The use of functional performance tests and simple anthropomorphic measures to screen for comorbidity in primary care

Abstract

Background: Many older adults are unaware that they have comorbid diseases. Increased adiposity and reduced muscle mass are identified as key contributors to many chronic diseases in older adults. Understanding the role they play in the development of comorbidities in older populations is of prime importance.

Objectives: To identify the optimal body shape associated with three common functional performance tests and to determine which anthropometric and functional performance test best explains comorbidity in a sample of older adults in Hong Kong.

Methods: A total of 432 older adults participated in this cross-sectional study. Researchers assessed their body height, body mass index, waist circumference, waist-to-hip ratio, handgrip strength (kg), functional reach (cm), and results in the Timed Up and Go (TUG) test (seconds). The Charlson Comorbidity Index was used to assess comorbidity.

Results: Allometric modelling indicated that the optimal body shape associated with all functional performance tests would have required the participants to be taller and leaner. The only variable that predicted comorbidity was the TUG test. The inclusion of body size/shape variables did not improve the prediction model.

Conclusion: Performance in the TUG test alone was found to be capable of identifying participants at risk of developing comorbidities. The TUG test has potential as a screening tool for the early detection of chronic diseases in older adults.

Implications for Practice: Many older people are unaware of their own co-existing illnesses when they consult physicians for a medical condition. TUG can be a quick and useful screening measure to alert nurses in primary care to the need to proceed with more detailed assessments. It is an especially useful screening measure in settings with high patient volumes and fiscal constraints. TUG is low-cost and easy to learn, and is therefore also relevant for nurses and health workers in low-resource, low-income countries.

Keywords: Allometric; body mass; waist circumference; older people; primary care; comorbidity; multiplicative model; Timed Up and Go, health screening

Implications for practice

What does this research add to existing knowledge in gerontology?

- Many older adults, particularly those with lower levels of literacy and those living in developing or underdeveloped countries, are unaware of their own comorbid conditions.
- This cross-sectional study found that performance in the TUG test alone can identify participants at risk of developing comorbidities. Further studies will be useful to verify this finding.

What are the implications of this new knowledge for nursing care with older people?

- The TUG test costs little and is easy to administer. It should be promoted in health assessments of older people, particularly in settings with high patient volumes and/or fiscal constraints, or in low-resource, low-income countries.
- The test is non-invasive in nature and therefore likely to be acceptable to older adults as an assessment measure.

How could the findings be used to influence research, education, policy, or practice?

- Many older adults, especially those with low levels of literacy, are often unaware of their comorbidities even when they visit their doctor for a medical consultation. Using a simple TUG test will help to alert clinicians to the possibility of comorbid conditions in their clients or patients. A finding that is outside of the normal range can prompt further evaluation by nurses and other health care providers, and can therefore facilitate early referrals to physicians for timely diagnosis and treatment of any comorbid conditions.
- Under the supervision of nurses and allied health professionals, community health workers in settings with manpower shortages and fiscal constraints – as well as those

in low-resource, low-income countries – can learn how to use the TUG test at a minimal cost.

- It is suggested that replication studies be conducted in other populations to further examine the predictive power of using TUG to identify those at risk of multiple comorbidities.

Background

On chronic illness and comorbidity

Globally, the top four major chronic diseases are cardiovascular disease, cancer, chronic respiratory disease, and diabetes; these are responsible for close to 80% of deaths from non-communicable diseases (World Health Organization, 2018). Eighty to 85% of older adults have at least one chronic condition (National Council on Aging, 2018; National Institute of Aging, 2017). Comorbidity, defined as the simultaneous presence of two or more diseases in an individual (Newman, 2012), has been observed in two-thirds of older adults worldwide (Marengoni et al., 2011). Comorbidities may be associated with each other through pathogenetic mechanisms (Grumbach, 2003) that contribute to patient complexity.

Chronic comorbidities contribute to the burden and cost of many different medical conditions that have been reported (Cortaredona & Ventelou, 2016). Both comorbidity and multi-morbidity have been found to be associated with mortality (Ferrer, Formiga, Sanz, Almeda, & Padrós, 2017; Fraccaro et al., 2016), disability, and poor functional status (Garin et al., 2014; Ryan, Wallace, O'Hara, & Smith, 2015), poor quality of life (Wang, Palmer, Cocker, & Sanderson, 2017), and higher health service utilization (van Oostrom et al., 2014).

Unfortunately, patient awareness of chronic diseases is reportedly low (Cavanaugh et al., 2008). Moreover, even if most patients are aware of their primary medical diagnosis, a large number may not be aware that they have comorbidities (Bansode & Nagarajan, 2017). Those who are affected by dementia (Fox et al., 2014; Scrutton & Brancati, 2016) or are less educated (Hoffmann et al., 2018) are compromised in their ability to provide timely reports to their formal caregivers about their comorbid health problems.

Increased adiposity and reduced muscle mass as contributors to chronic diseases

Increased adiposity and reduced muscle mass with ageing have been identified as key contributors to many chronic diseases in older adults (Chang, Beason, Hunleth, & Colditz, 2012). There is substantial evidence that obesity is an important contributor not only to cardiovascular disease and diabetes, but also to cancer, arthritis, liver and kidney diseases, as well as to other adverse health outcomes (Pi-Sunyer, 2009). These complications are associated with obesity in older populations (Amarya, Singh, & Sabharwal, 2014), yet it is not known which anthropometric measure best predicts health risks in obese older people (Mathus-Vliegen et al., 2012).

Muscle mass has also been found to be a strong predictor of many chronic diseases suffered by older people, such as diabetes (Kim et al., 2014) and cardiovascular disease (Afilalo et al., 2014). However, measuring muscle mass usually involves expensive imaging procedures (e.g., dual X-ray absorptiometry) (Tosato et al., 2017). Consequently, simple anthropometric and functional performance measures are more commonly used as markers to identify chronic diseases in primary healthcare settings.

Anthropometric and functional measures as predictors of comorbidity

Systematic reviews have suggested that the majority of studies overwhelmingly rely on body mass index (BMI) as a measure of adiposity (Chang et al., 2012). Notwithstanding the criticisms of BMI as a measure, the process of ageing results in greater central adiposity (MacInnis et al., 2006). Therefore, measures of central adiposity, waist circumference (WC), and waist-to-hip ratio (WHR) may be better predictors of the risk of comorbidities in older adults (Chang et al., 2012).

Nevill et al. (2017) examined the question of what would be the most appropriate anthropometric index associated with cardiovascular disease risk in adults aged 20-69 years (Nevill, Duncan, Lahart, & Sandercock, 2017). Using an allometric approach, they compared BMI, WC, WHR, waist-to-height ratio, and A Body Shape Index (ABSI) results as predictors of cardiovascular risk. ABSI is a recently developed measure of adiposity (Geraci et al., 2019). Nevill et al. found that the ratio of waist to height (0.5) was a better predictor of cardiovascular disease risk than the other predictors. In the context of an older adult population and given the limitations of prior studies using anthropometric indices of risk, it is important to determine which anthropometric indicator of obesity best predicts comorbidity in primary care settings, at a relatively low cost, in order to prevent chronic diseases.

Functional assessment tools are frequently used as prognostic tools by researchers and clinicians (Carey, Walter, Lindquist, & Covinsky, 2004). Poor functional status is associated with adverse health outcomes (Shah, Leonard, & Thakar, 2018), including hospitalizations and emergency room visits (O'Hoski et al., 2019), higher healthcare costs (Chuang et al., 2003), nursing home admission (Gaugler, Duval, Anderson, & Kane, 2007) and death (Carey et al., 2004). More work has been done on prognostic evaluations using functional measures of mortality than using measures of morbidity. For example, Formiga et al. (2016) studied the predictive value of functional impairment, chronic conditions, and laboratory biomarkers of ageing to predict mortality (Formiga et al., 2016). Wu and team (2016) examined functional status, health-related quality of life, and survival in cardiac patients (Wu, Lennie, Frazier, & Moser, 2016).

Slow gait is associated with sarcopenic obesity as well as with many subclinical conditions (Waters, Hale, Grant, Herbison, & Goulding, 2010). Jacob et al. (20I7) reported that a subgroup of their older participants with mobility limitations from existing musculoskeletal conditions as well as other comorbidities had the worst functional impairment among all of their participants (Jacob et al., 2017). Gait speed has been regarded as an objective measure of physical function in older adults for predicting morbidity and mortality (Albert, Bear-Lehman, & Anderson, 2015; Lyons et al., 2016). It has been studied as a predictor of falls (Verghese, Holtzer, Lipton, & Wang, 2009) and poor long-term outcomes such as disabilities (Flint et al., 2018), nursing home placement (Lyons et al., 2016), and survival (Studenski et al., 2011; Wu et al., 2016). Other functional measures, such as the Timed Up and Go (TUG) test, provide more information than just measures of gait speed in the risk of falls and other outcomes (Laddu et al., 2018). From their longitudinal study, Bergland et al. (2017) found that the TUG score is significantly associated with mortality (Bergland, Jargensen, Emaus, & Strand, 2017). Pieper, Bowling and Fillenbaum (2019) reported that the level and trajectory of comorbidity correlated with the functional measures in their longitudinal sample (Pieper, Bowling, & Fillenbaum, 2019).

This background illustrates that it is important to understand the role of increased adiposity, reduced muscle mass, and functional performance in relation to chronic conditions and comorbidities in an older adult population. Performance-based measures may be particularly useful in clinical settings serving community populations, because they are easy to perform and require only a few minutes to complete (Viccaro, Perera, & Studenski, 2011). Nurses play a pivotal role in primary health care (Pan American Health Organization, 2018), and such simple prognostic indicators can help them to carry out this role in screening and health promotion.

The aim of this study was to: 1) examine which anthropometric index best explains and predicts functional performance in a sample of older adults from Hong Kong; 2) examine which anthropometric index best explains and predicts comorbidity; and 3) examine which functional performance test, in combination with anthropometric characteristics, best explains and predicts comorbidity in the same sample.

Methods

Design

This paper is part of a longitudinal study on frailty conducted by the project team, although the data presented here is cross-sectional in design. The aim of the main study on frailty was to examine factors associated with the development of frailty over time. Convenience sampling was employed. Non-governmental organizations (NGOs) throughout the territory of Hong Kong were approached. These NGOs offer a range of services for older people, including operating senior centers and providing day care, home care, and long-term residential care. The NGOs that agreed to support this study disseminated information about it to their service clientele, sought their approval (or that of their proxies) to take part in the study, and obtained their phone numbers so that the research personnel could contact them. The participants were then approached and provided with a detailed explanation of the study. Written informed consent was obtained from each participant before they could take part in the study.

Participants

The criteria for eligibility to participate in this study were: 1) being aged 60 or older; and 2) ability to communicate in Cantonese, the major dialect in Hong Kong. Written consent was obtained from the participants or from their proxies if their Abbreviated Mental Test (AMT) score was lower than 7 (which indicates possible cognitive impairment). A more inclusive approach was adopted in setting up the recruitment criteria so as to identify a diverse sample of community participants. This study was approved by the Human Subjects Ethics Sub-Committee of The Hong Kong Polytechnic University (HSEARS20130609001).

Data collection

The participants were assessed in terms of their demographic data (gender, age, years of education, economic status, religion, fall history, and smoking and drinking habits), physical measures (including hip and waist circumferences, body weight, and BMI), and functional status (handgrip strength, TUG test, and functional reach). There is as yet no clear scientific definition of body shape, but various studies have demonstrated that waist-to-hip ratio (WHR) (calculated by waist circumference divided by hip circumference) and body mass index (BMI) (calculated by body weight in kilograms divided by the square of body height in metres) can be used to quantify body shape. The classifications of WHR and BMI are already well established. Two new anthropometric indices of adiposity – the A Body Shape Index (ABSI) and the Body Roundness Index (BRI) – have been developed in recent years as possible alternatives to BMI and waist circumference (Geraci et al., 2019). The calculation of ABSI involves waist circumference, BMI, and body weight. The data were collected by trained undergraduate nursing students through face-to-face interviews and assessments of the participants. If needed, supplementary information such as confirmed medical diagnoses were provided by the proxies or formal caregivers. The students were trained up to the point at which they were able to achieve no less than 90% agreement with the two key expert assessors in the project team.

Measurements

Functional Performance

Three measures of functional performance – handgrip strength (HG, measured in kg), the timed-up-and-go (TUG, measured in seconds) test, and functional reach (FR, measured in cm) – were adopted in the present study. These measures were used because they represent key, widely used tests for determining different aspects of the functional performance of older populations.

Grip strength is a recommended clinical measure of general muscle strength (Ong et al., 2017; Roberts et al., 2011). Handgrip strength (dominant hand) was assessed using the Jamar handheld dynamometer (hydraulic), following guidelines reported by Mathiowetz (Mathiowetz, 1990). Three trials were undertaken, with the mean score of the last two trials being taken for subsequent analysis. A study of older populations in Singapore showed that the handgrip strength of the Chinese subgroup aged between 65 to 85 and above ranged from 12.79 to 18.93 kg (Ong et al., 2017).

The TUG test is regarded as a combined measure of muscular strength, limb movement speed, and agility (Rikli & Jones, 1999). The TUG was administered following previously described procedures (Podsiadlo & Richardson, 1991). The TUG test involved taking note of the number of seconds required by an individual to get up from a seated position, walk 3 metres, turn, and return to a seated position. Two trials were undertaken, with the results of the second attempt being used for a subsequent analysis. Taking a shorter time to complete TUG indicates a better ability to balance. The cut-off level for TUG is 13.5 seconds or longer (Shumway-Cook, Brauer, & Woollacott, 2000). Its validity and reliability were confirmed in a study conducted in Hong Kong (Ng & Hui-Chan, 2005).

The functional reach test is considered a measure of dynamic balance (P. W. Duncan, Weiner, Chandler, & Studenski, 1990) . FR correlates with physical frailty (Weiner, Duncan, Chandler, & Studenski, 1992) and is used for detecting balance impairment and changes in balance performance over time (P. W. Duncan et al., 1990). It measures the distance an individual can reach in the forward direction from a comfortable standing posture without experiencing a loss of balance. The administration of the test followed previously described procedures (P. W. Duncan et al., 1990). The participants were asked to flex the shoulder of their dominant arm, with the elbow joint fully extended, and then to reach as far as possible without taking a step, while ensuring that their heels remain in contact with the ground. A metre measure was mounted horizontally on the wall at the same height as the acromion. Reach distance was measured as the displacement of the most distal part of the hand from the initial to the end position (P. W. Duncan et al., 1990) . Three trials were undertaken. The first attempt was employed as a practice trial to familiarize the participant with the procedure. The mean value of the two subsequent trials was used for analysis. An inability to reach more than 15 centimetres indicates a high fall risk and frailty (Weiner et al., 1992).

Comorbidity

The Charlson Comorbidity Index (CCI) was employed in the current study to measure comorbidity (ME Charlson, Pompei, Ales, & MacKenzie, 1987) . It consists of 19 comorbid conditions, such as cardiovascular disease, dementia, diabetes, and chronic pulmonary diseases. The age-adjusted CCI was calculated using a previously reported method (Charlson, Szatrowski, Peterson, & Gold, 1994) , in which comorbid conditions were weighted and scored, with additional points added for age. A score of 0-1 was considered low and a CCI of ≥ 2 was regarded as high (Ofori-Asenso et al., 2018). CCI scores of 0, 1-2, 3-4, and ≥5 represent comorbidity levels of none, low, medium, and high, respectively. In the medical literature, CCI is the most extensively studied as well as the most widely used index for studying comorbidity (Maringe, Fowler, Rachet, & Luque-Fernandez, 2017). CCI has also been validated in an older population in Hong Kong (Chan, Luk, Chu, & Chan, 2014).

Statistical Analysis

To identify the characteristics of body size and shape most closely associated with the three physical performance (PP) variables (handgrip strength, TUG, functional reach test) and the CCI in this older population, as well as any differences in the population (sex, age group), we adopted the following multiplicative model (Eq. 1) with allometric body size components. This model is similar to one that has been used to model the physical performance variables of Greek and Peruvian children (Bustamante Valdivia, Maia, & Nevill, 2015; Nevill, Tsiotra, Tsimeas, & Koutedakis, 2009), as well as older adults (Duncan, Mota, Carvalho, & Nevill, 2015).

$$Y = a \cdot mass^{k_1} \cdot height^{k_2}\, waist^{k_3} \cdot \varepsilon \qquad \text{(Eq. 1)}$$

where k_1, k_2, and k_3 are the mass, height, and waist exponents and 'a' is the intercept parameter that is allowed to vary between groups (sex, age group, etc.). This model has the advantage of having proportional body-size components that will identify the most appropriate height-to-weight-to-waist ratio associated with different measures of physical performance (Y). Note that 'ε', the multiplicative error ratio, where the assumption is that the error will increase in proportion to the physical performance variables (PP) or CCI dependent variables Y; see, for example, the heteroscedasticity present in Fig. 5. (Heteroscedasticity refers to data with unequal variability scattered across a second, predictor variable)

The model (Eq. 1) can be linearized with a log transformation. A linear regression analysis on log(Y) can then be used to estimate the unknown parameters of the log transformed model (i.e., the transformed model 2 is now additive, which conforms with the assumptions associated with ordinary least squares):

$$\log(PP) = \log(a) + k_1 \cdot \log(height) + k_2 \cdot \log(mass) + k_3 \cdot \log(waist) + \log(\varepsilon). \qquad \text{(Eq. 2)}$$

Further categorical or group differences within the population (e.g., sex and age group) can be explored by allowing the constant intercept parameter 'log(a)' in Eq. 2 to vary for each group (by introducing them as fixed factors within an ANCOVA) using log(height), log(mass), and log(waist) as covariates. Having fitted the saturated model (all available variables including sex, age group, and the age-by-sex interaction plus the three body size dimensions), an appropriate 'parsimonious' model can be obtained using '*backward elimination*' (Draper and Smith, 1981), in which at each step the least important (non-significant) body size variable is dropped from the current model. Statistical Packages for the Social Science (SPSS) version 20 was used in all analyses, and the level of significance was set at $P < 0.05$.

The influence of body size, composition, and shape in physical performance tests in older adults is a matter of continuing debate (Tomas, Galan-Mercant, Carnero, & Fernandes, 2018). To investigate which body size/shape characteristics and type of physical performance (HG, TUG, and FR) would best be able to explain and predict the comorbidity in the sample, the multiplicative allometric model (Eq. 1) was expanded to incorporate the physical performance variables (HG, TUG, and FR) as follows:

$$CCI = a \cdot mass^{k_1} \cdot height^{k_2}\ waist^{k_3} \cdot HG^{k_4} \cdot TUG^{k_5}\ FR^{k_6} \cdot \varepsilon \qquad \text{(Eq. 1a)}$$

where k_4, k_5, and k_6 are the additional HG, TUG, and FR exponents. As before, 'a' is the intercept parameter that is allowed to vary between groups (sex, age group, etc.). The model (Eq. 1a) can be linearized with a log transformation and linear regression analysis or ANCOVA can then be used to estimate the unknown parameters of the log transformed model, i.e., by allowing sex and age group as fixed factors in the ANCOVA and using log(height), log(mass), log(waist), log(HG), log(TUG), and log(FR), as covariates.

The allometric approach is a suitable model to use to answer our research questions, given its sound theoretical basis and versatile statistical methodology (Nevill 1997; Nevill et al. 2004). This technique can be used in comparisons between groups that differ in size, structure, and body shape (Nevill, Ramsbottom, & Williams, 1992).

Results

Participant characteristics

A total of 432 older adults (mean age = 78.0 ± 9.0 years) participated in this study. The majority lived in the community (71.8%), were female (71.5%), retired (78.5%), non-smokers (86.6%), and non-drinkers (92.6%). Almost half had an educational attainment of secondary school or lower (56.7%). The mean number of chronic diseases that they had been diagnosed with was 3.1 ± 1.9. The number of people (373 out of the total of 432 = 87%) had two or fewer comorbidities, as measured using the CCI. The three most common comorbidities found in this sample of participants were diabetes (25.2%), cardiovascular disease (17.4%), and connective tissue disease (8.1%). Details of the demographic characteristics and health conditions of the participants are shown in Table 1.

---Table 1 about here---

Results to explain Aim 1

Handgrip strength

To examine which anthropometric index best explained functional performance in the sample, we compared the results of the handgrip strength test, the TUG test, and the functional reach test. Concerning the handgrip strength test, the multiplicative model relating handgrip strength (kg) (Eq. 3) to the body size components was found to be:

$$\text{Handgrip strength (kg)} = a \cdot \text{mass}^{1.08} \cdot \text{height}^{1.72} \cdot \text{waist}^{-1.35}, \qquad \text{(Eq. 3)}$$

with the mass, height, and waist exponents being $k_1 = 1.084$ (SEE = 0.210), $k_2 = 1.717$ (SEE = 0.654), and $k_3 = -1.345$ (SE = 0.252), respectively. Note that the mass and height exponents were both positive, but the waist exponent was negative. The adjusted coefficient of determination, adjusted R^2, was 40.2%. The constant ‘a’ varied by sex and age group, but no interaction was identified between age group and sex ($p > 0.05$), as seen in Fig. 1 below.

---Figure 1 about here---

Timed Up and Go (TUG) Test

The multiplicative model relating the TUG(s) (Eq. 4) to the body size components was found to be:

$$\text{Timed get up and go test(s)} = a \cdot \text{height}^{-0.914} \cdot \text{waist}^{0.779}, \qquad \text{(Eq. 4)}$$

with the height and waist exponents being $k_2 = -0.914$ (SEE = 0.451) and $k_3 = 0.779$ (SE = 0.174), respectively. Note that, for this test, the waist exponent was positive but the height exponent was negative. The adjusted coefficient of determination, adjusted R^2, was 29.1%. The constant 'a' varied by age group alone, a trend that increased with each age group and that was common to both males and females, as seen in Fig. 2 below.

---Figure 2 about here---

Functional Reach

The multiplicative model relating the functional reach test (cm) (Eq. 5) to the body size components was found to be:

$$\text{Functional reach test (cm)} = a \cdot \text{mass}^{0.894} \cdot \text{waist}^{-1.315}, \qquad \text{(Eq. 5)}$$

with the mass and waist exponents being $k_1 = 0.894$ (SEE = 0.261) and $k_3 = -1.315$ (SE = 0.334), respectively. Note that, for this test, the mass exponent was positive but the waist exponent was negative. The adjusted coefficient of determination, adjusted R^2, was 15.5%. The constant 'a' varied by age group alone, a trend that increased with each age group and that was common to both male and females, as seen in Fig. 3 below.

---Figure 3 about here---

In addressing the first research question, handgrip was found to have the greatest explanatory power on functional performance.

Results to explain Aim 2

Comorbidity

The second research question attempts to examine which anthropometric index best explained comorbidity. Here, the multiplicative model (Eq. 1) was also adopted to identify the optimal body size and shape characteristics associated with the CCI and the three body size components. The parsimonious solution (Eq. 6) was found to be as follows:

$$CCI = a \cdot mass^{-0.295} \cdot waist^{0.564}, \quad \text{(Eq. 6)}$$

with the mass and waist exponents being k_1 = -0.295 (SEE = 0.117) and k_3 = 0.564 (SE = 0.149), respectively. Note that, for this test, the mass exponent was negative but the waist exponent was positive. The adjusted coefficient of determination, adjusted R^2, was 55.3%. The constant 'a' varied by age group and sex (main effects, no interaction), a trend that increased with each age group and that was greater for males than for females, as seen in Fig. 4 below. Table 2 shows the TUG scores in seconds by age group and sex.

---Figure 4 about here---

Results to explain Aim 3

To investigate which body size/shape characteristics AND physical performance test (HG, TUG, and FR) were best able to explain the comorbidity in the sample, the multiplicative allometric model (Eq. 1a) identified the following parsimonious solution (Eq. 7) requiring just one physical performance variable (TUG) covariate to predict CCI:

$$CCI = a \cdot TUG^{0.184}, \quad \text{(Eq. 7)}$$

with the TUG exponent being k = 0.184 (SEE = 0.032). The adjusted coefficient of determination, adjusted R^2, was 58.2%. The association between CCI and TUG can clearly be seen in Figure 5. Note that the heteroscedastic errors observed in Fig. 5 fully support the need to adopt the log-linear allometric modelling approach as described in the methods section, i.e., the 'shot-gun' effect, where CCI clearly increases with greater TUG times that will naturally be controlled by taking logs. The constant 'a' varied by age group alone, a trend that increased with each age group and that was common to both males and females, as seen in Fig. 6 below.

---Figure 5 and 6 about here---

Discussion

This study determined which anthropometric index best explained/predicted functional performance and comorbidity in a sample of older adults from Hong Kong, and then examined which functional performance test best explained/predicted comorbidity in the same sample. Although there are a number of studies (Garin et al., 2014; Ryan et al., 2015) that have examined comorbidity and functional performance in older age, no study to date has used the allometric approach (e.g., body weight and waist circumference) documented in the current study. As such, the results of the current study extend the understanding of how body shape relates to functionality and comorbidity in older adults.

Allometric scaling, as used here, enables scientists and clinicians to account for known differences in body size when examining health-related variables, making it possible to better quantify the impact of age on these variables. The changes in body composition and, subsequently, body shape due to ageing are well established (Montero-Fernandez & Serra-Rexach, 2013). However, researchers continue to favor BMI as the main anthropometric measure of adiposity in older adults, despite known changes in central adiposity as age increases (Chang et al., 2012). Although other anthropometric measures have been used in the context of comorbidity, the resulting data are equivocal (Chang et al., 2012). The present study provides additional clarity with regard to the body shape that best explains functional performance and comorbidity in this sample of older adults in Hong Kong.

In addressing the first research question, our results suggest that there are different body shape contributors (height, body mass, and waist circumference) to each of the functional tests that were examined. Handgrip strength was best explained by a height times mass divided by waist circumference ratio. Clearly, being taller and heavier but with as little waist adiposity as possible with benefit handgrip strength performances. Similarly, TUG performance was best explained by a height-to-waist circumference ratio. Here, the faster performances (interpreted as a speed of $m.s^{-1}$, not measured simply in terms of time, as reported in Eq. 4) would be achieved by taller but more slender individuals. In order to provide a physiological interpretation of the coefficients reported in Equations 3-5, Astrand and Rodahl (1986, Table 9.1, p406) have provided an insight into dimensions in physics and physiology that relate to the three performance tests in the current study. In their classification L is a linear dimension of body size, L2 cross sectional area and L3 is a volumetric dimension such as body mass. In equation 3, for handgrip strength, the sum of the exponents equates to L3 in terms of Astrand and Rodahl's classification (i.e., three dimensions). This reflects the energy requirement to perform the movement. While it may have been anticipated that cross sectional area (L2) would have been predominant in explaining handgrip strength, the current study suggests that for this population, performance relies on three dimensions reflecting the overall energy requirements needed to perform the action. Equation 4 predicted TUG is proportional to approximately height divided by waist. Velocity, as is the case in TUG performance relates to a dimensionless function which agrees with the observations in the current study. The coefficients for functional reach (equation 5) predominantly reflect a linear dimension with small contribution from cross sectional area, according to Astrand and Rodahl's (1986) classification. Such a finding is logical with functional reach being a product of body length (height), with contribution from the body's cross- sectional area (waist circumference).

When data relating to comorbidity were examined to address the second research question, CCI scores were best explained or predicted by a positive waist circumference exponent and a negative body mass exponent, i.e., waist-to-mass ratio, where increased waist circumference per body mass was associated with greater comorbidity (see Eq. 6). The results of the present study suggest that comorbidity scores would increase in instances where there is a lower body mass but increased waist circumference. This would be indicative of increased central adiposity and/or a decrease in total muscle mass and be congruent with prior research (Montero-Fernandez & Serra-Rexach, 2013).

The third aim of the present study was to examine the utility of the three functional tests (HG, TUG, & FR) assessed here to explain comorbidity. All three tests are commonly used in the literature because they relate to independent living and are considered key functional indicators for older adults (Unhjem, van den Hoven, Nygard, Hoff, & Wang, 2019). When we examined CCI scores along with height, mass, waist circumference, and the scores for the three functional performance tests, a parsimonious model was revealed where only TUG was required to predict comorbidity. This finding has a number of important implications. The TUG reflects a combination of measures of muscular strength, gait speed, and agility, and therefore provides a holistic measure of functional motor performance for older adults. In order to perform well on the TUG test, an individual needs to have the capacity to generate high muscle force as quickly as possible, alongside dynamic balance – qualities that have been identified as essential for good functioning during older adulthood (Unhjem et al., 2019). Individuals with a more favorable body shape, i.e., a smaller waist circumference and body mass within the normal range, will also perform better on this test. Furthermore, scores on the TUG test could potentially be used to pre-screen for comorbidity in community settings.

Health professionals need to be mindful of co-existing conditions when seeing patients who seek medical attention for a particular condition. Even though people may consult a doctor for a primary condition, they may not be aware of other co-existing medical problems. The issue of multi-morbidity is a growing global health concern (Academy of Medical Sciences, 2018). The prevalence of multi-morbidities among older people in low-resource, low-income countries has been found to be high, for instance, reaching a level of 53.8% in rural Bangladesh (Khanam et al., 2011). Unfortunately, as previously mentioned, awareness of chronic diseases among patients is low despite more than 80% of older people have more than one medical condition. TUG is therefore potentially useful for promoting public and community health because it is a low-cost and time-efficient test and, based on the current study, has clinical relevance for healthcare for ageing populations.

The mean TUG score of our sample was 16.3 (SD 11.9) seconds. In Asia, the mean TUG value was 13.3 seconds among community-dwelling elderly aged 65 and older in Taiwan (Lin et al., 2004). Older people with a TUG score reflecting poorer functional mobility (long duration in seconds) are more likely to be at risk of a higher level of comorbidities. A trend of age-related declines in mean TUG test scores has been observed among both male and female subjects (Steffen, Hacker, & Mollinger, 2002), and was also noted in our study.

Nurses are regarded as well positioned to advance primary care (Flaherty & Bartels, 2019). Early signs of a poor TUG performance should prompt nurses and other healthcare providers such as community health workers under their supervision to make further assessments, as well as to implement interventions to prevent deterioration in a person’s condition.

There are, of course, limitations to the current study. The cross-sectional sample prevents a determination of causality, i.e., does an increase in waist circumference result in poorer functional performance or does impaired functionality result in reduced mobility, leading to an increase in waist circumference? The sample size was not large and the sample was recruited through convenience sampling, thus the generalizability of the findings needs further testing.

Conclusion

In summary, the current study suggests that a person's performance in the TUG test can identify that person's risk of reporting comorbidities. No other anthropometric or body size/shape variables have been found to improve the prediction model. The elements that are required to perform well in the TUG test, such as the ability of an individual to make dynamic movements of his/her body mass as quickly as possible, may better differentiate comorbidity than static functional tests. Thus, for an older population, the TUG test has the potential to act as a screening tool for the identification and prevention of chronic diseases, and is particularly relevant for clinical settings with high patient volumes, as well as for low-resource, low-income countries. Further investigations of the predictive ability of the TUG test may give primary care nurses a useful tool to use in screening patients with comorbidities of which they are unaware.

Abbreviations

ABSI: A Body Shape Index; AMT: Abbreviated Mental Test; ANCOVA: Analysis of Covariance; BMI: Body Mass Index; BRI: Body Roundness Index; CCI: Charlson Comorbidity Index; NGOs: Non-Governmental Organizations; PP: Physical Performance; SE: Standard Error; SEE: Standard Error of Estimation; SPSS: Statistical Packages for the Social Science; TUG: Timed Up and Go; WC: Waist Circumference; WHR: Waist to Hip Ratio

Declarations

Ethics approval and consent to participate

Ethics approvals for this study were obtained from the Human Subjects Ethics Sub-committee (HSESC) of The Hong Kong Polytechnic University and from all participating non-governmental organizations prior to the collection of data. All of the participants completed a written informed consent form indicating their willingness to participate in this study.

Consent for publication

Not applicable.

Availability of data

Requests for the datasets used during the current study will be considered by the corresponding author on reasonable request.

Competing interests

The authors declare that they have no conflicts of interest.

Authors' contributions

AN: developed prediction models, reviewed the results, and drafted and reviewed the manuscript. MD: developed prediction models, reviewed the results, and drafted and reviewed the manuscript. DC: collected data, conducted the initial data analysis, reviewed the results, and drafted and reviewed the manuscript. AW: co-drafted the study proposal, co-designed the study, developed the questionnaire, collected data, conducted the initial data analysis, reviewed the results, and drafted and reviewed the manuscript. RK: collected data, conducted the initial data analysis, reviewed the results, and drafted and reviewed the manuscript. CL: drafted the study proposal, designed the study, developed the questionnaire, collected data, conducted the initial data analysis, reviewed the results, and drafted and reviewed the manuscript. All of the authors read and approved the final manuscript.

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FIGURE CAPTIONS

Figure 1. The mean (± SE) log-transformed handgrip strength (kg) by age group and sex, adjusted for differences in log(mass), log(height), and log(waist).

Figure 2 The mean (±SE) result in the log-transformed Timed Up and Go test (sec) by age group, adjusted for differences in log(height) and log(waist).

Figure 3 The mean (±SE) result of the log-transformed functional reach test (cm) by age group, adjusted for differences in log(mass) and log(waist).

Figure 4 The mean (±SE) result of the log-transformed Charlson Comorbidity Index (CCI) by age group and sex (main effects, no interaction), having controlled for log(mass) and log(waist).

Figure 5 The Charlson Comorbidity Index (CCI) versus the Timed Up and Go test (TUG) results (sec)

Figure 6 The mean (±SE) result in the log-transformed Charlson Comorbidity Index (CCI) by age group, adjusted for differences in log(TUG) test results

TABLE CAPTIONS

Table 1 Details of the demographic characteristics and health conditions of the participants (N=432).

Table 2 TUG scores in seconds by age group and sex.