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Original Study

Gait Variability Related to Muscle Quality and Muscle Power Output in Frail Nonagenarian Older Adults

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ABSTRACT

Background: Frailty has become the center of attention of basic, clinical, and demographic research because of its incidence level and the gravity of adverse outcomes with age. Moreover, with advanced age, motor variability increases, particularly in gait. Muscle quality and muscle power seem to be closely associated with performance on functional tests in frail populations. Insight into the relationships among muscle power, muscle quality, and functional capacity could improve the quality of life in this population. In this study, the relationship between the quality of the muscle mass and muscle strength with gait performance in a frail population was examined.
Methods: Twenty-two institutionalized frail elderly individuals (93.1 $\pm$ 3.6) participated in this study. Muscle quality was measured by segmenting areas of high- and low-density fibers as observed in computed tomography images. The assessed functional outcomes were leg strength and power, velocity of gait, and kinematic gait parameters obtained from a tri-axial inertial sensor.
Findings: Our results showed that a greater number of high-density fibers, specifically those of the quadriceps femoris muscle, were associated with better gait performance in terms of step time variability, regularity, and symmetry. Additionally, gait variability was associated with muscle power. In contrast, no significant relationship was observed between gait velocity and either muscle quality or muscle power.
Interpretation: Gait pattern disorders could be explained by a deterioration of the lower limb muscles. It is known that an impaired gait is an important predictor of falls in older populations; thus, the loss of muscle quality and power could underlie the impairments in motor control and balance that lead to falls and adverse outcomes.

Research on frailty has grown over the past few decades.[1–3] The consequences of frailty range from loss of mobility, increased risk of falls,[4–6] and future mobility disability,[4,7] which affects dependence and leads to hospitalization and death.[3,8,9] One of the main causes of frailty syndrome is exacerbated sarcopenia and detrimental effect of increasing age on neuromuscular innervation, which causes a decline in overall physiological function.[1,2,10] Together with a reduction in muscle size, aging is associated with a decrease in muscle quality.[10,11] Although the loss of muscle mass is related to the decline in strength in older adults, strength and muscle power output occur more rapidly than the associated loss of muscle mass, suggesting a decline in muscle quality.[12]

Numerous studies stress the importance of quadriceps muscle strength in older persons for successful chair rise and gait performance.[13,14] Muscle quality and muscle power seem to be closely associated with performance on functional tests in elderly populations.[15]

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Nevertheless, although muscle size and quality are important parameters related to the functionality of older adults, these parameters are poorly investigated in the oldest elderly patients, a population in which frailty is highly prevalent.[16]

Moreover, with advanced age, there are increases in motor variability, particularly in gait.[17–19] Gait variability has been widely related to muscle system impairments.[20] It could be useful to understand the motor control of gait and to quantify alterations in the locomotor control system and functional capacity.[21] Although gait variability is already recognized as a significant predictor of falls in frail populations,[22,23] its relationship with decreased muscle quality and muscle strength is not yet clear. Accordingly, it would be interesting to assess the quality of the muscles associated with gait variability in this population.

Currently, an important research area linked to gait analysis is being developed to investigate frailty syndrome in an attempt to improve its diagnosis.[19,24] With this aim, the use of inertial sensors is a useful technique for analyzing human movements. Recent studies have demonstrated that the parameters obtained with these sensors during walking are significantly related to different motor deficiencies, frailty, Parkinson disorder, diabetes, and mild cognitive impairment.[25–27]

Insight into the relationships among muscle power, muscle quality, and functional capacity could improve exercise interventions aimed to enhance quality of life in this population. The purpose of this work was to examine the relationship of muscle quality and muscle strength/power with the variability, regularity, and symmetry of gait performance in a frail population. We hypothesized that frail individuals would present low muscle quality that correlates with variability in step time during walking in nonagenarians with frailty syndrome.

Methods

Experimental Design

This study was designed to evaluate the associations between thigh muscle quality and strength of the thigh and kinematic gait parameters with the goal of explaining gait disorders in frail populations. Computerized tomography (CT) images of the mid-thigh muscles and leg-strength tests were conducted to assess muscle quality and muscle capacity, respectively. Gait kinematics was assessed with a unique inertial accelerometer. This study is part of a larger project with the purpose of determining functional and morphological changes that are induced by exercise intervention.

Study Participants

The participants were institutionalized oldest among the elderly patients (older than 90 years) in the Pamplona area in Spain. They were included in the study according to the Fried criteria of frailty or robustness.[28] The Fried criterion of frailty was determined by the presence of 3 or more of the following components: slowness, weakness, weight loss, exhaustion, and low physical activity.[28] Individuals who showed 2 or fewer of these characteristics (prefrail and robust) were excluded from the study.

The other exclusion criteria were the diagnosis of dementia, disability (defined as a Barthel Index lower than 60, and inability to walk independently without the assistance of another person), recent cardiac arrest, unstable coronary syndrome, active cardiac failure, cardiac block, or any unstable medical condition.

The 24 elderly subjects who volunteered to participate in the study met the necessary requirements to join the study. They or their legal guardians completed an ethical consent form. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the Public University of Navarra, Spain.

The physical characteristics of the participants are presented in Table 1. The participants were transported from the geriatric nursing home to the hospital for CT assessments.

Gait Testing Procedures

The participants walked 7 m in a straight line without obstacles at a self-regulated speed. Measurements were obtained in a 5-m section, thus allowing a 1-m acceleration distance at the start and end of the path.

The results of the walking test were recorded using the acceleration data from an inertial Orientation Tracker MTx (XSENS; Xsens Technologies B.V., Enschede, Netherlands) attached over the lumbar spine (L3-L4). The inertial sensors most commonly used for motion capture are Micro-Electro-Mechanical System (MEMS) solid-state accelerometers, gyroscopes, and magnetometers. These sensors can be externally mounted on the participant at precise points of interest and provide, often in real-time, direct and accurate measurements of motion and posture. MTx itself combines 9 individual MEMS sensors to provide drift-free 3-dimensional (3D) orientation as well as kinematic data: 3D acceleration, 3D rate of turn (rate gyro), and 3D magnetometers.

Kinematic Parameters

The measured gait parameters, which have been related in the literature to gait disorders,[23,27,29–32] are as follows: gait symmetry, gait variability, and gait regularity. All of these parameters were obtained from the vertical (VT) acceleration as measured by the MTx unit.

Gait symmetry was obtained from the autocorrelation function of the acceleration signal x. The autocorrelation function is represented by a sequence of autocorrelation coefficients A over increasing time lags m (Equation 1). The autocorrelation coefficients were divided by the number of samples in the time series to obtain unbiased coefficients. Moreover, the samples of the autocorrelation were normalized to its maximum. The gait symmetry (Sym) is considered the difference between the prominence of the first peak ($Ad1$) and the second peak ($Ad2$) after the central (zero lag).

$$A = \frac{1}{N-|m|}\sum_{i}^{N-|m|} x_i x_{i+m} \qquad \text{Equation 1}$$

$$Sym = \frac{|Ad1 - Ad2|}{\max(Ad1, Ad2)} \qquad \text{Equation 2}$$

The gait variability can be estimated by calculating the coefficient of variation, CoV, of the step time, where $\bar{t}$ is the mean and σ is the SD.

$$CoV = \frac{\bar{t}}{\sigma} \qquad \text{Equation 3}$$

Table 1
Subject Characteristics

	Frail Participants, n = 24
Age, y	93.1 ± 3.6
Women/Men	18/6
Body mass, kg	55.2 ± 10.5
Height, cm	152.7 ± 9.8
Body mass index, kg/m^2	23.9 ± 1.5

Values are mean ± SD unless otherwise noted.