



Review Article

Effects of aging on biomechanical gait parameters in the healthy elderly and the risk of falling

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Abstract

The biomechanics of walking seems to be affected in the elderly compared to young adults. These adjustments are likely to be associated with an increase in the risk of falling. This review aims to investigate the effect of age on walking ability specifically focusing on studies that have assessed spatiotemporal, kinematics and kinetics variables using three-dimensional (3D) analysis. A systematic review of the research literature was applied until January 2019 across Pubmed electronic database. A targeted search strategy traced full papers that fulfilled the inclusion and exclusion criteria. Eleven of 214 articles met the predetermined inclusion criteria and were included in the review. Differences between older and young adults were found in the most parameters which were evaluated. Changes in the lower-limb walking kinematics in elderly during walking may compromise the quality of gait. However, there is a bibliographic gap, as there are no articles that assess the risk of falling taking into account joint kinematic and kinetic parameters.

Keywords: Falls, Gait disorders, Kinematics, Kinetics, Motion analysis

Introduction

Human gait is one of the most basic movements of the human body¹. It is the result of a series of rhythmic alternating movements of different segments of the body with the least energy expenditure, which leads to the forward propulsion of human body's center of gravity. It is a mechanism which depends upon closely integrated action of the musculoskeletal, cardiopulmonary and nervous system².

The maintenance of walking ability is important for older adults as it provides independence and is necessary to carry out several activities of daily life³. Normal aging brings about significant changes in the elderly gait pattern^{2,4}. Some researchers use the term "senile gait disorders" when referring to modifications in age-related biomechanical characteristics of gait⁵. The prevalence of walking disorders of the elderly over 70 years is estimated to be 35%⁶. However, 85% of people aged 60-69 years still walk normally, but only 20% of people aged over 85 years do⁷.

Age-related changes in biomechanical gait characteristics of elderly have been investigated in several studies, mainly using three dimensional gait analysis^{3,8-10}. The majority of these studies present comparable gait characteristics between younger and older age groups¹¹⁻¹⁵. Common

disorders affecting the gait pattern of elderly are the attenuation of postural reflexes, the poor posture control and the presence of a rigid and less coordinated gait pattern. Also, the poor posture in standing position as becomes more stooped with age displacing forward the body's center of gravity. Displacement of the center of gravity from the midpoint may lead to a balance lost².

Moreover, age-related gait modifications associated with reduced muscle strength and limited lower-limb joint range of motion as a result of physiological and neuromuscular changes¹⁶⁻²³. In particular, sarcopenia is a well-described effect of aging, which is characterized by a muscle atrophy (a decrease in the cross-sectional area) along with a reduction

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in muscle tissue quality due to replacement of muscle fibers with adipose tissue²⁴. This process may cause increased joint stiffness²⁵ whereas muscle mass loss is generally associated with muscle weakness²⁶. In addition, studies have shown that in normal aging greater co-activation of muscles is induced during walking in elderly adults²⁷. Muscle co-activation although it plays an important role in enhancing joint stabilization during activities such as walking²⁸⁻³⁰ is likely to be associated with increased walking energy cost²⁸.

In walking performance of elderly it is particularly important to take into account changes identified in the joint movement angles^{20,31-33}. From the biomechanical analysis of lower extremity activity a reduced hip and ankle range of motion in the sagittal plane has been observed during walking tasks^{5,34,35}. This is associated with changes observed in the joints kinetic data. Both the joints moments generated during the movement and the power are disrupted during the gait cycle³.

Differences were also observed in the spatio-temporal data of elderly walking should be considered³. The elderly compensate their reduced physical performance using some protective gait strategies^{2,36}. Specifically, the stance and gait base is widened. Elderly adults prefer a step with a 40% wider width than young persons³⁷, the feet are lifted less high during the swing phase and often shuffling walk is observed. The step length becomes shorter and the walking speed is reduced^{4,5}.

These findings show that elderly experience exacerbated declines in the biomechanical parameters of gait associated with their functional worsening³⁴. Difficulties in walking can be the precursors of falls, which is the most common cause of serious injuries in older age^{7,38}. Nearly one third of older adults aged over 65 fall at least once a year^{39,40}. Approximately 10-15% of these falls lead to serious injuries such as brain trauma⁴¹ or hip fractures^{7,42} and are associated with repeated hospitalizations and premature death⁴³.

Gait is a sensitive indicator of overall health status and is closely correlated with life expectancy in elderly adults⁴⁴. Gait abnormalities may lead to loss of autonomy, affect the social interaction, the sense of well-being and reduce quality of life^{5,45}. However, gait disturbances and falls are largely underdiagnosed and often receive inadequate assessment⁴⁶. For gait evaluation the spatio-temporal, kinematic and kinetic data collected by the three-dimensional gait analysis is of the utmost importance. The purpose of the present study was to examine through a systematic review of the literature the effect of normal aging on biomechanical parameters of gait which have been evaluated with the three-dimensional gait analysis.

Method

Search strategy

A systematic review of the research literature was applied until January 2019. The literature search was performed in the Pubmed electronic database. The search

strategy is presented below: "aging" OR elderly AND "gait" OR "locomotion" OR "walking" OR "gait disorders" OR "falls" AND "biomechanics" OR "kinematic" OR "kinetics" OR "three dimensional (3D) analysis".

Inclusion criteria for selection of the studies were determined a priori: In this systematic review original articles, written in English and referred to healthy elderly subjects were studied. Participants had to be healthy and able to ambulate independently. Studies were required to assess gait characteristics between elderly and young people in terms of spatial-temporal, kinematics and kinetics variables. The gait evaluation should be carried out through the three-dimensional gait analysis system (e.g. camera systems, wearable sensors, electronic walkways, force platforms). Both overground and treadmill walking were deemed acceptable.

Results

Review selection and identification

The initial search yielded 214 citations. Duplicates were then removed and 180 records remained. From titles and abstracts review were selected 18 articles for full text screening, of which 11 met the inclusion criteria and were included.

Of the eleven studies that focused on gait, nine studies compared healthy elderly subjects with healthy young adults^{16,20,27,47-52}. Two papers additionally examined age-related differences in gait characteristics between healthy older adults^{34,53}.

Study characteristics

All papers implied a specific measurement protocol with using 3D motion analysis system (MAS). The number of markers and cameras used was adequately provided in all studies. Seven papers reported the use of AMTI force platforms (Advanced Medical Technology Inc., 151 California Street, Newton)^{34,48-53} to determine gait kinetics and two papers reported the assessment of muscle activation during gait through 12-channel desktop direct transmission system sEMG device (Noraxon Inc., Scottsdale, AZ, USA)^{27,47}. The majority of studies reported overground walking and a specific gait protocol^{20,27,34,47-53} at a self-selected speed during walking. However in a study was selected treadmill walking¹⁶.

Measurement approach - Gait parameters

Eleven studies collected spatial-temporal data, eight studies reported kinematic data, seven studies assessed kinetic variables and two studies used electromyography.

Spatial-temporal variables

Eleven papers reported quantitative gait data, which included gait velocity (n=10), cadence (n=7), step length (n=4), step width (n=5), stride length (n=8), swing time

(n=1), stance time (n=3), levels of variability for the stride length and the stride time (n=1).

Gait Velocity - Among articles which reported gait velocity, nine found significant decrease in older persons in comparison with young persons^{16,20,27,34,47,50-53}, whereas one did not identify significant difference⁴⁹.

Cadence - Three paper identified a significant decrease in cadence for older persons^{16,27,47}, two papers identified significant increase in cadence for older persons^{52,53} and in two papers no significant differences were observed^{20,50}.

Step width - Older adults were observed to increase their step width during walking in tree studies^{27,34,47}, however Oliveira et al. (2017)¹⁶ observed a decrease in this variable.

Other variables which showed significant differences between older and young persons were that of stride length decreasing^{16,20,27,34,47,49,51,53}, step length decreasing^{20,49,50,52}, swing phases percentage decreasing²⁰, stance phases percentage increasing²⁰, single support time decreasing⁵².

Kinematic variables

There are considerable kinematic differences observed in various studies between older and young adults. Particularly with respect to changes in kinematic data, the elderly subjects walked with a greater anterior tilt of the pelvis^{51,52}. Age also appears to alter hip joint kinematics. Three paper identified a significant increase at mean values for the hip flexion at toe off¹⁶ as well as higher percent of the gait cycle for hip flexion^{34,52}. In addition, the elderly had reduced hip extension^{50,51}. An increase in knee flexion is observed at the initial contact in older adults walking^{16,50}. Between-group comparisons of joint ankle kinematics there are also significantly reduced mean values for the ankle dorsi flexion at heel strike¹⁶ and for the ankle plantar flexion during late stance and at toe off^{16,50-52}. Afiah et al. (2016)²⁰ found that in older adults the peak extension timing of the hip, peak flexion timing of the knee and peak plantar flexion timing of the ankle joint were significantly later. Should also be mentioned that in two studies there were no significant differences observed relative to the joint angle parameters between two groups^{48,20}.

Kinetic variables

From the literature review it was observed that there are significant differences in the findings between the kinetic variables.

Hip: Kim and colleagues⁵⁰ noted a lower hip extension moment with reduced hip extensors power at the loading phase in elderly but no statistical differences in the hip flexion moment. Kerrigan and colleagues⁵¹ report lower hip flexion moment stance of elderly. Judge et al.⁵² also reported that if the analysis was adjusted for differences in step length, older subjects developed 16% more hip flexor power than younger subjects. Older age was also associated with higher peak joint power in the adduction and abduction movements of the hip and knee⁵³.

Knee: Kerrigan et al. (1998)⁵¹ observed reduction in knee extension moment at initial contact, in knee flexion moment at midstance and in knee flexion moment at preswing. Also, identified significant decrease in knee power absorption at loading response, knee power generation at midstance and knee power absorption at preswing.

Ankle: A study by Kim et al. (2014)⁵⁰ noted that the ankle plantar flexion moment and the ankle plantar flexion power burst of elderly was slightly smaller than younger subjects. Ko et al. (2009)⁵³ reported that elderly have lower peak joint power in plantar flexion and dorsi flexion movements. Judge et al. (1996)⁵² recorded that elderly subjects developed 17% lower peak ankle plantar flexor power than young subjects.

Discussion

The aim of the present systematic review was to provide a comprehensive overview of studies that investigate the effect of normal aging on biomechanical parameters of gait which have been evaluated with the three-dimensional gait analysis. Overall, the results of the systematic review provides sound evidence that aging has a substantial impact on specific spatiotemporal, kinematics and kinetics variables.

An activity such as walking is an overall result of several movement parameters, and may be fairly representative of the individual's performance³. Documented changes in some walking parameters may be the most indicative gait adaptations selected by elderly and not the result of age-specific impairments³.

Reduced walking speed is the most consistent change associated with age⁵. Spontaneous walking speed is usually reduced by 1% per year from the age of 60 years onwards.^{54,55} Walking speed of less than 0.8 m/s are associated with limited ambulatory capability and walking speed equal to or less than 0.4 m/s is related with an inability to respond to daily life activities^{5,56}. It is important to mention that decrease in walking speed was associated with a 7% increased risk for falls⁶. It is considered a simple measure to detect changes in mobility⁵ and it is a good indicator of health and survival in older adults, especially after age 75^{2,57}.

The results regarding the walking cadence are not clear. Some studies reported a decrease and some increase in this variable. In addition, some studies have indicated that the elderly maintain a normal cadence during walking^{3,23,58,59}. Cadence maintenance are considered to be the result of generally high physical activity levels in older adults. When older participants have moderate physical activity, they also have better walking capacity⁵⁹. Consequently, it might be difficult to notice any significant difference in the cadence of the older adults.

From the review of the literature was observed smallest stride length in elderly. The average stride length in healthy adults ranges between 150 and 170 cm. Shorter stride length in very elderly is correlated with the short stature [59]. This

observation is also consistent with the results of previous studies^{32,58,60} in which/where it was observed that height are significantly associated with stride length and walking speed. Moreover, elderly prefer a 40% wider step width than young persons (average step width in elderly women about 8 cm and in elderly men 10 cm)³⁷. According to Maki (1997)³⁶ and contrary to common expectation, a wider stride does not necessarily increase stability but instead seems to predict an increased likelihood of experiencing falls.

Smaller percentages of swing phase observed in older adults may be the result of reductions in swing limb advancement as well as muscle power. The higher percentages of the support phase could be due to the decrease in the stability of trunk and lower extremities. Furthermore, increasing the percentage of the support phase propose that more time is required after the limb advancement so that older adults maintain weight-bearing stability⁵⁹. The aforementioned findings are supported by the results of previous studies^{61,62} showing/which indicate that elderly adopt a slower walking pattern.

For the elderly in gait analysis should also take into account kinematic and kinetic parameters. It has been found that many of the joints movements are typical for the gait patterns for the gait patterns of older adults^{58,59}. Kerrigan et al. (1998)⁵¹ and Judge et al. (1996)⁵² reported an increased anterior pelvic tilt, while Ko et al. (2010)³⁴ recorded reductions in the range of motion in the joints of hip, knee and ankle. Another important finding was that hip extension was significantly reduced. A decrease in hip extension has been recorded by Oliveira et al. (2017)¹⁶, Kim et al. (2014)⁵⁰ and Kerrigan et al. (1998)⁵¹ while Ko et al. (2010)³⁴ and Judge et al. (1996)⁵² found that the percent of the gait cycle for hip flexion were higher. A reduction in hip extension may imply a functional tightness that would be preventing the full extension of the hip mainly in the toe-off¹⁶.

Moreover, Afiah et al., (2014)^{20,59} in their study provides new information about the motion of the hip joint, more specific about the peak extension timing of the joint throughout the gait cycle. According to studies conducted by Kerrigan et al. (1998)⁵¹; Alcock et al. (2013)⁶³ and Anderson and Madigan (2014)⁶⁴, the delay in the maximum extent of the hip joint may be related to various parameters. As already mentioned, there is a decrease in the range of hip extension. Also, the weakness of the hip flexor muscles affects the individual's effort to change the joint position while poor hip flexor power affects/influences the push-off.

Although the moments have been used to characterize the gait of older people, in most studies either limited to a flat analysis or when was performed a three-dimensional (3D) analysis information was provided only for the sagittal level³. Kerrigan et al. (1998)⁵¹ noted that during walking, there were significant reductions in peak hip flexion moment at stance in elderly. Judge and colleagues (1996)⁵² in their study noticed that when the analysis was adjusted for differences in step length, older subjects developed 16%

more hip flexor power than younger subjects. Kim et al. (2014)⁵⁰ report that the hip extension moment as well as the hip power exerted by the hip extensors at the loading phase was reduced in elderly compared to that of young persons. Also, the hip flexor power burst of elderly was smaller. Information about knee movement is not clear. There is a disagreement in researchers' findings and no statistical significant differences.

According to other alterations observed in the walking pattern of elderly, they indicate decreased plantar flexion peak ankle in late stance compared to young participants⁵². This condition is likely to contribute to older person's shorter step length. This finding is in agreement with previous studies^{16,50,51} and provide novel information about the effect of aging on kinematic angular parameters. Elderly individuals appear to have restricted range of movement at the knee^{33,52} and also demonstrate limited capacity in limb advancement during the push-off period due to reduced plantar flexor moments³⁴.

Some previous studies have determined the kinetic characteristics of ankle joint in elderly. According to Judge et al. (1996)⁵² there was significant difference in joint power between old and young subjects in peak ankle plantar flexor power. Older subjects developed 17% lower power than young subjects. Kim et al. (2014)⁵⁰ noticed that the elderly showed smaller ankle plantar flexor power burst. This adaptation seems to be a compensatory mechanism to the reduction in hip extension. There are no significant differences identified in joint angle parameters between two groups from Kulmala et al. 2017⁴⁸ and Afiah et al. 2016²⁰.

A number of parameters showed significant differences between older and young adults. The necessary adjustments that may have taken place for weight acceptance and body propulsion during the walking from elderly may contribute to age-related differences in gait biomechanics. Progressive age-related deterioration in neuromuscular and neurophysiological function causes declines in sensory systems, sarcopenia, slower movement and central processing, all linked to deficits in gait⁶⁵. It is important to mention, that most gait studies of elderly people focus on the risk of falling during gait in clinical populations and often are limited to the evaluation of spatiotemporal parameters. There is a bibliographic gap, as there are no articles that assess the risk of falling taking into account joint kinematic and kinetic data. Joint kinematic and kinetic parameters are essential to understanding age-related changes in gait. Changes in gait are generally directly involved in fall mechanisms and are robust prediction factors. Further research aiming at a holistic approach to the gait disturbances that may lead to falling is necessary.

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