score of three trials.[9] However, in a systematic review by Sousa-Santos and Amaral (2017), the most widely used practice from 72 studies was the highest score of three trials.[7]

Since HGS is mainly used as an indicator of overall muscle strength, it is beneficial in diagnosing sarcopenia.[10] The European Working Group on Sarcopenia in Older People (EWGSOP) recommends using both low muscle mass and low muscle function to diagnose sarcopenia. Measuring muscle mass with imaging equipment, such as computed tomography (CT), magnetic resonance imaging (MRI), and dual-energy X-ray absorptiometry (DEXA), is not easily utilized in day-to-day clinical practice due to high cost and accessibility.[10] HGS clears these barriers as a simple index of overall muscle strength and a good predictor of muscle mass.

Normative Standards for HGS

Normative standards for HGS in a "population of non-handicapped individuals" were determined in 1971 by Kellor, et al.[11] Kellor specifically used a Jamar dynamometer adjusted for hand size to measure grip force in pounds and the norms were developed separately for men

and women for both right and left hands.[11] This study did control for age and sex, but did not have a standardized procedure nor "best practice".[9] The subjects were given two tests with each hand to exert their most forceful grip and the highest of the two measurements was recorded.[11] Subjects were allowed to keep their arm in any position that they felt comfortable during the grip test, even resting their arm on the tabletop.[11] Kellor reported that the "sample is not atypical and represents fairly all adult age groups."[11] These norms were developed for a clinical setting in order for a healthcare professional to quickly determine how their patient compares to normal individuals of the same age and sex.[11]

The ASHT best practice was developed in 1981 to provide a standardized protocol utilizing results from Kellor's study.[7] The ASHT protocol was updated in 1992, and again in 2015.[7] However, as mentioned previously, not all providers follow the best practice procedure.

Normative standards are now provided with some dynamometers, but not all instruments have established normal values for comparison. While the normative standards were collected from a healthy population of adults, they have been used as reference values for a variety of patient populations, despite the lack of good data for specific conditions and populations.[1]

There have been several large population studies that tried to develop more specific standards for different disease states, but these results are challenging to use because the variables of each study are not always the same. Bohannon (2015) provided an overview of eight studies in a systematic review of the literature.[12] Most of these studies provided norms for older adults, but two of the studies provided norms for children.[12] All of the studies had sample sizes greater than 2000 participants and accounted for sex and age, but additional non-

consistent variables were side (both left vs. right and dominant vs. nondominant), height, weight, self-rated health, functional disability, and number of chronic diseases.[12] Inconsistent variables and small sample sizes prevent development of normative standards for chronic illness populations. However, research has shown that grip strength is diminished in individuals with multiple chronic diseases, lower in patients with depression or reduced self-rated health, lower in nursing home residents than in rehabilitation inpatients, and lower in rehabilitation inpatients than in community-dwelling individuals.[12] In order to develop normative values for specific chronic disease populations, a large population study would be needed.

Factors Affecting HGS

Chronic Illness and CKD

Comparing data from chronic illness populations to healthy adult reference values can pose problems because each disease state has its own specific complications that need to be accounted for when comparing data. For example, CKD complications of carnitine deficiency, water and electrolyte imbalance, and secondary hyperparathyroidism may negatively impact HGS in patients with CKD. Severe uremia, which can cause muscle weakness, may also lower HGS and high levels of ultrafiltration can lead to hypotension, which may result in lower HGS scores if the test is performed after dialysis.[4] Other factors can affect HGS for patients with CKD on dialysis including fistula placement, hand dominance, aging, LBM and MUAC, and these need to be accounted for in HGS interpretation.

Vascular Access

There are two types of vascular access available for hemodialysis (HD), the arteriovenous (AV) fistula and the AV graft. The AV fistula is the preferred long-term access and

is associated with the best outcomes for HD treatments.[13,14] In 30 patients on maintenance HD, Branz and Newton (1988) reported a weaker HGS of two kilograms in vascular access hands compared to the contralateral side.[14,15] However, a subsequent study of 25 patients on HD found that there was no reduction in HGS on the vascular access side.[14] A 2016 study found only a trend to a greater weakness, with the fistula arm being 2.7 kilograms weaker than the contralateral arm. However, when they considered dominant and non-dominant arms, there were no statistically significant differences in the magnitude of bilateral grip strength between fistula and contralateral arms when compared to the normally present difference found between non-dominant and dominant arms of healthy controls.[14]

Age

Studies have shown that grip strength declines after the age of 30 years with an estimated mean annual loss of grip strength of 0.5%-1% between the ages of 30 and 70 in healthy adults.[16,17] According to the CDC, 38% of patients with CKD are 65 years or older, so age is a factor in this population.[18] These same studies have also shown that the rate of decline in grip strength increases with age.[16] Hasheminejad, et al. (2016) also showed a significant negative correlation between age and HGS.[1] Vogt, et al. discusses another aspect of age-associated grip strength decline in the context of patients with CKD associated with uremia.[2] Conditions such as osteoporosis, atherosclerosis, frailty, and muscle wasting are characteristics of accelerated premature aging caused by uremia. These conditions could create a disconnection between calendar age and biological age in CKD that effects the muscle of these patients.[2]

Phosphorus

An important mineral for cell structure and energy is phosphorus. Less than 1% of the phosphorus in the body is circulating in the serum, 70% is intracellular and about 29% is located in the bone matrix. In healthy individuals, the kidneys regulate phosphorus balance by glomerular filtration and proximal tubule resorption. In this situation, the skeleton remains neutral in phosphorus homeostasis.[19]

In patients with CKD, the kidneys are no longer able to filter the phosphorus, which results in a positive phosphorus balance.[19] Due to the mineral bone disorders associated with CKD, phosphorus is released from skeletal tissue and contributes to hyperphosphatemia.[19] Hyperphosphatemia leads to phosphorus accumulation in the soft tissue organs and vasculature and ultimately leading to vascular calcification.[19] Vascular calcification leads to blood vessel stiffness, which increases the risk of cardiac disease events.[20]

While current research regarding phosphorus and HGS is limited, there is evidence that abnormal blood phosphorus concentrations may impact HGS. A 2007 study by Dong, et al. reported that HGS values were higher in the presence of hyperphosphatemia in patients on peritoneal dialysis (PD) who had a GFR of less than 2 mL/min while patients with residual renal function (RRF) (GFR >2 mL/min) did not have differences in HGS related to serum phosphorus concentrations.[21]

Protein-rich foods are also rich in phosphorus. Dietary protein intake is a stimulus for muscle protein synthesis and a key factor that regulates skeletal muscle mass.[22] As mentioned previously, loss of muscle mass has a strong association with decreased nutrition status and increased morbidity and mortality.[1-3] Leal, et al. inferred that hyperphosphatemia could suggest

a better protein intake and improved maintenance of protein stores.[4] In support of this theory, Carrero, et al. found lower HGS scores in men on HD with anorexia compared to those without anorexia.[23] If protein equals good nutrition and improved strength, then anorexia may mean poor nutrition status and poor strength.

Phosphorus Binders

Hyperphosphatemia is independently associated with an increased risk of death among patients on dialysis and contributes to the development of secondary hyperparathyroidism and vascular calcification.[21] One treatment provided to patients on dialysis to improve phosphorus balance is to administer phosphorus binders. In a cross-sectional study by Dong, et al., 205 patients on dialysis were evaluated for phosphorus control. The results showed a relatively lower incidence of hyperphosphatemia in patients on dialysis with and without RRF compared with other studies. However, those with loss of RRF and a decrease of dietary protein intake and dietary phosphorus intake did show lower LBM, serum albumin, and HGS levels.[21]

Calcium

Calcium metabolism is a complex mechanism even in healthy individuals. Calcium circulates in the blood in three forms – albumin-bound, ionized, and as a complex with citrate, phosphate or bicarbonate. The ionized and complexed forms are filtered by the glomerulus, but the albumin-bound calcium is not. During the first 30 years of life, intestinal calcium absorption is greater than the renal excretion of calcium. This creates a positive calcium balance which allows for bone growth. However, after the age of 30, increasing bone loss creates an increasingly negative calcium balance.[24]

As mentioned earlier, individuals with CKD develop a complex mineral bone disorder (CKD-MBD). This disorder is characterized by elevated fibroblast growth factor-23 (FGF-23) and parathyroid hormone (PTH), decreased 1,25-dihydroxyvitamin D ($1,25(OH)_2D$), elevated serum phosphorus, and decreased serum calcium.[25] This disorder is also characterized by decreased calcium absorption, decreased urinary calcium excretion and excessive vascular and soft tissue calcification.[25] Maintaining calcium balance is very important for patients with CKD-MBD. A negative balance can increase risk of osteoporosis and fractures, but a positive balance can increase risk of vascular calcification and cardiovascular events.[25] The increased PTH, $1,25(OH)_2D$, and acidosis increases the release of phosphate from bone, but PTH and $1,25(OH)_2D$ can sometimes increase phosphate deposits in the bone. These mechanisms are very complex and further complicate management of calcium.[24]

Currently, there is a lack of published research investigating serum calcium and HGS in those with CKD. A 2020 National Health and Nutrition Examination Survey (NHANES) study using 2013-2014 data showed that serum calcium levels did not correlate with HGS measurements in a group of healthy individuals.[26] A 2002 study by Humphreys, et al. also found that there was no correlation between HGS measurements and serum calcium in a group of hospitalized individuals.[27] In both studies, the serum calcium concentrations were within normal limits for all patients including those who had diminished HGS.[26,27] Typically, advanced CKD can lead to hypocalcemia due to the actions of PTH described above.[24]

Nutrition Status

Nutrition status is an important measure for muscle strength and function. Many patients with CKD develop malnutrition and frailty. Frailty is defined as a “state of increased

vulnerability to stressors as a consequence of degeneration in multiple systems."[28] Frailty in the general population is predictive of adverse outcomes, including falls, hospitalizations, decreased quality of life, and mortality.[29] Patients with ESRD are at an even greater risk of developing frailty.[30] Published prevalence of frailty ranges from 7% in a pre-dialysis population with CKD (median eGFR = 49mLs/min) to 42.6% in a population of patients with more severe CKD (mean eGFR = 27mLs/min).[31,32]

Lean Body Mass

Age-related changes in body composition are characterized by an increase in fat mass and a decrease in lean tissues with increasing age. The decrease in lean tissues, including skeletal muscle mass, is related to reduced muscle strength and functional capability in older adults, as well as greater morbidity and mortality.[33] The amount of muscle mass is associated with strength, but not always directly correlated with LBM function.[34] Rossato, et al. were the first to measure lean muscle function independently of the amount of LBM by measuring HGS/LBM ratio in general hospitalized individuals.[34] This study reported that the patients with lower HGS were older and presented with lower weight, lower LBM, and lower LBM quality than patients with adequate HGS suggesting that the main predictor of HGS in hospitalized individuals was lean muscle.[34] Patients with CKD typically have lower LBM and therefore would presumably have lower HGS.

Mid-Upper Arm Circumference

MUAC has been used as an indicator of underweight and malnutrition across all populations, especially in a global setting. Bioelectrical Impedance Analysis (BIA) for the measurement of skeletal muscle mass can result in error due to fluctuations in body fluid

hydration status, which could be a problem for dialysis patients.[35] MUAC measures correlate with DEXA measurements of LBM, and Stosovic, et al. showed that MUAC was a significant predictor of mortality in HD patients.[36,37] Slee, et al. investigated the prevalence of muscle wasting, weakness, and sarcopenia in post-dialysis patients using MUAC and HGS.[35] The entire study group had low MUAC at 25% of normal and muscle weakness was high regardless of the cut-point used.[35]

Conclusion

Studies have shown that reduced HGS is associated with malnutrition in patients with CKD as their GFR declines.[1] However, no study has determined if other factors associated with CKD, such as LBM and MUAC, influence HGS scores and how these HGS scores compare to normative standards. If these factors can be determined, it could be possible to more accurately interpret HGS in patients with CKD and potentially identify and treat malnutrition at earlier stages in this population. This study will expand the understanding of HGS in patients with CKD and how HGS may be used to assess nutrition status and detect the presence of malnutrition.

Specific Aims

The overall goal of this project was to describe HGS in individuals with CKD by examining the effects of LBM, MUAC and other factors on HGS measurements. The specific aims of this project were:

Specific Aim 1: To compare HGS in individuals diagnosed with CKD to normative standards.

Hypothesis: We hypothesized that HGS would be lower than normative standards in those who had kidney disease.

Specific Aim 2: To determine the effect of LBM and MUAC on HGS in individuals diagnosed with kidney disease.

Hypothesis: We predicted that HGS would be lower in those individuals with lower LBM and MUAC.

Specific Aim 3: To analyze the association between phosphorus and calcium concentrations and HGS in individuals diagnosed with CKD.

Hypothesis: We hypothesized that HGS would be lower in those individuals with abnormal serum phosphorus and calcium concentrations.

Specific Aim 4: To correlate renal diet adherence with HGS in individuals who had kidney disease.

Hypothesis: We predicted that HGS would be lower in those individuals withCKD who were following a renal diet.

Methods

General Design

For this study, the NHANES 2011-12 and 2013-14 demographic, dietary, anthropometric, laboratory, and questionnaire data were examined to determine associations between HGS, body composition, renal diet components, and serum lab concentrations.

Study Population

NHANES is a nationally-representative survey of US residents conducted by the National Center for Health Statistics and includes a combination of in-person interviews, physical examination, and laboratory data. NHANES releases data sets in 2-year data cycles.[38] All participants for this study were surveyed as part of NHANES 2011-12 or 2013-14. All subjects were ≥20 years of age, with available serum creatinine measurements, dietary intake, HGS, LBM, and MUAC data, and had no prior reported surgeries on either hand or wrist. (Table 1).

Table 1: Inclusion/Exclusion Criteria

Inclusion Criteria	**Exclusion Criteria**
1. ≥20 years of age 2. Serum creatinine available 3. Dietary intake data available 4. HGS, LBM, and MUAC data available	1. <20 years of age 2. Serum creatinine unavailable 3. Incomplete dietary intake 4. Incomplete HGS, LBM, or MUAC data 5. Reported prior surgeries on either hand or wrist

Variables

The following information was obtained from each participant's record: demographic data including age, gender, race/ethnicity, education level; dietary intake data including: energy (kcal), phosphorus (mg), potassium (mg), protein (g), sodium (mg); examination data including

arm circumference, waist circumference, height, weight, body mass index, dominant hand side, HGS from three tests for each hand (kg), self-reported surgery for either hand/wrist, and LBM and appendicular skeletal muscle mass (ASM) in order to calculate lean body mass index (LBMI) and appendicular skeletal muscle mass index (ASMI); and laboratory data including serum albumin (g/dL), total serum calcium (mg/dL), serum creatinine (mg/dL), and serum phosphorus (mg/dL).

Diet Recall

NHANES participants completed two 24-hour dietary recalls to determine energy, sodium, potassium, phosphorus, and protein intakes. The first NHANES dietary recall interview was in-person and collected in a private room of the NHANES Mobile Examination Center. The second interview was collected three to ten days later via telephone. Due to some participants not having a recorded intake for the second 24-hour dietary recall, only the first 24-hour dietary recall was used to analyze the number of participants adhering to a renal diet. The in-person interview utilized measuring guides, including glasses, bowls, mugs, mounds, circles, thickness sticks, spoons, a ruler, cartons, water bottles, and some two-dimensional tools, such as a grid, two wedges, and pictures of shapes, chicken pieces and spreads, to help the participant estimate the portion size.[39]

Renal Diet Adherence

The renal diet was defined as a daily intake meeting the following criteria: <2000 mg sodium, 800-1000 mg phosphorus, <2000 mg potassium, 0.8 g protein/kg body weight (Table 2). Adherence to this diet was determined by using the participants' day one diet recall.

Table 2: Renal Diet Parameters

Nutrient	Restricted Amount
Sodium	<2000 mg/day
Phosphorus	800-1000 mg/day
Potassium	<2000 mg/day
Protein	0.8 g/kg body weight

Kidney Function

Kidney function was determined using Modification of Diet in Renal Disease study (MDRD) eGFR equation of eGFR=175 x $(S_{Cr})^{-1.154}$ x $(age)^{-0.203}$ x 0.742 (if female) x 1.212 (if Black). CKD was defined in this study as eGFR <60 mL/min/1.73m^2.

HGS Measurements

All HGS measurements were collected by the trained NHANES staff using NHANES protocol. The muscle strength component consisted of two sections, a pretest questionnaire and an isometric grip strength test using a Takei handgrip dynamometer. The protocol was explained to the participant and then asked a series of questions to determine if they should be excluded from parts of the exam and to collect information on items that may influence the results. The pretest questionnaire determined if there were any visible limitations for either hand, whether the participant had any surgery on their hands/wrists in the past three months and which hand/wrist this occurred on, and whether there was any reason the participant felt they should not squeeze the instrument as hard as they could. The pretest questionnaire also asked about previous surgeries on hands/wrists for arthritis or carpal tunnel syndrome, any pain, aching, or stiffness in hands in the past seven days, whether this feeling had gotten worse in the past seven days, and ultimately, hand dominance.[40]

The participant was seated during the pretest questionnaire, the preparation, and warm-up prior to the test. The participant was asked to remove all hand and wrist jewelry and to perform two warm-up exercises to loosen up the hands and fingers. The warm-up exercises included shaking both hands three times and bending and stretching all fingers three times. Following the warm-up exercises, the dynamometer was adjusted for grip size to both hands, unless one hand was excluded due to pretest questionnaire determination.[40]

The protocol for the HGS test was explained to the participant with a demonstration by the technician to accompany the prepared script. A practice trial on one hand with submaximal effort was conducted after completing the demonstration. For the test, the participant was asked to stand unassisted with feet hip width apart and even, with toes pointing forward, knees comfortable but not bent, shoulders, back and chest up, head level, eyes straight ahead, and arm at side with palm facing leg. The technician then turned the dynamometer on and handed it to the participant. The participant grasped the dynamometer between the fingers and the palm at the base of the thumb and held the dynamometer in line with the forearm at the thigh level so that it was not touching the body. Once in position, the participant was instructed to squeeze as hard as they could until unable to squeeze any harder and to blow air out through their mouth while squeezing.[40]

The test was conducted using the Takei Digital Grip Strength Dynamometer (Model T.K.K. 5401). Three repeated trials on each side were completed with a 60 second rest between measurements on the same hand. The order of the tests was randomized by the participant's ID number and the participant's self-reported hand dominance, (i.e., odd number ID started with dominant hand; even number ID started with nondominant hand; people with unidentifiable

dominant hand randomly assigned order by ID). All values of the six consecutive HGS tests were recorded in kilogram units. The mean was calculated for each hand by the current study's researcher. These results were compared to normative standards provided with Takei digital dynamometer (Appendix A).[40]

Lean Body Mass

DEXA was used to evaluate body composition, including LBM, LBMI, and ASMI. The NHANES whole body DEXA data was first collected starting in 2011 and was originally used to determine age, sex, and racial/ethnic differences in body composition (bone mineral, lean soft tissue, and fat mass) during the life cycle to explore the relationship between body composition and behavioral factors, such as diet and physical activity, and physiologic factors, such as muscle strength. All individuals, ages 8-59 years, were eligible for the whole body scan, with the exception of pregnant females.[41]

In order to define sarcopenia, a measure of relative muscle mass was necessary.[42] Since muscle mass is strongly correlated with body size, LBM and ASM were adjusted for height (LBM/height^2, ASM/height^2, respectively) to provide LBMI and ASMI.[43] Cutoff measurements of ASMI for sarcopenia were provided by the Global Leadership Initiative on Malnutrition (GLIM) criteria. Males with an ASMI less than 7 kg/m^2 and females with an ASMI less than 5.4 kg/m^2 were considered to have sarcopenia.[44]

Mid-Upper Arm Circumference

Arm circumference was measured on the right arm at the level of the upper arm mid-point mark. The examiner made this mark on the posterior surface of the arm immediately after measured the upper arm length and divided the value in half to calculate the midpoint.

The examiner then wrapped the measuring tape around the arm at the level of the upper arm mid-point mark, positioned the tape perpendicular to the long axis of the upper arm, and pulled the two ends of the overlapping tape together so that the zero end was below the measurement value and the result lied on the lateral aspect of the arm (not the posterior surface). The examiner ensured that the tape fit snugly around the arm but did not compress the skin. The measurement was taken to the nearest 0.1 cm.[45]

Biochemical Analyses

Outcome measures of serum blood samples were collected from the NHANES participants for albumin, creatinine, phosphorus, and total calcium and analyzed based on concentration in mg/dL. Participants were instructed to fast at least 8.5 hours, but less than 24 hours before the blood draw.[46] Lab values of albumin and total calcium were used to calculate corrected calcium. Lab values of creatinine were used to calculate eGFR. Lab values of phosphorus and calculated corrected calcium were compared to established normal ranges for each laboratory measurement (Table 3).

Table 3: Normal Serum Concentrations

Serum Measurement	**Normal Serum Concentrations**
Phosphorus	3.4-4.5 mg/dL (1.12-1.45 mmol/L)
Calcium	8.5-10.5 mg/dL (2.2-2.7 mmol/L)

Consent

The NHANES data utilized for our study was approved by the National Center for Health Statistics Research Ethics Review Board. Further IRB approval was not required for this study as the data used was free of personal identifiers and publicly available.

Statistical Analysis

Data was expressed as mean +/- standard deviation (SD). Two-sample t-tests were used to determine significant differences ($p<0.05$) between mean HGS, LBM, LBMI, ASMI, and MUAC in individuals diagnosed with kidney disease and those without kidney disease. Tests of proportions were used to count participants who met normative HGS standards and GLIM criteria. One-way ANOVA with post-hoc Bonferroni test was used to test means between all 5 CKD stages. Linear regression was used to determine correlation between HGS, GFR, LBM, LBMI, ASMI, MUAC, serum levels, and dietary intakes (Table 4).

Table 4: Statistical Analysis Summary

Specific Aim	Hypothesis	Statistical Test
Specific Aim 1: To compare normative standards for HGS in individuals with kidney disease to individuals without kidney disease.	We hypothesized that HGS would be lower than normative standards in those who have kidney disease.	A two-sample t-test was used to test mean HGS between GFR groups and CKD stages. A test of proportions was used to count participants who met normative standards. Linear regression was used to compare HGS to GFR.
Specific Aim 2: To determine the effect of lean body mass and mid-upper arm circumference on HGS in individuals who have kidney disease.	We predicted that HGS would be lower in those with lower LBM and MUAC.	A two-sample t-test was used to test mean LBM, LBMI, ASMI, and MUAC between GFR groups. Linear regression was used to compare HGS with LBM, LBMI, ASMI, and MUAC. A test of proportions was used to count participants who met GLIM criteria for sarcopenia.
Specific Aim 3: To analyze the association between serum phosphorus and calcium and HGS in	We hypothesized that serum phosphorus and calcium abnormalities would correlate with HGS in those	A two-sample t-test was used to determine significant difference of mean serum phosphorus and corrected calcium between GFR groups

individuals diagnosed with kidney disease.	diagnosed with kidney disease.	and CKD stages. Linear regression was used to compare HGS with serum phosphorus and corrected calcium in the case group.
Specific Aim 4: To correlate renal diet adherence with HGS in individuals who have kidney disease.	We predicted that HGS would be lower in those with CKD who were following a renal diet.	A two-sample t-test was used to test mean dietary intakes between GFR groups and CKD stages. Linear regression was used to compare HGS to dietary intakes of sodium, phosphorus, potassium, energy, and protein.

Results

Demographics

Four thousand nine hundred and one (4,901) participants out of 7,431 participants were included in this study after removing subjects based on exclusion criteria (Figure 1). Participants were divided into case and control groups according to GFR<60 (case) and GFR≥60 (control). There were 141 participants in the case group and 4,760 participants in the control group (Table 5). The mean age in the case group was 49 ± 8.17 years and 38.41 ± 11.49 in the control group. When stratified by gender, there was a statistically significant difference ($p<0.0001$) in the mean age of male participants between the control group (38.08 ± 11.56 years) and case group (49.65 ± 7.63 years). There was a statistically significant difference ($p<0.0001$)in the mean age of female participants between the control group (38.75 ± 11.41 years) and case group (48.58 ± 8.51 years). There was not a statistically significant difference in the proportions of participants for most races between the case and control groups. However, the proportion of non-Hispanic white participants was significantly greater ($p=0.0005$) in the case group than in the control group. The proportion of non-Hispanic Asian participants in the control group was significantly greater ($p=0.0038$) than in the case group.

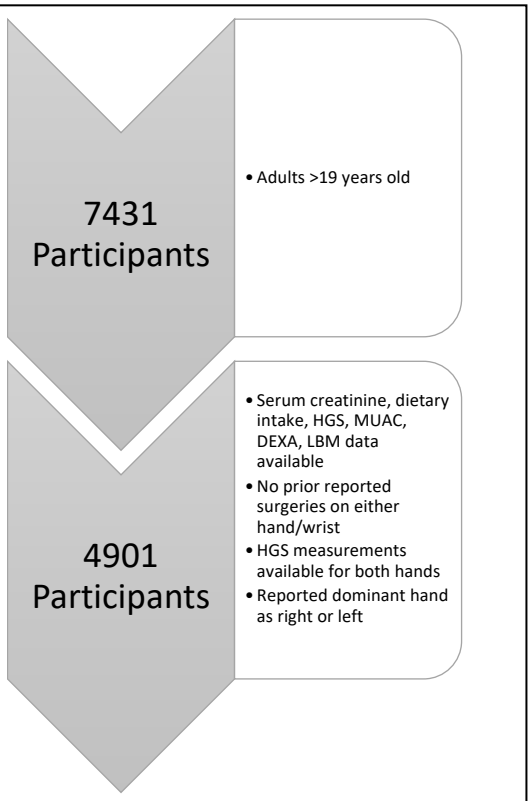


Figure 1: Participant Inclusion/Exclusion

Table 5: Demographics by Control and Case Groups

Characteristic	Controls (GFR≥60) (n=4,760)	Cases (GFR<60) (n=141)	*p-Value*
Gender, n (%)			
Male (n=2,468)	2,413 (50.7%)	55 (39%)	p=0.0062[a]
Female (n=2,433)	2,347 (49.3%)	86 (61%)	p=0.0062[a]
Age at Screening (mean ± SD)	38.41 ± 11.49	49 ± 8.17	p<0.0001[b]
Race, n (%)			
Mexican-American (n=625)	614 (12.9%)	11 (7.8%)	p=0.0736[a]
Hispanic (n=436)	424 (8.9%)	13 (9.2%)	p=0.9019[a]
Non-Hispanic White (n=1,951)	1,875 (39.4%)	76 (53.9%)	p=0.0005[a]
Non-Hispanic Black (n=1,071)	1,040 (21.8%)	31 (21.9%)	p=0.9774[a]
Non-Hispanic Asian (n=637)	630 (13.2%)	7 (4.9%)	p=0.0038[a]
Other Non-Hispanic (n=181)	177 (3.7%)	4 (2.8%)	p=0.5756[a]

[a] Test of proportions
[b] T-test of means

Demographics were further divided into CKD stages in order to examine results of participants as GFR decreased (Table 6). Cutoffs for CKD stages were referenced from the National Kidney Foundation.[47] Stage 1 has a GFR ≥90 mL/min, stage 2 has a GFR range between 60-89 mL/min, stage 3 has a range of 30-59 mL/min, stage 4 has a range of 15-29 mL/min, and stage 5 has a GFR<15 mL/min.[47] There was a statistically significant difference in the proportion of male and female participants in CKD Stage 1 ($p<0.01$) and in stages 2 and 3 ($p<0.0001$), and stage 4 ($p<0.001$). There was no significant difference in the proportion of male and female participants in CKD Stage 5. There was a statistically significant difference in the average age of participants between CKD Stage 1 and Stage 2 ($p<0.001$), between CKD Stage 1 and Stage 3 ($p<0.001$), between CKD Stage 1 and Stage 5 ($p<0.001$), and between CKD Stage 2 and Stage 3 ($p<0.001$). A chi-square test was performed between the proportion of participants of each race within each CKD stage. There was a statistically significant difference in the proportions of

participants within each CKD stage with different races ($p<0.001$); however, it was not possible to determine significance between the different races in each CKD stage.

Table 6: Demographics by CKD Stage

Characteristic	CKD Stage 1 (n=2,832)	CKD Stage 2 (n=1,928)	CKD Stage 3 (n=128)	CKD Stage 4 (n=5)	CKD Stage 5 (n=8)	*p-Value*
Gender, n (%)						
						p=0.0056[a]
Male (n=2,468)	1,380 (48.7%)[a]	1,033 (53.6%)[b]	51 (39.8%)[c]	1 (20%)[d]	3 (37.5%)[e]	p<0.0001[b,c]
						p=0.0008[d]
Female (n=2,433)	1,452 (51.3%)[a]	895 (46.4%)[b]	77 (60.2%)[c]	4 (80%)[d]	5 (62.5%)[e]	p=0.1441[e]
Age at Screening (mean ± SD)	35.61 ± 11.15[f,g,h]	42.53 ± 10.72[f,i]	49.05 ± 8.18[g,i]	43.6 ± 9.58	51.63 ± 6.35[h]	p<0.001[f,g,h,i]
Race, n (%)[j]						p<0.001[j]
Mexican-American (n=625)	454 (16%)	160 (8.3%)	10 (7.8%)	1 (20%)	-	
Hispanic (n=436)	261 (9.2%)	163 (8.5%)	11 (8.6%)	1 (20%)	-	
Non-Hispanic White (n=1,951)	879 (31%)	996 (51.6%)	75 (58.6%)	-	1 (12.5%)	
Non-Hispanic Black (n=1,071)	718 (25.4%)	322 (16.7%)	22 (17.2%)	3 (60%)	6 (75%)	
Non-Hispanic Asian (n=637)	418 (14.8%)	212 (11%)	6 (4.7%)	-	1 (12.5%)	
Other Non-Hispanic (n=181)	102 (3.6%)	75 (3.9%)	4 (3.1%)	-	-	

[a-e] Test of proportions between same letters

[f-i] T-test of means between same letters

[j] Chi-squared test of proportions

Comparing HGS Between Case and Control Groups

To determine if the participants' HGS (kg) was higher or lower than the average for their age and sex, total average HGS (kg) for all participants was compared to the averages provided with the Takei dynamometer (Appendix A).

There was not a statistically significant difference in the proportions of male participants with a total average HGS above or below the Takei average when comparing the case and control groups (Table 7). Within the case group, there was not a significant difference in the mean age between male participants with HGS above or below the Takei average; however, there was a statistically significant difference ($p<0.0001$) in the mean age between male participants with HGS above and below the Takei average within the control group. There was a statistically significant difference in the mean age at screening between the case and control groups for male participants with above average HGS ($p=0.0002$) and with below average HGS ($p<0.0001$) (Table 7). There was not a statistically significant difference in the proportions of male participants with a total average HGS above and below the Takei average between case and control groups for any race.

Table 7: Total Average HGS (kg) Compared to Takei Average HGS (kg) for Male Participants

	Control (GFR≥60) (n=2,413)		Cases (GFR<60) (n=55)		
Characteristic, n (%)	**Above TAKEI Avg HGS (n=771)**	**Below TAKEI Avg HGS (n=1,642)**	**Above TAKEI Avg HGS (n=20)**	**Below TAKEI Avg HGS (n=35)**	***p-Value***
Males (n=2,468)	771 (32%)[a]	1,642 (68%)[b]	20 (36.3%)[a]	35 (63.6%)[b]	p=0.4994[a], p=0.4895[b]
Age at Screening (mean ± SD)	40.54 ± 11.29[c,d]	36.93 ± 11.51[c,e]	49.95 ± 7.44[d,f]	49.49 ± 7.83[e,f]	p<0.0001[c,e], p=0.0002[d], p=0.8319[f]
Race, n (%)					
Mexican-American (n=321)	72 (3%)[g]	244 (10.1%)[h]	2 (3.6%)[g]	3 (5.5%)[h]	p=0.7969[g], p=0.2606[h]
Hispanic (n=203)	38 (1.6%)[i]	157 (6.5%)[j]	1 (1.8%)[i]	7 (12.7%)[j]	p=0.9071[i], p=0.0678[j]
Non-Hispanic White (n=1,001)	382 (15.8%)[k]	598 (24.8%)[l]	11 (20%)[k]	10 (18.2%)[l]	p=0.3996[k], p=0.2615[l]
Non-Hispanic Black (n=511)	211 (8.7%)[m]	286 (11.9%)[n]	4 (7.3%)[m]	10 (18.2%)[n]	p=0.7152[m], p=0.1557[n]
Non-Hispanic Asian (n=337)	38 (1.6%)[o]	294 (12.2%)[p]	0 (0%)[o]	5 (9.1%)[p]	p=0.3444[o], p=0.4863[p]
Other Non-Hispanic (n=95)	30 (1.2%)[q]	63 (2.6%)[r]	2 (3.6%)[q]	0 (0%)[r]	p=0.1137[q], p=0.2258[r]

[a-b, g-r] Test of proportions between same letters

[c-f] T-test of means

There was not a statistically significant difference in the proportions of female participants with a total average HGS above or below the Takei average when comparing the case and control groups. Within the case group, there was no significant difference in the mean age between female participants with HGS above or below the Takei average; however, there was a statistically significant difference ($p=0.0454$) in the mean age between female participants with HGS above or below the Takei average within the control group. There was a statistically significant difference ($p<0.0001$) in the mean age at screening between the case and control groups for female participants with above average HGS and with below average HGS (Table 8). There was no statistically significant difference in the proportions of female participants with a total average HGS above and below the Takei average between case and control groups for Mexican-American, Hispanic, or other non-Hispanic races. However, there were significantly ($p<0.0001$) more non-Hispanic white female participants in the case group with above average HGS than in the control group. There were also significantly more ($p=0.0299$) female non-Hispanic black participants with above average HGS in the control group than the case group. There were significantly ($p=0.0057$) more non-Hispanic Asian female participants with below average HGS in the control group than in the case group.

Table 8: Total Average HGS (kg) Compared to Takei Average HGS (kg) for Female Participants

	Control (GFR≥60) (n=2,347)		Cases (GFR<60) (n=86)		
Characteristic, n (%)	**Above TAKEI Avg HGS (n=952)**	**Below TAKEI Avg HGS (n=1,395)**	**Above TAKEI Avg HGS (n=43)**	**Below TAKEI Avg HGS (n=43)**	***P-value***
Females (n=2,433)	952 (40.6%)[a]	1,395 (59.4%)[b]	43 (50%)[a]	43 (50%)[b]	p=0.0816[a,b]
Age at Screening (mean ± SD)	39.32 ± 11.74[c,d]	38.36 ± 11.17[c,e]	48.3 ± 8.91[d,f]	48.86 ± 8.19[e,f]	p=0.0454[c], p<0.0001[d,e], p=0.7623[f]
Race, n (%)					
Mexican-American (n=304)	83 (3.5%)[g]	215 (9.2%)[h]	1 (1.2%)[g]	5 (5.8%)[h]	p=0.2490[g], p=0.2811[h]
Hispanic (n=233)	60 (2.5%)[i]	169 (7.2%)[j]	2 (2.3%)[i]	2 (2.3%)[j]	p=0.9070[i], p=0.0808[j]
Non-Hispanic White (n=950)	391 (16.6%)[k]	504 (21.5%)[l]	33 (38.4%)[k]	22 (25.5%)[l]	p<0.0001[k], p=0.3763[l]
Non-Hispanic Black (n=560)	329 (14%)[m]	214 (9.1%)[n]	5 (5.8%)[m]	12 (13.9%)[n]	p=0.0299[m], p=0.1317[n]
Non-Hispanic Asian (n=300)	56 (2.4%)[o]	242 (10.3%)[p]	1 (1.2%)[o]	1 (1.2%)[p]	p=0.4713[o], p=0.0057[p]
Other Non-Hispanic (n=86)	33 (1.4%)[q]	51 (2.2%)[r]	1 (1.2%)[q]	1 (1.2%)[r]	p=0.8765[q], p=0.5314[r]

[a-b, g-r] Test of proportions between same letters

[c-f] T-test of means

Mean dominant, non-dominant, and total average HGS (kg) were compared for the total study population, between GFR groups (case/control), and between CKD stages (3-5) (Table 9). There was a statistically significant difference in the dominant HGS (p=0.0216), non-dominant HGS (p=0.0011), and total average HGS (p=0.0047) between the controls and cases with the cases having a lower dominant, non-dominant and total average HGS (33.80 kg, 33.32 kg and 33.56 kg, respectively). A two-sample t-test with Bonferroni post-hoc test revealed that there was no significant difference in the mean HGS between CKD stages of the case population (GFR<60) due to the small sample sizes. The same test showed the same results for non-dominant HGS as well as total average HGS between CKD stages. Since there was not a statistically significant difference between the different types of HGS, all correlations were analyzed using only dominant HGS. There was a non-significant positive correlation between dominant HGS (kg) and final GFR (mL/min) within the case group (Figure 2).

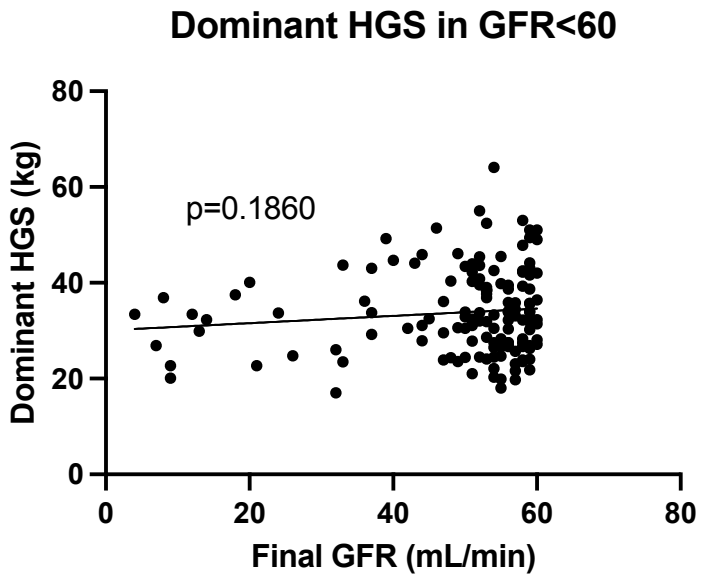
Table 9: Mean ± SD by GFR Group and CKD Stage

	Dominant HGS (kg)	**Non-Dominant HGS (kg)**	**Total Average HGS (kg)**	***P-value***
Total Population (n=4,901)	36.15 ± 10.59[a,b]	36.20 ± 10.62[a]	36.18[b]	p=0.6750[a] p=0.4666[b]
GFR				p=0.0216[c]
≥60 (n=4,760)	36.22 ± 10.63[c]	36.28 ± 10.64[d]	36.25 ± 10.40[e]	p=0.0011[d]
<60 (n=141)	33.80 ± 8.81[c]	33.32 ± 9.71[d]	33.56 ± 8.97[e]	p=0.0047[e]
CKD Stage				
1 & 2 (n=4,760)	36.22 ± 10.63[f,g]	36.28 ± 10.64[h,i]	36.25 ± 10.40[k,l]	p=0.408[f], p=0.510[g]
3 (n=128)	34.16 ± 8.97[f]	33.79 ± 9.91[h,j]	33.98 ± 9.13[k,m]	p=0.050[h], p=0.140[i]
4 (n=5)	31.75 ± 7.69	30.22 ± 7.00	30.99 ± 7.21	p=0.723[j], p=0.144[k]
5 (n=8)	29.44 ± 5.80[g]	27.74 ± 5.43[i,j]	28.60 ± 5.47[l,m]	p=0.236[l], p=0.887[m]

[a-m] T-test of means with post-hoc Bonferroni between same letters

*P-values for groups that are not listed in this table were not significantly different (p=1.000).

Figure 2: Dominant HGS in GFR<60



[a] Simple linear regression, p=0.1860, r^2=0.01255

Body Composition and HGS

Means of LBM, LBMI, ASMI, and MUAC were all compared between males and females in the case and control groups (Table 10). There was a statistically significant difference (p<0.0001) in the means of LBM, LBMI, ASMI, and MUAC between male and female participants within the control group with men having higher values in all categories except ASMI (60.42 ± 10.73, 19.66 ± 3.03, 7.59 ± 2.23 and 34.34 ± 4.48 vs 43.82 ± 9.08, 16.7 ± 3.08, 8.63 ± 2.65 and 34.69 ± 5.6, respectively). There was a statistically significant difference in the means of LBM (p<0.0001), LBMI (p<0.0001), and ASMI (p=0.0007) between male and female participants within the case group with men having higher values in all categories except ASMI (61.82 ± 10.75, 20.08 ± 2.86 and 7.31 ± 2.36 vs 47.54 ± 9.79, 17.67 ± 3.28 and 8.74 ± 2.41, respectively). MUAC was not significantly different between the males and females in the case group.

There was not a significant difference in the means of LBM, LBMI, ASMI or MUAC between the male participants of the control and case groups. There was a statistically

significant difference in the means of LBM (p=0.0002), LBMI (p=0.0042), and MUAC (p=0.0002) between the female participants of the control and case group with the females in the case group having higher LBM, LBMI and MUAC.

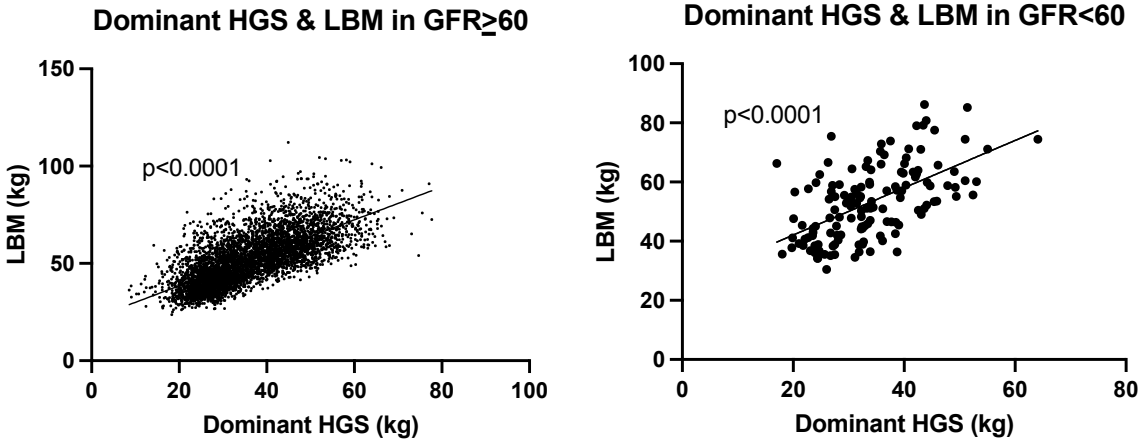
Table 10: Mean ± SD LBM, LBMI, ASMI, & MUAC by GFR Group

	Control (GFR≥60)		Cases (GFR<60)		
	Males (n=2,413)	**Females (n=2,347)**	**Males (n=55)**	**Females (n=86)**	***P-Value***
LBM (kg)	60.42 ± 10.73[a,c]	43.82 ± 9.08[a,d]	61.82 ± 10.75[b,c]	47.54 ± 9.79[b,d]	p<0.0001[a,b] p=0.3388[c] p=0.0002[d]
LBMI (kg/m2)	19.66 ± 3.03[e,g]	16.7 ± 3.08[e,h]	20.08 ± 2.86[f,g]	17.67 ± 3.28[f,h]	p<0.0001[e,f] p=0.3089[g] p=0.0042[h]
ASMI (kg/m2)	7.59 ± 2.23[i,k]	8.63 ± 2.65[i,l]	7.31 ± 2.36[j,k]	8.74 ± 2.41[j,l]	p<0.0001[i] p=0.0007[j] p=0.3579[k] p=0.7046[l]
MUAC (cm)	34.34 ± 4.48[m,o]	32.27 ± 5.45[m,p]	34.68 ± 4.3[n,o]	34.48 ± 5.6[n,p]	p<0.0001[m] p=0.8218[n] p=0.5776[o] p=0.0002[p]

[a-p] T-test of means between same letters

There was a significant positive correlation between LBM (kg) and dominant HGS (kg) within the control ($p<0.0001$, $r^2=0.4834$) and case ($p<0.0001$, $r^2=0.3272$) groups (Figure 3), even after controlling for height (Figure 4). There was a significant negative correlation ($p<0.0001$, $r^2=0.04036$) between dominant HGS (kg) and ASMI (kg/m^2) within the control group and within the case group ($p=0.0217$, $r^2=0.03734$) (Figure 5). There was a significant positive correlation ($p<0.0001$, $r^2=0.1141$) between dominant HGS (kg) and MUAC (cm) in the control group, but a non-significant positive correlation ($p=0.1703$, $r^2=0.01348$) in the case group (Figure 6).

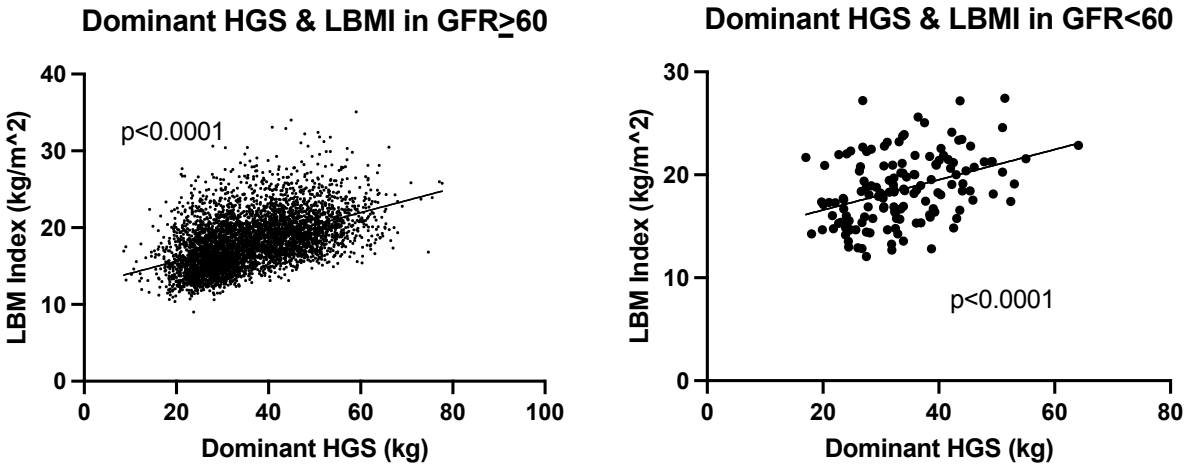
Figure 3: Correlation of LBM and Dominant HGS



[a] Simple linear regression, $p<0.0001$, $r^2=0.4834$

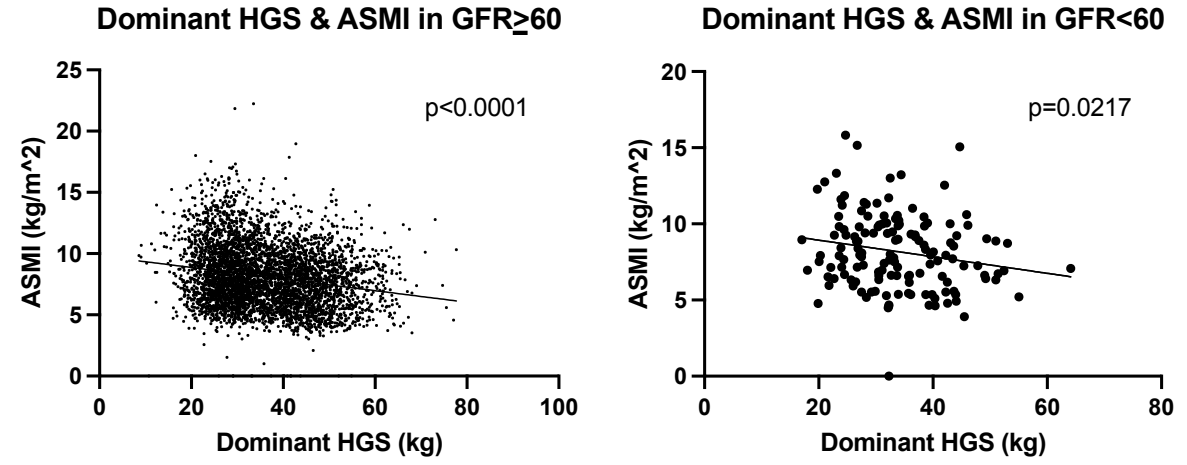
[b] Simple linear regression, $p<0.0001$, $r^2=0.3272$

Figure 4: Correlation of LBMI and Dominant HGS



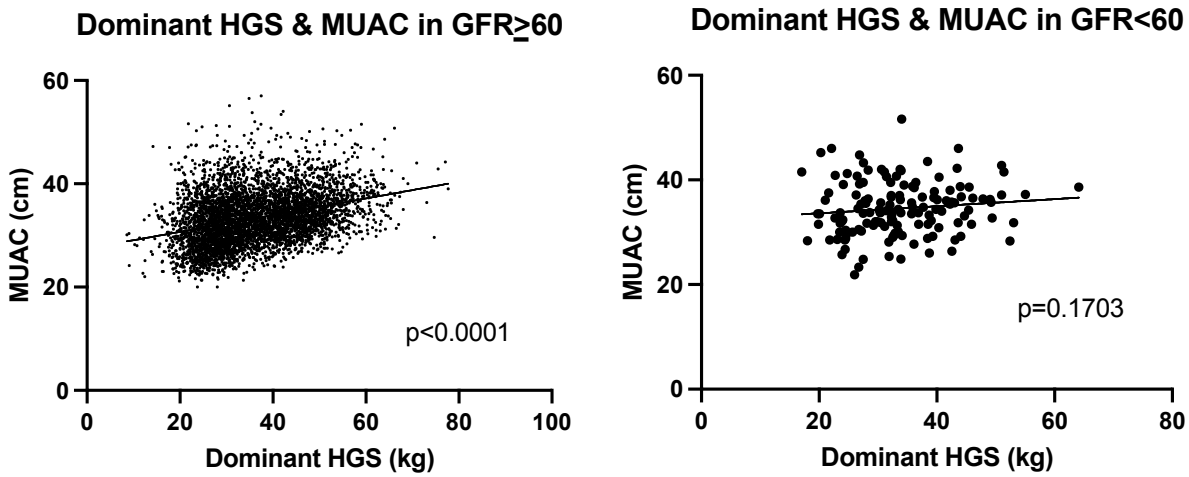
[a] Simple linear regression, p<0.0001, r^2=0.2450
[b] Simple linear regression, p<0.0001, r^2=0.1513

Figure 5: Correlation of ASMI and Dominant HGS



[a] Simple linear regression, p<0.0001, r^2=0.04036
[b] Simple linear regression, p=0.0217, r^2=0.03734

Figure 6: Correlation of MUAC and Dominant HGS



[a] Simple linear regression, p<0.0001, r^2=0.1141
[b] Simple linear regression, p=0.1703, r^2=0.01348

Using the GLIM ASMI cutoffs for sarcopenia (males<7 kg/m^2 and females<5.4 kg/m^2), the participants were classified with sarcopenia (below GLIM cutoffs) or without sarcopenia (above GLIM cutoffs).[44] There was not a significant difference in the proportions of participants with and without sarcopenia within control and case groups (Table 11) or in the proportions of participants with and without sarcopenia between CKD stages and the control group (Table 12).

Table 11: Sarcopenia Using GLIM ASMI Cutoffs by Control vs. Cases

	Control (GFR≥60) (n=4,760)	**Cases (GFR<60) (n=141)**	***P-Value***
Sarcopenic (n=1,260)	1224 (25.7%)	36 (25.5%)	p=0.9573[a]
Not Sarcopenic (n=3,641)	3,536 (74.3%)	105 (74.5%)	p=0.9573[a]

[a] Test of proportions

Table 12: Sarcopenia Using GLIM ASMI Cutoffs by CKD Stage

	Control (GFR≥60) (n=4,760)	Cases (GFR<60)			
		CKD Stage 3 (n=128)	CKD Stage 4 (n=5)	CKD Stage 5 (n=8)	*P-Value*
Sarcopenic (n=1,260)	1224 (25.7%)[a,b,c]	34 (26.6%)[a,d,e]	0 (0%)[b,d,f]	2 (25%)[c,e,f]	p=0.8182[a], p=0.1886[b] p=0.9639[c], p=0.1812[d] p=0.9208[e], p=0.2242[f]
Not Sarcopenic (n=3,641)	3,536 (74.3%)[g,h,i]	94 (73.4%)[g,j,k]	5 (100%)[h,j,l]	6 (75%)[i,k,l]	p=0.8182[g], p=0.1886[h] p=0.9639[i], p=0.1812[j] p=0.9208[k], p=0.2242[l]

[a-l] Test of proportions between same letters

Serum Phosphorus, Serum Corrected Calcium and HGS

Mean serum concentrations of phosphorus and corrected calcium were analyzed for case and control groups (Table 13). There was a statistically significant difference in the means of serum phosphorus (p=0.0084) and serum corrected calcium (p=0.0035) between the case and control groups. There was a statistically significant difference (p<0.0001) in the means of serum phosphorus between the control group and CKD Stage 5 and between CKD Stage 3 and Stage 5, but not between other groups (Table 14, Figure 7). There was a statistically significant difference (p=0.0004) in the means of serum corrected calcium between the control group and CKD Stage 3, but not between other groups. There was a significant difference (p=0.0364) in the means of serum corrected calcium between CKD Stages 3 and 4, but not between other groups.

Table 13: Mean ± SD Serum Phosphorus and Serum Corrected Calcium

	Control (GFR≥60) (n=4,760)	Cases (GFR<60) (n=141)	*P-Value*
Serum Phosphorus (mg/dL)	3.78 ± 0.57	3.91 ± 0.77	p=0.0084[a]
Serum Corrected Calcium (mg/dL)	9.12 ± 0.72	9.3 ± 0.72	p=0.0035[a]

[a] T-test of means

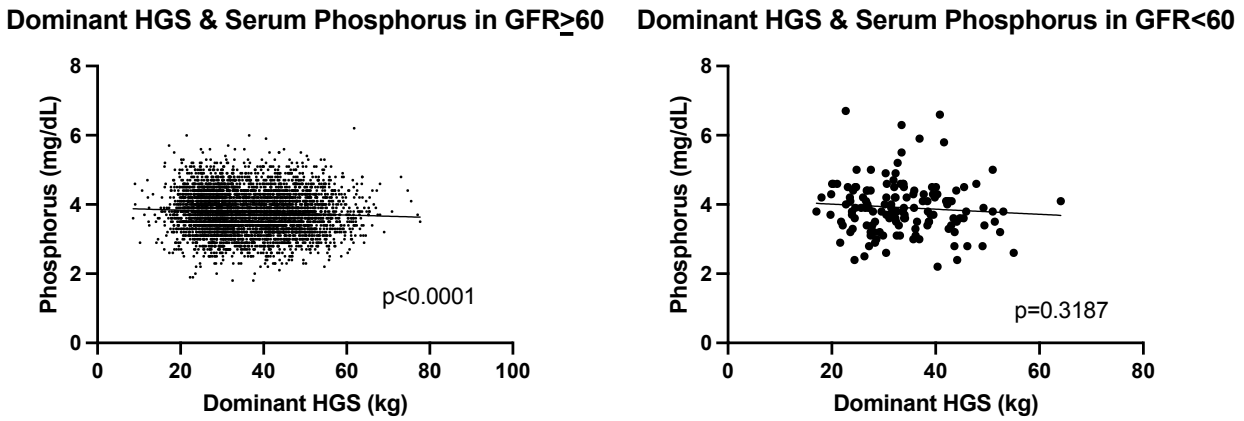
Table 14: Mean ± SD Serum Phosphorus and Serum Corrected Calcium by CKD Stages

	Control (GFR≥60) (n=4,760)	Cases (GFR<60)			
		CKD Stage 3 (n=128)	CKD Stage 4 (n=5)	CKD Stage 5 (n=8)	P-Value
Serum Phosphorus (mg/dL)	3.78 ± 0.57[a,b,c]	3.82 ± 0.67[a,d,e]	4.28 ± 0.48[b,d,f]	5.13 ± 1.21[c,e,f]	p=0.4357[a],p=0.05[b] p<0.0001[c,e], p=0.1316[d] p=0.1670[f]
Serum Corrected Calcium (mg/dL)	9.12 ± 0.72[g,h,i]	9.35 ± 0.7[g,j,k]	8.68 ± 0.52[h,j,l]	8.9 ± 0.73[i,k,l]	p=0.0004[g], p=0.1720[h] p=0.3879[i], p=0.0364[j] p=0.0807[k], p=0.5713[l]

[a-l] T-test of means between same letters

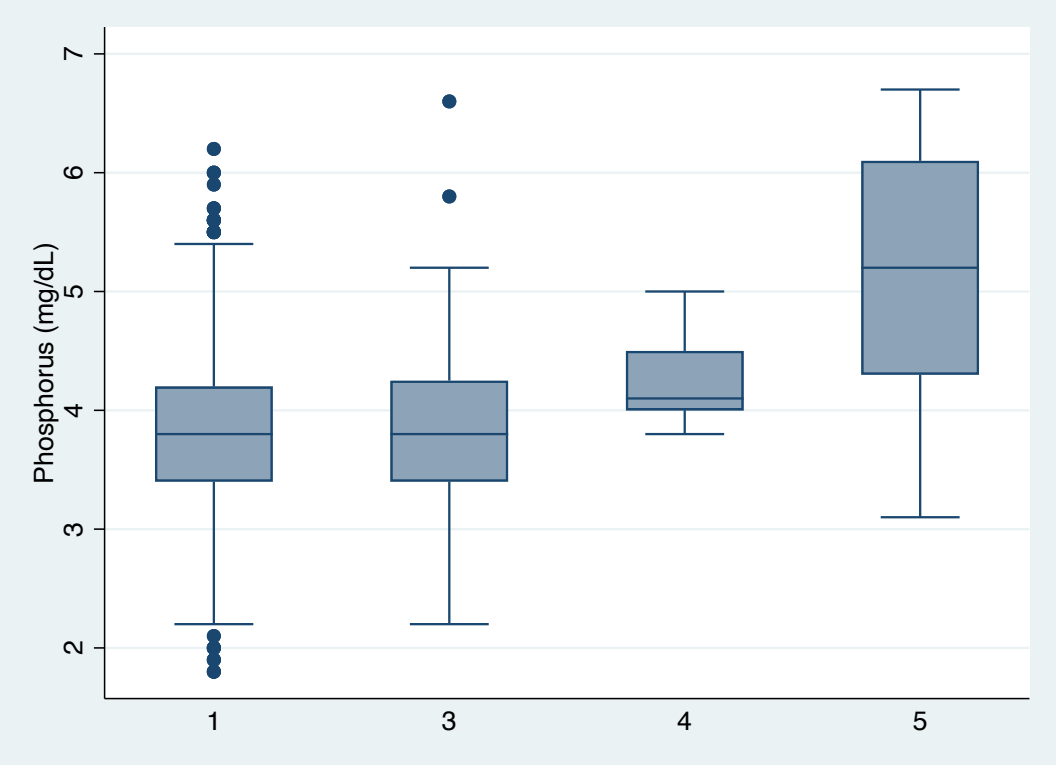
There was a significant negative correlation (p<0.0001, r^2=0.004292) between dominant HGS (kg) and serum phosphorus (mg/dL) in the control group and a non-significant negative correlation (p=0.3187, r^2=0.007153) in the case group (Figures 7, 8). There was a significant positive correlation (p=0.0092, r^2=0.001426) between dominant HGS (kg) and serum corrected calcium (mg/dL) in the control group, but a non-significant negative correlation (p=0.1145, r^2=0.01783) in the case group.

Figure 7: Correlation of Serum Phosphorus and Dominant HGS



[a] Simple linear regression, p<0.0001, r^2=0.004292
[b] Simple linear regression, p=0.3187, r^2=0.007153

Figure 8: Serum Phosphorus by CKD Stage[a]



[a] Mean serum phosphorus (mg/dL) by CKD Stages 3-5. CKD Stage 1 represents all of control group.

Renal Diet Adherence on HGS

Daily dietary intakes of sodium, potassium, and phosphorus were examined in the case and control groups (Table 15). After adjusting for body weight, there was a statistically significant difference in the means of sodium intake (p=0.0007), potassium intake (p=0.0439), and phosphorus intake (p=0.0029) between case and control groups, with higher intakes in the control group for all 3 nutrients. There was a statistically significant difference (p=0.0037) in the mean sodium intake between the control group and CKD Stage 3, but not between other groups (Table 16). There was a statistically significant difference (p=0.0311) in the means of potassium intake between the control group and CKD stage 5, between stages 3 and 4, 3 and 5, and between stages 4 and 5. There was a statistically significant difference (p=0.0145) in the

mean intake of phosphorus between the control group and CKD stage 3, but not between any other groups.

Table 15: Mean ± SD Dietary Intakes of Sodium, Potassium, and Phosphorus

	Control (GFR≥60) (n=4,760)	**Cases (GFR<60) (n=141)**	***P-Value***
Sodium Intake (mg/kg)	48.13 ± 26.67	40.46 ± 22.41	p=0.0007[a]
Potassium Intake (mg/kg)	34.87 ± 18.5	31.69 ± 17.2	p=0.0439[a]
Phosphorus Intake (mg/kg)	18.52 ± 9.93	16 ± 8.9	p=0.0029[a]

[a] T-test of means

Table 16: Mean ± SD Dietary Intakes of Sodium, Potassium, and Phosphorus by CKD Stage

	Control (GFR≥60) (n=4,760)	Cases (GFR<60)			P-Value
		CKD Stage 3 (n=128)	CKD Stage 4 (n=5)	CKD Stage 5 (n=8)	
Sodium Intake (mg/kg)	48.13 ± 26.67[a,b,c]	41.22 ± 22.56[a,d,e]	35.03 ± 11.32[b,d,f]	31.57 ± 24.63[c,e,f]	p=0.0037[a], p=0.2722[b] p=0.0793[c], p=0.5437[d] p=0.2449[e], p=0.7759[f]
Potassium Intake (mg/kg)	34.87 ± 18.5[g,h,i]	32.79 ± 17.46[g,j,k]	20.72 ± 10.08[h,j,l]	20.76 ± 8.43[i,k,l]	p=0.2088[g], p=0.0874[h] p=0.0311[i], p=0.1279[j] p=0.0558[k], p=0.9940[l]
Phosphorus Intake (mg/kg)	18.52 ± 9.93[m,n,o]	16.35 ± 8.87[m,p,q]	11.9 ± 4.92[n,p,r]	13.19 ± 11[o,q,r]	p=0.0145[m],p=0.1362[n]p=1294[o], p=0.2680[p] p=0.3367[q], p=0.8115[r]

[a-r] T-test of means

Energy (kcal) and protein (g) intake was adjusted for weight (kg) to compare participant's intake between control and case groups (Table 17). There was a statistically significant difference in the mean energy intake (p=0.0001) and the mean protein intake (p=0.0053) between the control and case groups. There was a statistically significant difference (p=0.0010) in the mean energy intake between the control group and CKD stage 3, but no significant difference between the remaining groups. There was a statistically significant difference (p=0.0193) in the mean protein intake between the control group and CKD stage 3, but no significant difference in the remaining groups (Table 18). The highest intake of energy and protein was noted in the control group (29.19 $\pm$ 14.55 kcal/kg and 1.12 $\pm$ 0.62 g protein/kg) with decreasing intakes as GFR declines.

Table 17: Mean $\pm$ SD Energy and Protein Intakes

	Control (GFR$\geq$60) (n=4,760)	**Cases (GFR<60) (n=141)**	***P-Value***
Energy Intake (kcal/kg)	29.19 $\pm$ 14.55	24.44 $\pm$ 12.52	p=0.0001[a]
Protein Intake (g/kg)	1.12 $\pm$ 0.62	0.97 $\pm$ 0.62	P=0.0053[a]

[a] T-test of means

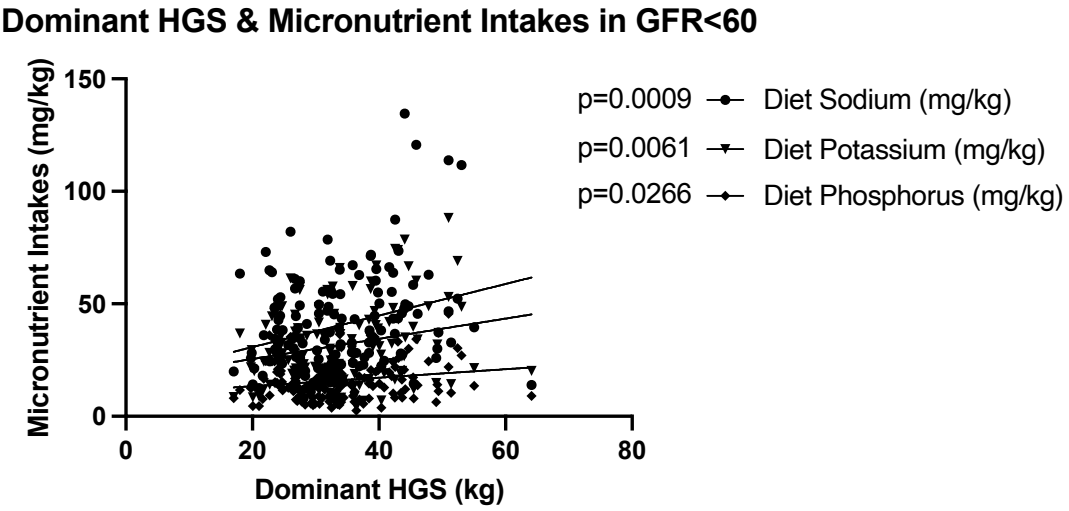
Table 18: Mean ± SD Energy and Protein Intakes by CKD Stage

	Control (GFR≥60) (n=4,760)	Cases (GFR<60)			
		CKD Stage 3 (n=128)	CKD Stage 4 (n=5)	CKD Stage 5 (n=8)	*P-Value*
Energy Intake (kcal/kg)	29.19 ± 14.55[a,b,c]	24.92 ± 12.28[a,d,e]	17.61 ± 5.39[b,d,f]	21.04 ± 18.22[c,e,f]	p=0.0010[a], p=0.0752[b] p=0.1136[c], p=0.1884[d] p=0.4018[e], p=0.6940[f]
Protein Intake (g/kg)	1.12 ± 0.62[g,h,i]	0.99 ± 0.63[g,j,k]	0.68 ± 0.12[h,j,l]	0.85 ± 0.6[i,k,l]	p=0.0193[g], p=0.1126[h] p=0.2185[i], p=0.2752[j] p=0.5421[k], p=0.5504[l]

[a-l] T-test of means

There was a significant positive correlation between dominant HGS (kg) and dietary intakes of sodium (mg/kg) (p=0.0029, r^2=0.001857) and phosphorus (mg/kg) (p<0.0001, r^2=0.003978) and a non-significant positive correlation between dominant HGS (kg) and dietary intake of potassium (mg/kg) (p=0.2251, r^2=0.0003094) in the control group. There was a significant positive correlation between dominant HGS (kg) and dietary intakes of sodium (mg/kg) (p=0.0009, r2=0.07606), potassium (mg/kg) (p=0.0061, r2=0.05285), and phosphorus (mg/kg) (p=0.0266, r2=0.03489) in the case group (Figure 9).

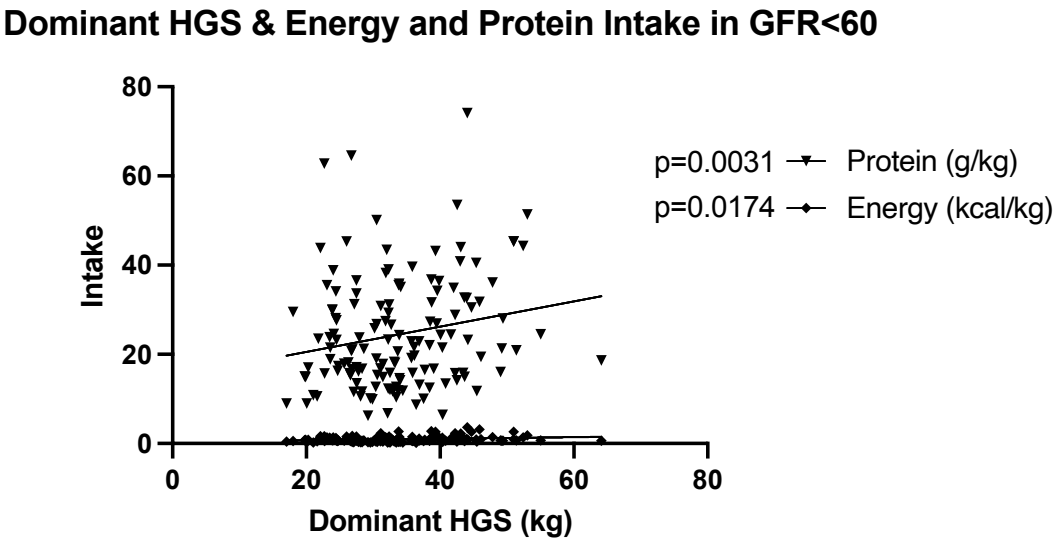
Figure 9: Correlation of Dietary Intakes and Dominant HGS



a Simple linear regression, p=0.0009, r^2=0.07606
b Simple linear regression, p=0.0061, r^2=0.05285
c Simple linear regression, p=0.0266, r^2=0.03489

There was a significant positive correlation between dominant HGS (kg) and intakes of energy (kcal/kg) (p<0.0001, r^2=0.003688) and protein (g/kg) (p<0.0001, r^2=0.006395) in the control group. There was also a significant positive correlation between dominant HGS (kg) and energy (kcal/kg) (p=0.0174, r^2=0.04004) and protein intake (g/kg) (p=0.0031, r^2=0.06107) in the case group (Figure 10).

Figure 10: Correlation of Energy and Protein Intake and Dominant HGS



[a] Simple linear regression, p=0.0031, r^2=0.06107
[b] Simple linear regression, p=0.0174, r^2=0.04004

Discussion

Significant Findings

The overall goal of this project was to expand the understanding of HGS in individuals with kidney disease and how HGS may be used to assess nutrition status and detect the presence of malnutrition by examining the effects of LBM, MUAC and other factors on HGS measurements.

We hypothesized that HGS would be lower than normative standards in individuals with kidney disease. We found that there was no significant difference in the proportion of male or female participants with kidney disease who had HGS below the Takei average. An equal proportion of female participants with kidney disease had HGS above or below the Takei average. A significantly greater proportion of male participants with kidney disease had HGS below average compared to those without kidney disease. When looking at males and females together, 55% of the individuals with kidney disease, had below average HGS.

It is important to note that the Takei dynamometer was used to measure HGS in this study. We know from comparison studies that the Takei dynamometer tends to report lower HGS measurements than the Jamar dynamometer, which is the recommended best practice dynamometer.[8] Studies have also shown that HGS declines with age beginning at 30 years of age and the rate of decline in HGS increases with age.[1,16,17] Conditions associated with kidney disease, such as frailty and muscle wasting are characteristics of accelerated premature aging that can be caused by uremic phenotype, and thus, further contribute to decreased HGS in this population.[2]

The Takei normative standards were determined in an Asian population. Our results showed that in the female population there were significantly more non-Hispanic Asian participants with below average HGS in the control group. There was no difference between any race in the male population for the control or the case group. When males and females were combined, 84% had below average HGS, but only 7 non-Hispanic Asian participants were included in the case group as having kidney disease. Only 58% of non-Hispanic white and 49% of the non-Hispanic black participants had below average HGS when compared to the Takei normative standards. This could indicate that the Takei normative standards are more appropriate in an Asian population. Since normative values for the Jamar dynamometer typically report higher HGS measurements according to comparison studies, the Takei dynamometer could be skewing our study's measurements.[8]

As expected, this study found the men had significantly higher LBM, LBMI, and MUAC when compared to females in both groups. However, females had higher ASMI when compared to men in both groups. This could be due to ASM only accounting for about 30% of the total body's muscle mass, where LBM accounts for the entire body. It was also surprising to find that LBM, LBMI, and MUAC were higher in those with kidney disease compared to those without. Studies have shown that patients with lower HGS are typically older, present with lower weight, lower LBM, and lower LBM quality than patients with adequate HGS.[33,34] Since patients with kidney disease typically have lower LBM, we presumed that they would have lower HGS in our study. Using NHANES data, our oldest participant was less than 60 years old and may have contributed to the higher LBM in the case group than was expected.

We predicted that HGS would be lower in those with lower LBM and MUAC. There was a significant positive correlation between LBM and HGS in individuals with and without kidney disease. Even after controlling for height, there was still a significant positive correlation between HGS and LBMI in individuals with and without kidney disease. Similarly, Rossato, et al. found that the primary predictor of HGS in their population was LBM.[34] This study specifically measured muscle function by muscle mass (HGS/LBM ratio) and found that LBM predicted 33.1% of HGS and had a highly significant association ($p<0.001$).[34] We did not use this specific measurement, but instead accounted for muscle mass by adjusting for height (m^2) with LBMI and ASMI. Even after accounting for height, LBMI still positively correlated with HGS, but ASMI did not. Our results found a significant negative correlation between HGS and ASMI in individuals with and without kidney disease. Furthermore, there was a significant positive correlation between HGS and MUAC in individuals without kidney disease, but this was not significant in individuals with kidney disease. Our data would suggest that LBM and LBMI both are good predictors of HGS with highly significant associations of $p<0.0001$.

As expected, serum phosphorus and calcium concentrations were higher in those with kidney disease and increased with increasing CKD stage. There was a significant negative correlation between HGS and serum phosphorus in those without kidney disease, but a non-significant negative correlation in individuals with kidney disease. Previous studies have shown that HGS values were higher in the presence of hyperphosphatemia.[21] Some researchers suggest that hyperphosphatemia in this population could indicate a better protein intake and nutrition status.[4,23] This was not seen in our study as hyperphosphatemia was evident in advanced CKD stages of 4 and 5, but HGS decreased as GFR declined. This could be due to loss

of appetite and poor intake of phosphorus-rich protein foods as CKD progresses, which contributes to loss of LBM.[22] Dietary protein intake is a stimulus for muscle protein synthesis and a key factor that regulates skeletal muscle mass.[22] As protein intake decreases with the progression of kidney disease, muscle mass and strength, as shown by HGS, declines.

There was a significant positive correlation between HGS and serum corrected calcium in individuals without kidney disease but a non-significant negative correlation in those with kidney disease. To our knowledge, this is the first study to examine serum calcium and HGS in a CKD population. Other studies in healthy populations and hospitalized individuals have not noted a correlation between serum calcium and HGS.[26,27] Since advanced CKD can lead to hypocalcemia due to the actions of PTH, we wanted to look at the correlation within our population.[24] Serum corrected calcium concentrations were lower in the advanced stages of CKD, however, HGS was not correlated.

When we examined dietary intake, we found that the intakes of sodium, potassium, and phosphorus were highest in participants without kidney disease and decreased as kidney disease progressed and GFR declined. There was a significant difference in the mean energy and protein intakes between participants with and without kidney disease. Highest intakes of energy and protein were in participants without kidney disease and decreased as kidney disease progressed and GFR declined. We did note that protein and energy intakes were higher in individuals with stage 5 CKD than those in stage 4. A reduced appetite is an early and common sign of uremia and becomes increasingly more prominent as the GFR declines.[23] Therefore as dialysis treatments are started when the patient progresses to stage 5 CKD, they may have a slightly improved appetite as the uremia is improved.

In subjects with and without kidney disease, there was a positive correlation between dietary intakes of sodium, phosphorus, potassium, energy and protein and HGS suggesting that higher overall dietary intake is associated with higher HGS. The higher intake of these nutrients may indicate higher muscle mass. Studies have shown that PEM is a common complication for patients with CKD, especially those with ESRD.[1] PEM is often characterized by muscle mass loss leading to reduced muscle strength, which we measured as HGS.

One method of managing CKD is following a renal diet that adjusts the parameters we described previously (Table 2). By restricting diet intake to follow all renal diet recommendations, and combined with potentially decreased appetite, nausea, and taste changes in the CKD population, overall dietary intake can be compromised. This can then contribute to the development of PEM. Studies have shown that reduced HGS is associated with malnutrition in patients with CKD as GFR declines.[1] While the diagnosis of malnutrition was not recorded as part of the NHANES data, we can see that lower dietary intakes of energy and protein leads to lower HGS. Loss of muscle mass has a strong association with decreased nutrition status and men on dialysis with anorexia have been found to have lower HGS scores.[1-3,23]

Increasing evidence of negative outcomes from strict adherence to dietary changes have led to changes in diet recommendations by the National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (KDOQI).[48] We used previously recommended micronutrient recommendations for our study in order to look at a large group of people. However, in individualized practice, 2020 KDOQI guidelines recommend an intake that will maintain the serum concentrations within normal ranges for phosphorus and potassium.[48] They do still

recommend to limit sodium to less than 2300 mg/day for individuals diagnosed with CKD and receiving dialysis to reduce blood pressure and improve volume control.[48] It would be difficult to monitor individualized dietary restriction in a large population study, which is why we chose to make a more generalized renal diet for our study.

Limitations

There were some limitations to our study. First, it was difficult to compare our control group of individuals with kidney disease to our control group of individuals without kidney disease due to the very small population size of those with GFR<60 mL/min. The NHANES emphasized data from healthy individuals in order to provide a good snapshot of the nutrition status of the general public, but this limits a good snapshot of individuals with kidney disease.

Second, while NHANES staff are highly trained, the dietary intake variables were based on self-reported data from the participants. This could lead to some errors in reporting that could affect the results. There could also be human error on the part of the NHANES staff in recording data from tests.

A third limitation is that there are few previous studies examining HGS in the CKD population and these studies often did not measure the same variables. This made it difficult to compare our findings and limited our ability to make firm conclusions with supporting evidence from prior research. This was further compounded by the use of the Takei dynamometer in the NHANES population. This specific dynamometer is not the "gold standard" tool as defined by the ASHT and the normative standards were calculated based on a healthy Asian population.

Strengths

Our study did have some strengths. First, we were able to use NHANES data from two different data cycles. NHANES is a nationally-representative subset of the general public in the United States and has been used in many studies over many years. Another strength stemming from the NHANES data is the large population from which we were able to glean our participants.

Future Research

Future research is needed in a larger population of individuals with CKD that utilizes the Jamar dynamometer to measure HGS, as recommended by the ASHT. Future research should continue to assess the complexities of CKD, but could be expanded to focus more on the effects of dialysis on HGS. It would also be prudent to include older adults in the future research population.

Conclusion

In conclusion, lower HGS was associated with declining GFR, LBM, LBMI, MUAC, serum phosphorus, and renal diet adherence. While the renal diet is restrictive and is meant to help manage the complications of CKD, it was interesting to see the association between renal diet adherence and lower HGS. In addition to these findings, this was a novel study in examining the effect of serum calcium on HGS in this population.

It is evident that normative standards for HGS are well-above the average HGS of the CKD population. With further research and larger population studies, it may be possible to

identify appropriate HGS ranges that can be used to assess nutrition status and changes in HGS in the CKD population to allow for earlier detection of malnutrition in affected individuals.

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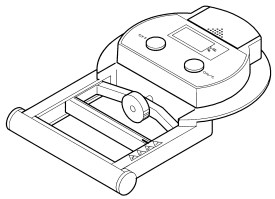
T.K.K.5401

GRIP D

Operation Manual



■ Please be sure to read this operation manual before you start using the device in order to use it correctly.

■ Keep this operation manual in a safe place so that anyone using the device can take it out to read.

Cautions for handling the device

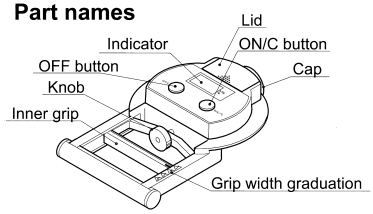
- Do not press the ON/C button while the inner grip is being gripped. Doing so will not provide correct measurement results.
- Release pressure from the grip as soon as the measurement is over. The device starts measurement when a force of 5 kg is reached, and judges the measurement is over when the force decreases below 4 kg.
- Do not turn the cap. Doing so will not provide correct measurement results.

Safety cautions

To use the device correctly, please read these safety cautions carefully before you start using the device.
Each of the following descriptions presents important safety cautions.
Please observe these safety cautions.
These safety cautions show cases where you may be injured or damage property.

CAUTION	⊘	Do not drop the device on your foot. ・This may cause an accident or damage the device.
	⊘	Do not try to take the device apart. ・This may cause the device to fail.
	❗	Handle the batteries correctly. ・Insert the batteries with (+) and (-) marks placed in the correct positions. ・Use only the specified model batteries. ・Take the batteries out of the device if you are not going to use the device for an extended period of time. Store the batteries safely. Improper handling can cause device failure or contamination due to electrolyte leakage from the batteries.

Part names



Average grip values by age (kg)

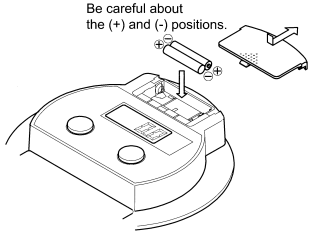
Age	Male	Female	Age	Male	Female	Age	Male	Female	Age	Male	Female
			10	17.3	15.9	30	49.6	30.8	50	45.4	28.2
			11	20.4	19.1	31	49.8	30.8	51	45.0	28.0
			12	24.6	22.1	32	50.0	30.8	52	44.9	27.6
			13	30.7	24.6	33	50.4	31.0	53	44.2	27.5
			14	36.2	26.1	34	50.0	31.0	54	43.8	27.3
			15	39.8	26.5	35	49.7	30.9	55	43.4	27.3
			16	43.3	27.2	36	49.5	30.9	56	42.7	26.9
			17	44.6	28.0	37	49.5	30.9	57	42.3	26.9
			18	45.2	28.1	38	49.1	30.7	58	42.0	26.4
			19	45.8	28.4	39	48.5	30.7	59	41.5	25.9
			20	46.5	28.6	40	48.5	30.7	60	40.8	25.7
			21	47.1	29.1	41	48.0	30.7	61	39.7	25.5
			22	47.8	29.3	42	48.0	30.6	62	39.2	25.3
3	6.5	4.4	23	48.3	29.3	43	47.3	30.5	63	38.5	24.7
4	7.2	6.0	24	48.8	29.4	44	47.4	30.3	64	37.5	24.7
5	9.3	8.7	25	48.9	29.7	45	47.1	29.8	65	36.8	24.2
6	10.0	9.7	26	49.0	30.0	46	46.9	29.6	66	36.3	24.0
7	11.0	10.3	27	49.3	30.0	47	46.6	29.6	67	36.0	24.0
8	13.0	12.0	28	49.3	30.1	48	45.7	29.0	68	35.8	24.0
9	15.2	14.0	29	49.6	30.1	49	45.6	28.5	69	35.5	23.6
									70	35.0	23.0

Source:
"Average values of new physical strength for the Japanese Ⅱ".
"Physical strength Average value Study Society,
Tokyo Metropolitan University".

Preparation

How to place the batteries:

1. Remove the lid.
2. Insert two 4A size batteries.
3. Replace the lid.



Time to replace the batteries

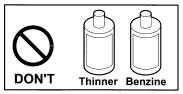
・When the batteries have been used up,

When "LOBAT" flashes,
replace the batteries with two new batteries.

When you finished using the device

Cleaning the device:

・If the device gets dirty, wipe it with the cloth which is dipped into neutral detergent and wrung tightly. Then wipe it with a dry cloth.
・Do not use thinner or benzine.



Storage and storage locations

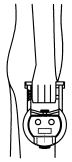
・Clean the device, and store it in a place with low humidity.
・Avoid storing the device in any place where there will be direct sunlight on the device or where the temperature will be high, such as near a heater.

Items to check if you are having problems with your device

■ Before asking a dealer for repairs, check the table below.

Symptom	Check	Action
No indication appears even if the ON/C button is pressed.	Are the batteries dead? Are the (+)(-) connections of the batteries in the correct positions?	Replace them with new batteries. Correct the (+)(-) positions.
"LOBAT" indication is flashing. Indication is dim.	Batteries are low.	Replace them with new batteries.

Measuring method



1. Hold the device so that the grip meter indicator faces outward. Turn the knob to adjust the grip width so that the second joint of the pointing finger makes a right angle.
2. Stand upright, let your arm down naturally, and clasp the grip with full force. Do not swing the grip meter at this time.

Operation method

Perform measurements twice each with the left and right hands alternately. The mean value of the highest values of the forces of both hands is indicated by the flashing measurement result.

1. Press the ON/C button.
- The power supply is turned on, the indicator changes the value for several seconds, and settles down to 0.0 kg.

2. Start measurement with the right hand.
- The indicator shows the measurement of the right hand.

3. Continue the measurement with the left, and then the right and left hands again for a total of four measurements.
- The mean value of the highest values of the forces of both hands is indicated by flashing after about three seconds.
- No mean value will be indicated if the ON/C button is pressed after each measurement.

4. Record the measurements.
- To repeatedly perform the measurement, press the ON/C button.

5. As soon as the measurement is over, press the OFF button.

※ If the device is not used for about one minute and the power supply is turned on, then the power will be automatically be turned off.

Product specifications

Product No.: T.K.K. 5401

Measurement range	5.0 to 100.0 kg
Minimum measurement unit	0.1 kg
Accuracy	±2 kg or better
Power supply	Two 4A size batteries
Operation time	100 hours of continuous operation.
Operating environment	Temperature of 5 to 35℃ Relative humidity of 80% or lower
Dimensions (mm)	154 W x 235 D x 62 H
Weight	About 680 g

PURSUIT OF HUMAN POTENTIALITIES
TAKEI SCIENTIFIC INSTRUMENTS CO., LTD.
No. 619, Yashiroda, Akiha-Ku, Niigata-City, Niigata-Pref, 956-0113, Japan
PHONE: 0250-38-4132 FAX: 0250-61-1211

Average grip values by age (kg)

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14	36.0	26.0	34	50.0	30.3	54	43.5	27.0
15	40.5	26.5	35	49.8	30.3	55	43.0	26.9
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17	46.0	27.9	37	49.0	30.5	57	41.9	26.4
18	47.4	27.7	38	48.9	30.5	58	41.5	26.3
19	48.4	28.1	39	48.5	30.4	59	41.0	25.8
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22	50.0	28.5	42	47.7	30.2	62	39.3	24.6
23	50.1	28.6	43	47.4	30.0	63	38.7	24.2
24	50.1	29.3	44	47.1	29.5	64	38.2	23.8
25	50.2	29.1	45	46.8	29.6	65	37.5	23.4
26	50.2	29.4	46	46.5	29.6	66	37.0	23.1
27	50.2	29.7	47	46.1	29.4	67	36.5	22.7
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29	50.2	30.2	49	45.4	28.6	69	35.4	21.9
						70	34.8	21.5

Source: "Average values of new physical strength for the Japanese 2000"
Physical Strength Average Value Study Society,
Tokyo Metropolitan University