Review of Tools and Technologies to Assess Multi-System Functional Impairment and Frailty

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Abstract: The term 'frailty' has often been used—by clinicians and researchers alike—to characterize the most vulnerable and weak amongst the elderly. The treatment and care of this subgroup of older individuals presents the most challenge to clinicians and other health care professionals. Although there is no clear consensus on the issue of definition of frailty, most definitions emphasize the multi-system functional impairment and increased vulnerability to stressors.
In order to intervene early and reverse or delay the decline in functional (physical and mental) capacity, it is of utmost importance to diagnose and objectively quantify the degree of functional deficit. This article aims to take an holistic approach by reviewing current and emerging tools and technologies available to assess multi-system functional impairment in older adults. Several widely-used indices of frailty, tests of physical function, and questionnaires to assess quality of daily life, nutritional status and mental and emotional functioning in older adults will be discussed in brief. Finally one emerging technology, accelerometry, which may enable the early diagnosis of loss of functional capacity as well as provide the ability to objectively quantify the degree of deficit in both clinical and non-clinical environments, will be described.

Keywords: frailty, mobility, ageing, physical function, monitoring, accelerometers

Understanding Frailty

The term frailty is commonly used to indicate the increased risk for adverse health outcomes such as disability, morbidity, or mortality in older persons. To date, there is no clear consensus on the definition of frailty; however it has been proposed that frailty be defined as a collection of factors linked to a state of reduced physiological reserve resulting in decreased capacity to withstand environmental stress.[1] There is, in addition, growing agreement among experts that frailty is a distinct syndrome which occurs in a subset of highly vulnerable elderly individuals who are at increased risk of dependency and hospitalisation and decreased life expectancy.[2–4] In fact age-related frailty is present in 20%–30% of the population over the age of 75 years and increases significantly with advancing age.[5] As the world population continues to age, disability is an increasingly important concept for public health both as a contributor to adverse health outcomes and increasing health care costs, as well as for its negative impact on quality of life of the older population.

Although frailty is considered—by some researchers and clinicians—a syndrome distinct from disability or comorbidity (multiple pathology) there is a clear relationship between these three geriatric conditions[2]; comorbidity is considered a risk factor for frailty and disability is an outcome of frailty. In fact, disability and frailty share many characteristics including their increased prevalence in advanced age, multifactorial nature and common risk factors.[6] Among the elderly population over 70 years of age, 20%–30% report reduction in mobility, functional capacity and/or basic activities of daily life (ADL) such as bathing, dressing and walking.[7] In 2001, this corresponded to in excess of seven million chronically disabled Americans over the age of 65 years.[8] However, the prevalence of chronic disability in the U.S. elderly population is declining; the age-adjusted prevalence in chronic disability amongst Americans has declined from 26.5% in 1982 to an estimated 19.0% in 2004 despite the growth of the elderly population by 34.6% in this period.[9] Evidence suggests that the recent decline in disability rates is due to advances in biomedical research and its translation into clinical innovations, including identifying and controlling risk factors and diagnosing and monitoring early disease states.

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Diagnosing Impaired Function

Preventing loss of function and disability in the elderly is a primary objective of geriatric medicine. In order to prevent the development or progression of frailty and disability, functional assessment is critical in evaluating both current and prospective health of elderly individuals; mobility or balance problems detected by functional tests predict future development of disability, falls, hip fractures and mortality. However, the way in which functional capacity and/or disability are defined and assessed has remained controversial. To date, several definitions have been made, very few of which have been directly compared. One widely-adopted definition of disability is a reported difficulty or dependence in carrying out tasks required for independent living including activities important for an individual's quality of life.[3] Diagnosis of disability and/or functional capacity currently utilizes self-report questionnaires or performance-based tests including measures of mobility, muscle strength, balance or sensory functions. These physical performance tests and scores have been proven reliable and validated for predicting outcomes such as institutionalisation, hospitalization, falls, mortality, and disability.[10–14] These tests are recommended for screening purposes in individuals aged 70 years and older.[15,10]

In order to make best use of available resources as well as to undertake appropriate preventive measures and treatment for various manifestations of frailty, diagnosis and quantitative assessment are critically important. The method of choice for assessment of frailty depends on factors such as expertise available, clinical or community infrastructure and resources, on the operational definition of 'frailty'; One school of thought considers 'frailty' as a multi-system impairment and integrates multiple domains that include physical and cognitive decline, mood disturbances, nutritional deficiencies, sensory decline and poor social conditions, whilst other definitions are based solely on the physical aspects and use assessment methods such as gait speed and grip strength, as examples. Due to the variable existing definitions of frailty, here we take an holistic approach by briefly considering several widely-used indices, tests of physical function, and questionnaires to assess quality of daily life, nutritional status and mental and emotional functioning in older adults. We will conclude this brief review by describing one emerging technology, accelerometry, which may enable the early diagnosis of loss of functional capacity as well as provide the ability to objectively quantify the degree of deficit in both clinical and non-clinical environments. In the following section we will start by reviewing several commonly used frailty indices.

Frailty indices

Fried criteria

Fried et al.[2] have proposed a physical phenotype of frailty based on the work done in WHAS (Women's Health and Ageing Study) and CHS (Cardiovascular Health Study). The criteria used are unintentional weight loss, self reported exhaustion, weakness as measured by grip strength, low walking speed and low physical activity. The presence of three or more criteria identified the physically frail phenotype and predicted the adverse outcomes such as disability, falls, hospitalization and death.

Study of Osteoporotic Fractures (SOF) index

Ensurd et al[16] recently reported one of the few studies to compare two frailty indices, in this case the criteria derived from the CHS and the Study of Osteoporotic Fractures (SOF) index. Frailty defined by the SOF index included presence of two out of three criteria: (1) weight loss of 5% or more between exams an average of two-years apart; (2) weakness defined by grip strength (see summary section below); and (3) reduced energy levels (by self-assessment). Correlations between this index and the CHS criteria for associations with increased risk of adverse outcomes such as falls, diability, fracture and death were high. Due to the simplicity of this index, it may provide a useful definition of frailty for use in clinical practice.

SPPB

Guralnik and colleagues[17,18] validated a lower extremity performance-based battery in the Established Population for Epidemiologic Studies of the Elderly (EPESE) cohort, which consists of gait speed, repeated chair stands and hierarchical balance tests. The researchers found that this battery (Short Physical Performance Battery, SPPB) accurately predicts disability across diverse populations.[10]

Frailty Index and CHSA Clinical Frailty Scale

The 'Frailty Index' is a count of 70 clinical deficits from the CSHA (Canadian Study of Health and Ageing) clinical assessment.[19] The deficits include the presence and severity of current diseases, ability in carrying out activities of daily living (ADL) and physical signs from clinical and neurological exams. The clinical scale for assessment of frailty proposed by Rockwood and colleagues is a seven point scale based on 70 points in Frailty Index. The scale is divided into several categories or classes, namely:

1. Very fit—robust, active, energetic and fit;
2. Well—without active disease but less fit than people in Category 1;
3. Well—with treated, comorbid disease;
4. Apparently vulnerable, but not frankly dependent;
5. Mildly frail with limited dependency on others for instrumental activities of daily living (IADL);
6. Moderately frail, with assistance required for IADL and ADL;
7. Severely frail—entirely dependent on others and/or terminally ill.

Tests of physical function

Assessment of specific components of physical function includes a number of tests such as gait speed, balance assessment, muscle (grip) strength and tests for lower extremity performance. Administration of these tests usually involves the researcher or physician asking the subject to complete specific tasks and then grading the subject's ability to complete those actions. Mobility problems detected by functional tests predict the development of more severe disability and injurious events such as falls and hip fractures. Here we will summarise examples of widely-used tests to assess individual parameters of physical function.

Gait speed

Gait speed has been commonly used as one of the most important criteria for assessment of functional decline in the elderly population. Gait is a highly complex function that requires integration of mechanisms of locomotion with motor control, musculoskeletal function, balance and posture.[20] A number of approaches have been used in the community and clinical setting for gait analysis such as a walk of eight-feet in distance, a six-minute walk test (6MWT) and a 'timed up and go' test (TUG) discussed below.

An eight-foot walk is an integral part of the SPPB tests and has been shown to perform almost as well as the full battery in predicting incident disability.[10] Another test, the 6MWT, is a practical, simple test that measures the distance that a person can quickly walk on a flat, hard surface in a period of six minutes. The advantage of this test compared to the eight-foot walk is that it evaluates the global and integrated responses of all the systems involved during exercise, including the pulmonary and cardiovascular systems, systemic circulation, peripheral circulation, blood, neuromuscular units, and muscle metabolism. The self-paced 6MWT further assesses the submaximal level of functional capacity. Most participants do not achieve maximal exercise capacity during the 6MWT. However, because most activities of daily living (ADL) are performed at submaximal levels of exertion, the 6MWD may better reflect the functional exercise level for daily physical activities.[21]

Standing from sitting position and balance

A number of tests for balance and for lower extremity function are used as a part of functional assessment of the elderly. Chair stand is a part of SPPB and evaluates time required to stand up five times from a sitting position from a chair. This test gives an understanding of lower extremity function and strength. In contrast, the TUG test combines several tasks. The subject is requested to stand-up from a seated position on a chair, walk a fixed distance, turn around, walk back to the chair and sit-down in the starting position. The TUG test is an indicator of both motor ability and dynamic balance, both of which are important for a number of common mobility tasks, such as recovering after tripping and being able to walk across the street before the pedestrian crossing signal turns red, in addition to a variety of recreational and sports activities.

Balance tests

Balance is one of the most important aspects of physical performance and is responsible for maintaining ADL and preventing falls and subsequent disability. Balance deficits in the elderly can arise from the ageing process, such as from age-related changes associated with the sensory system (vestibular, visual, sensory) or diseases including cerebrovascular disease, arthritis, peripheral neuropathies or disuse due to immobility.[22] Impaired balance has been shown to be associated with falls[23] and predicts future disability.[18]

Hierarchical balance tests consist of three types of balance testing: feet side-by-side, semi-tandem and full tandem. These tests are included in the SPPB.

The Berg balance test is a 14-item scale designed to identify and evaluate balance impairments in older adults in a clinical setting.[22,24] The scale consists of fourteen tasks in everyday life that test the ability to maintain positions or movements of increasing difficulty. The test is designed to be used by a range of health care professionals such as physicians, nurses, and physiotherapists. Another tool to assess gait and balance in the elderly was developed by Tinetti et al.[25] The Tinetti mobility score is a combined score of gait and balance and identifies the risk of falling.

Grip strength

Hand-grip strength is an estimate of isometric strength in the upper extremity but it also correlates with strength in other muscle groups[26] and therefore has been used extensively as an estimate of 'overall strength'. A number of cross-sectional and longitudinal studies have shown that muscle strength in adults declines with increasing age among both men and women.[27–29] Also, grip strength has proved to be a strong predictor of phenotypes of special interest amongst the elderly, such as physical functioning and disability,[26,30,31] morbidity[32] and mortality.[33–35]

Questionnaires to assess functional capacity and/or quality of daily life

Although any of the functional assessment tests mentioned above will identify individuals with a higher risk of functional decline, it is of critical importance to further investigate the impact of this functional decline on the quality of life and independence. This will aid in identifying the individual's need for care and will direct towards appropriate medical assistance and intervention.

ADL (Activities of Daily Living) and IADL (Instrumental Activities of Daily Living)

The *Katz Index of Independence in Activities of Daily Living*[36] is an instrument that assesses an individual's ability to perform activities of daily life independently. The index uses six functions: bathing, dressing, use of toilet facilities, transferring, continence and feeding. Though the index is brief and reliable, it is not very sensitive to changes[37] and thus may not be appropriate for follow-up assessment.

Instrumental Activities of Daily Living (IADL) are activities related to independent living and include preparing meals, managing money, shopping for groceries or personal items, performing light or heavy housework, and using a telephone. Participants are scored based on their ability to carry out these activities independently without assistance from caregivers. The *Lawton-Brody Instrument Activities of Daily Living*[38] is further used to assess independent living skills. These skills are more complex than ADL, and include eight domains of function such as shopping, ability to launder clothing, food preparation, housekeeping and ability to handle finances.

Frailty wheel

The *Frailty Wheel* developed by the Kaiser Permanente Center for Health Research is a hand-held tool used to identify individuals with a high probability for dependency on others for daily care within the next 12 months. Questions related to medication assistance, bathing assistance and how their health conditions affect their everyday life assess the risk of frailty.[39] Although the Frailty Wheel has been found to be reliable and easy to use, its predictive validity has not been fully tested.

Assessing nutritional status

Nutrition has long been recognised an important component of healthy ageing. In fact, many frailty indices such as CHS, CSHA and WHAS include information regarding nutrition, in particular weight loss/low BMI.[5] Undernutrition, usually seen in frail elderly, can result in loss of muscle and bone mass and a compromised immune system, leading to functional impairment. However, the progression of undernutrition is often insidious; Early screening for undernutrition provides an opportunity for correction of nutritional deficits and thus may improve aspects of function. The widely-used Mini Nutritional Assessment (MNA) is an 18-item tool used to assess nutritional risk; it includes anthropometric measurements (body mass index, mid-arm and calf circumferences, and weight loss), a dietary questionnaire (number of meals consumed, food and fluid intakes, and feeding autonomy), global assessment (lifestyle, medication, and mobility), and self-assessment (self-perception of health and nutrition). The MNA was designed and validated to rapidly assess the nutritional status of frail older persons (http://www.mna-elderly.com). The score of between 17 and 23.5 correlated with weight loss, poor appetite, functional and cognitive decline and adverse outcomes like hospitalization.[40]

Assessing mental and emotional status

Negative emotions or psychosocial status can influence a variety of health-related conditions. Results from a number of studies associate depressive symptoms with poor physical and mental functioning and chronic medical conditions. Negative emotions such as depression and anxiety have been linked to health outcomes such as cardiovascular disease, osteoporosis, arthritis, and type 2 diabetes and have been associated with increased morbidity and mortality.[41] For example,[42] Penninx et al. have demonstrated that amongst more than 1200 individuals aged over the age of 70, baseline depressive symptoms predicted physical decline in a four-year follow-up.

Additionally, decreased cognitive performance is generally considered an important component of the frailty phenotype. It has now been established that physical performance measures such as slow walking speed independently predict the time of onset of cognitive decline.[43] Furthermore, untreated, long term depression can lead to physical, cognitive and psycho-social impairments. Thus, an holistic definition of frailty that acknowledges a multi-system impairment should include assessments of mood and cognition, along with other tests for physical function and quality of daily living. There are several assessment tools utilized to measure these parameters; The most commonly applied are the mini-mental state examination (MMSE) and the geriatric depression scale (GDS).

The MMSE is the most commonly used instrument for screening cognitive function which comprises a brief 30-point questionnaire.[44] This examination is not suitable for making a diagnosis but can be used to indicate the presence of cognitive impairment. The MMSE provides measures of orientation, registration (immediate memory), short-term memory (but not long-term memory) as well as language functioning. It has been extensively validated and is quick to administer.

Depression is common in late life and is frequently attributed to physical frailty. Alternatively, it has been shown that depression predicts decline in physical function[45,42] demonstrating the complex relationship between mood and physical function. The GDS has been tested widely in the elderly population[46] and further developed to include a shorter version with only 15 questions that takes only five to seven minutes to complete.[47]

Use of accelerometry—an exemplar emerging technology

As previously discussed, a variety of clinical scales and indices are currently being used to assess frailty and function. There are a number of highly sophisticated tools and techniques that have been developed to assess the functional ability. These include kinesiological EMG, optoelectronic systems, force plate analysis and computerised gait/balance analysis tools (e.g. GAITRite® system). One of the important drawbacks of these emerging tools is the relative lack of objectivity in a number of the tests; Depending on the clinician's judgement, subjective assessment by the researcher and/or subject recall, has the potential to induce error and problems with universal applicability of these tests. Another problem with these technologies is the lack of testing of functional assessment in the 'real life' situation (e.g. gait abnormalities in free-living individuals). It is well-established that measurement of movement in a clinical setting may not accurately reflect functional ability in the subject's normal environment.[48] Additionally, the utility of these techniques is also limited by the time, skills and expense inherent to this type of testing.

Accelerometry is emerging as a valuable technique to provide real-time quantitative motion analysis in the free-living situation. Accelerometers are small, lightweight and portable. They respond to frequency and intensity of movement and are hence of great interest for ambulatory, free-living assessment of various types of movements and functional ability. Accelerometry technology has been used to analyse aspects of physical function such as body sway, walking speed, gait, and sit-to-stand movement in addition to measuring total daily physical activity (which are integral to both the CHS and SOF indices of frailty). Accelerometers also have the potential to provide unique macro-data such as patterns of daily activity and sleep which may provide information on quality of daily life. Thus, when measured in conjunction with habitual physical activity and other macro data, accelerometry may provide novel insight into the functional status of an individual and may thus correlate with accepted indices of frailty such as the CHS and SOF. In fact, use of accelerometers in detecting falls in free-living individuals has been proposed.[49] Although this is an active area of research, there is currently very little data available to assess the utility of accelerometers in this application.

In the following paragraphs we will briefly describe reported application of accelerometry (micro-data) to assess measures of physical function including gait, time to stand from sitting position and sway/balance.

Gait is one of the most important indicators of change in functional ability. Accelerometers mounted on a subject's waist, thigh and ankle have been used to measure simple parameters such as stride symmetry, walking speed and step length.[50–52] Test-retest reliability of a trunk mounted accelerometer was found to be acceptable for gait analysis.[53]

Additionally, the ability to stand up and sit down in a controlled manner is critically important for independent living. Accelerometry has further been used to describe kinematics during rising from a sitting position[54,55] tested the validity of accelerometry for assessing the duration of the sit to stand movement and found that accelerometry showed discriminative validity in comparing stroke patients to healthy subjects.

The ability to maintain balance requires integration of complex sensory systems and the strength of lower extremity. Postural sway analysis using accelerometry has been used as a measure of balance. Larger body sway magnitude and higher frequency was found to be indicative of postural instability.[56]

Taken together, accelerometers provide a valuable technology that can be used to objectively measure and characterize various functional parameters in a real-life (non-clinical) environment. Technologies such as these will need to be validated against a battery of currently used—and widely accepted—techniques and indices. Use of these newer tools should be assessed on their ability to 'stand alone'—or independently assess frailty and function—as well as to be included as an integral part of a battery of tests and clinical assessment tools. A number of prospective studies are necessary to investigate the usefulness of such battery of tests—which include clinical assessment, subjective tests, patient recall as well as objective measures—in predicting various outcomes of functional decline and frailty.

Concluding remarks

Frailty is associated with a multi-system impairment in function; thus holistic approaches should be undertaken to assess this spectra of clinical disorders. This article has reviewed current and emerging tools and technologies available for both clinicians and researchers to investigate the complex, multi-system impairment associated with loss of functional capacity in older adults. We have briefly reviewed widely-used indices of frailty, tests of physical function and questionnaires to assess quality of daily life, nutritional status and mental and emotional functioning. We envisage that emerging technologies such as accelerometry will enable the early diagnosis of loss of functional capacity as well as providing the ability to objectively quantify the degree of deficit in both clinical and non-clinical environments. It is hoped that improvements in assessment capability will then enable intervention strategies to reverse or delay age-related decline in physical and mental performance.

Disclosure

The authors report no conflicts of interest.

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