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Hip but Not Thigh Intramuscular Adipose Tissue is Associated with Poor Balance and Increased Temporal Gait Variability in Older Adults

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Abstract

Background—Intramuscular adipose tissue (IMAT) of the lower extremity is a strong negative predictor of mobility function. Variability in temporal gait factors is another important predictor of mobility function. The purpose of this study was to examine the relationships between IMAT in the hip and thigh muscles, balance, and temporal gait variability in older adults.

Methods—Forty-eight healthy community dwelling older adults (74 $\pm$ 1 year) underwent a CT scan to quantify IMAT in the gluteus maximus (Gmax), gluteus medius/minimus (Gmed/min), hamstrings, vastus lateralis, and adductor muscles. Temporal Gait measures were collected on a GAITRite walkway and gait variability was determined by calculating intra-individual standard deviations. Individuals were divided by tertiles of temporal gait variability into categories of high, medium, and low variability. Differences in the IMAT of the hip abductors were calculated for those with high and low gait variability and partial correlations for gait variability and all muscle composition measures were determined for all variables with normalized gait speed as a covariate.

Results—Gmed/min IMAT was greater in those with higher gait variability compared to those with lower gait variability ($p < 0.05$). Gmed/min IMAT was related to stride width variability ($r = 0.30$, $p < 0.05$). Gmax IMAT was also related to time variability of swing ($r = 0.42$), stance ($r = 0.26$), double limb support ($r = 0.43$), double support loading ($r = 0.44$), and double support unloading ($r = 0.50$) (all $p < 0.05$).

Conclusion—Increased IMAT in the proximal hip muscles, particularly the hip abductors, was associated with increased gait variability and poorer balance. These findings may have implications for the assessment and treatment of balance and falls such that interventions for

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CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

PATIENT'S CONSENT

Declared none.

enhancing balance and mobility among older individuals should take into account the importance of gluteal muscle composition.

Keywords

Gait variability; hip abductors; intramuscular fat; mobility; older adults

INTRODUCTION

Aging is associated with declines in balance and mobility performance resulting in an increased risk of falls, disability, and mortality [1, 2]. Decreased mobility function is currently the leading cause of long-term care admissions [3]. Temporal gait variability is an important predictor of mobility function and fall risk in older adults. Greater stride-to-stride variability in swing, stride, stance, and double-support times predict fall-risk in older adults and increased gait variability may also be linked with decreased mobility function [4-6]. Poor muscle quality (strength/kg of lean muscle mass) in the thigh and calf muscles is related to increased gait variability in older adults and may be a mediating factor for decreased balance and mobility function [7]. The relationship between more distal lower limb muscle quality and gait variability has been identified, however the contribution of the proximal hip musculature, also crucial during gait and balance activities, to gait variability is relatively unknown [7]. The proximal muscles of the hip, and in particular the hip abductors, play a significant role in pelvic stabilization during both static and dynamic movements. Diminished capacity of the hip musculature may lead to an increase in step variability during gait or reflect a loss of balance and mobility function [8].

One contributor to decreased muscle function is an increase in the adipose tissue found beneath the deep fascia of a muscle, also known as intramuscular adipose tissue (IMAT). IMAT is a strong negative predictor of both muscle and mobility function in older adults [9, 10]. Increased IMAT in the lower limb is associated with decreased muscle quality and strength as well as decreased six-minute walk distance, slower gait-speed, and worse physical performance [9, 11-15]. High levels of IMAT in the thigh and calf muscles also increase the risk for frailty and physical decline [11, 12, 15] and are an independent predictor of mobility function in older adults [10-14].

While IMAT has a clear relationship with muscle performance and mobility function, it does not uniformly infiltrate the muscles of the lower limb. Previous work has demonstrated that IMAT infiltration in some muscles may have a larger impact on mobility function than IMAT infiltration into others [14]. While the relationship of IMAT in the thigh or calf and mobility function in older adults is known [9-16], there is a relative dearth of information concerning the impact of IMAT in the proximal hip muscles on mobility function as the majority of studies have focused on the thigh or calf. We recently reported that older adults with a history of falls have significantly increased IMAT within their proximal hip gluteal muscles (hip abductors and extensors) when compared to non-fallers [17, 18], which is associated with a loss of strength. This leads to the speculation that increased IMAT may impair hip function and in turn have a negative influence on balance and gait function [17, 18]. In this study, we sought to determine if differences exist in the proximal hip muscles'

composition (IMAT and lean tissue) of older adults with differing levels of gait variability. We hypothesized that older adults with increased temporal gait variability would also have increased IMAT in their proximal hip muscles and increased gait variability would be associated with greater IMAT. As a secondary analysis, we examined the relationship between muscle composition in the thigh with balance and gait variability to determine potential differences in regional effects of IMAT. Based on our previous work, we hypothesized that a stronger relationship would exist between IMAT and gait variability for the more proximal hip muscles than for the more distal thigh muscles.

METHODS

Participants

Older (>65 years) healthy community dwelling ambulatory adults were recruited for this study. All participants were part of a larger study examining lateral balance stability in older adults. Participants were recruited by advertisement. Exclusion criteria included: cognitive impairment (as determined by a Folstein Mini Mental Score Exam < 24), Center for Epidemiological Studies Depression Survey score of greater than 16, any sedative use, a significant functional impairment related to musculoskeletal, neurological, cardiopulmonary, metabolic, or other general medical problem that limited functional ability. Because obesity is known to result in increased IMAT levels as well as influence gait, we studied only individuals who had a BMI of less than 30 kg/m² and had completed all gait and muscle composition measures. Individuals who were interested initially underwent a telephone screen, followed by a complete medical examination to ensure all inclusion/exclusion criteria were met. All participants provided written informed consent approved by the Institutional Review Board of the University of Maryland.

Gait Variability and Clinical Balance Measures

Gait was assessed using a 25-foot GAITRite electronic walkway (CIR Systems, Inc., Sparta, NJ, USA)[7]. Temporal measures of gait were assessed including step time, swing and stance time, double limb support time, stride time, and double support loading and unloading of gait. These measures of gait variability were selected due to their clinically relevant relationship with balance and mobility function in older adults [4-6]. Stride width, a spatial measure of gait, was also measured as it is an important measure of gait variability related to balance and mobility in older adults [6]. Participants completed 4 trials at their self-selected pace. The first and last two steps of each trial were excluded. Gait variability for each measure (step, swing, stance, single and double support time etc) was first determined by calculating intra-individual standard deviations for each parameter over the remaining steps [7]. On average 36 ± 7 steps were measured. Standardized z-scores were then calculated, based on the intra-individual standard deviations for each individual. The z-scores for stride, stance, swing, and double support time were then summed to create an overall standardized score or composite index for temporal gait variability for each individual. These four specific measures were chosen to create an overall score for temporal gait variability due to their previously described relationship with balance, fall risk and mobility function in older adults [4-6, 19, 20]. The use of a composite score of variability would allow us to compare individuals who had abnormal gait variability across multiple

measures as opposed to a single gait variability measure. The Berg Balance Scale (BBS) was used to assess static balance whereas the 8-item Dynamic Gait Index (DGI) was used to assess dynamic balance and gait [21, 22].

Muscle Composition

Participants underwent a continuous computed tomography (CT) scan (Siemens Somatom Sensation 64 Scanner) from the 2nd lumbar vertebrae to the patella. Hip (at the 3rd sacral vertebrae) and mid-thigh (at 50% of the femur's length) were selected for this analysis. The following muscles were analyzed for muscle composition: Psoas (PS), Gluteus Maximus (GMax), Gluteus Medius and Minimus (GMin/Med), Vastus Lateralis (VL), Hamstrings (Ham), and the Adductor Magnus and Longus (Add). Cross-sectional area of high density lean tissue (HDL), low density lean tissue (LDL), and intra-muscular fat (mFAT) content were determined with Medical Image Processing, Analysis and Visualization (MIPAV, v 7.0, NIH) analysis software, with procedures previously reported in detail [23]. Briefly, CT data were expressed as a cross-sectional area of tissue (cm²) and using Hounsfield units (HU) for HDL between 30 to 80, LDL as 0-29, and mFAT as -190 to -30 HU. HDL, LDL and mFAT were normalized for the respective muscle's size by calculating a percentage of each measure relative to the muscle cross sectional area. As in previous studies, HDL was used as a measure of lean tissue. Both LDL and mFAT were used as measures of IMAT. Previous work has used both LDL and mFAT as a measure of IMAT hence both were included in this study [18, 23].

Statistical Analyses

All statistical analyses were performed using SPSS Statistics v 20.0 (IBM software). Individuals were divided into tertiles of high, medium, and low gait variability based on the calculated z-scores. Independent t-tests were used to compare GMax and Gmed/min HDL, LDL, and mFAT in those with high and low variability. Due to our sample size, we elected to compare only the high variability tertile to the low variability tertile to maximize difference in gait variability. We also examined the relationship of IMAT in the hip gluteal muscles with balance and gait variability. Pearson product correlations were calculated for both the BBS and DGI scores with GMax and Gmed/min LDL and mFAT. Because gait speed is known to influence gait variability, gait-speed was normalized for leg-length and used as a covariate to examine the relationship between gait variability and GMax and Gmed/min LDL and mFAT. Partial correlations for all muscle composition and gait variability measures with normalized gait speed as a covariate were calculated. In the secondary analyses, associations were determined using Pearson correlations between muscle composition (HDL, LDL, and mFAT) of the PS, VL, ADD, and Ham and the Berg, DGI. These same muscle composition measures were also correlated with all gait variability measures where normalized gait speed was used as a covariate. Significance was set at $p < .05$ for all tests.

RESULTS

Fifty-nine individuals with complete data were initially identified for the analyses, but 11 individuals were eliminated secondary to a BMI $>30 \text{ kg/m}^2$ leaving 48 older adults in the

final analyses. Subject demographics, BBS and DGI scores are summarized in Table 1. The average standard deviations for gait variability are summarized in Table 2.

Differences in Muscle Composition Between those with High and Low Gait Variability

Sixteen individuals were included in each tertile for gait variability based on the calculated z-scores. BMI's and gender were not significantly different in the high and low tertile of gait variability. However individuals in the high gait variability tertile were 5 years older than those in the low tertile of variability ($p<.05$). As seen in (Fig. 1), those with the highest levels of gait variability were found to have 2.2% higher levels of Gmed/min mFAT ($p<.05$) indicating increased levels of IMAT. Individuals with the highest levels of gait variability also had significantly less ($p<.05$) Gmed/min-Min lean tissue (5.7%). Although individuals with high amounts of gait variability were also noted to have higher levels of IMAT with in the GMax (mFAT (.5%) and LDL (2.3%)), as well as lower amounts of Gmax lean tissue (3.7% less), these did not reach statistical significance.

Balance and Muscle Composition

Significant associations were found between balance and muscle composition outcomes with muscles of the hip but not of the thigh. Gmed/min lean tissue (HDL) was positively related to both the BBS ($r=0.37$, $p<.05$) and DGI ($r=0.30$, $p<.05$) indicating that as lean tissue increased so did the scores on the BBS and the DGI. While Gmed/min IMAT (as measured by both LDL and mFAT) was negatively correlated with the BBS (LDL: $r=-0.30$, mFAT: $r=-0.36$, $p<.05$). Gmed/min IMAT (as measured by mFAT) was also negatively related to the DGI ($r=-0.26$, $p<.05$). Indicating that as fatty infiltration increased into the muscle balance scores on both the DGI and BBS decreased.

Intra-individual Gait Variability and Muscle Composition

Gluteus Maximus correlations—Significant correlations were found between intra-individual gait variability and muscle composition of the hip, but not of the thigh (data not shown). GMax IMAT (as measured by LDL) was correlated ($p < .05$) with 5 measures of temporal gait variability: Swing time ($r=0.43$), stance time ($r=0.26$), double limb support time ($r=0.44$), double support loading ($r=0.45$) and double support unloading ($r=.52$), indicating that as GMax IMAT increased so did temporal gait variability.

Gmed/min Correlations—Gmed/min IMAT (as measured by mFAT) was significantly positively correlated with stride width variability ($r=.28$, $p<.05$), indicating that as IMAT increased in the gluteus medius/minimus stride width variability also increased. Lean tissue of the Gmed/min muscles (HDL) was only significantly correlated with stride time variability ($r=-0.26$, $p<.05$).

Other muscle Correlations—When correlations were examined for the composition of the hamstrings, adductors, quads, and psoas with gait variability, only psoas muscle composition was related to gait variability. Lean tissue of the psoas was correlated ($p<.05$) with 4 measures of variability: stance time ($r=0.33$), double support time ($r=0.35$), double support loading ($r=0.33$), and double support unloading ($r=0.32$). Psoas IMAT (as measured by mFAT) was significantly negatively correlated with 4 measures of variability: stance

time ($r = -0.28$), double support time ($r = -0.33$), double support loading ($r = -0.32$), and double support unloading ($r = -0.31$). No other significant associations were found between any muscle composition or gait variability measures.

DISCUSSION

IMAT is increasingly recognized as an important contributor to mobility function in older adults [9-11, 14, 15]. As IMAT increases so do mobility deficits, however, the relationship of IMAT in the more proximal hip muscles with balance and gait variability has until now been largely unexamined. This study is the first that we are aware of to examine the relationship of muscle composition in the hips with clinical measures of balance and intra-individual gait variability. In agreement with our primary hypothesis, we found that individuals with higher levels of gait variability had higher levels of IMAT in their hip gluteal musculature, as measured by both low density lean tissue and intra-muscular fat. We also found that IMAT of the hip abductors and extensors were significantly associated with both balance and gait variability, particularly with temporal measures, in older community dwelling normal and overweight adults.

Previous studies that have examined the relationship between muscle composition in the lower limb and mobility have found that IMAT may be an important variable linked to function in older adults perhaps even as important as lean tissue, and that increased levels of IMAT in the mid-thigh are predictive of future loss of mobility [9-11, 14, 15, 24]. Our findings that older adults with higher levels of gait variability also have increased IMAT in the hips and that significant relationships with gait variability and IMAT exist for the hips but not the thighs, suggest that IMAT accumulation in the hips may be more important than thigh IMAT accumulation for balance and mobility function. This supports the perspective that fatty infiltration in some muscles may be more important for mobility and balance function than others [14, 18, 24].

While we found several moderately strong correlations between IMAT and gait variability, there were relatively few correlations between lean tissue and gait variability. Furthermore, relationships that were significant, were weaker than the associations between IMAT and gait variability. This suggests that IMAT may be a more important contributing factor to gait variability than lean tissue. This novel finding that IMAT in the hip abductor muscles is related to gait variability may have particular clinical importance. Samuel and colleagues demonstrated that the hip abductor muscles have a high functional demand during gait in older adults [25]. Thus, greater levels of IMAT in the hip abductors may disrupt muscle function and contribute to an inability to meet the high functional requirements of gait and may likewise contribute to the observed increase in gait variability [9, 10, 12, 15, 16, 24]. While we did not directly examine muscle function in this study, previous work has demonstrated that increased levels of IMAT are related to decreased muscle performance in both the thigh and calf muscles of older people [9, 10, 12, 15, 16, 24]. It is conceivable that similar relationships exist between increased IMAT in the hips and hip muscle function, and this may in turn contribute to increased gait variability, as demonstrated in (Fig. 2).

Gait variability has previously been related to decreased muscle quality, a measure of muscle function, in the thigh and calf muscles [7]. Our findings extend these observations by showing that increased levels of IMAT in the hips are also related to increased gait variability, indicating a possible link between IMAT in the hip muscles, muscle function, and gait variability. While this relationship currently remains speculative, further understanding of this association is of particular importance to aging related changes in gait performance, especially for temporal measures such as swing, stride, stance, and double-support time which have been prospectively linked with a history of falls in older adults [4-6, 19, 20]. When muscles become impaired due to disease, age, or inactivity, movement control may also be impaired leading to gait alterations and increased gait variability. In this regard, a number of studies have demonstrated that alterations in gait variability are closely related to fall risk [4-6, 19, 20]. For example, stride time variability has been noted to be two-times greater in those who experienced multiple falls compared to those who only reported one-fall over a one year period [5]. Stride time variability is also significantly related to a number of important muscle performance factors such as knee extension strength. Variability in stride time tends to increase with age and muscle weakness. IMAT also increases with age and muscle weakness and may be one factor to potentially explain these relationships. However it does appear that either too much or too little variability may be harmful to mobility and balance function. Brach *et al.* found that in 503 older individuals, the extremes of gait variability (individuals in the top and bottom 5%) for step width variability were more than 2.5 times likely to have fallen in the last year than those with moderate gait variability [26]. Given our smaller sample size we were unable to examine the relationship of too little gait variability with IMAT of the hip muscles. It is acknowledged, however, that there is most likely an optimal gait variability associated with better functional performance and future studies should examine this relationship with muscle composition.

Another novel finding of this study was that increased levels of IMAT in the gluteus medius/minimus were related to decreased balance performance on both the BBS and the DGI. While previous work has demonstrated a relationship between IMAT and single limb stance time or lower extremity performance [15], our findings are among the first to identify the relationship between IMAT and clinical measures of balance function. Specifically, we found similar but opposite relationships between balance and IMAT in the gluteal muscles and balance and lean tissue in the gluteal muscles. These similar but opposite relationships suggest that both lean tissue and IMAT may affect balance function. This is an intriguing possibility given that we did not find a strong relationship between gait variability and lean tissue. The difference in the findings between lean tissue and balance function and lean tissue and gait variability may be due to a relatively lower level of balance demand during over ground walking. Gait variability was only measured over a level surface at self-selected walking speed and it is possible that if gait was examined in more challenging situations for balance control such as in negotiating obstacles or on uneven terrain, then a stronger relationship between lean tissue and gait variability may be observed. It is also possible that with our small sample size we were underpowered to detect the relationship of lean tissue with gait variability.

In contrast to the other proximal hip muscles, IMAT of the psoas demonstrated negative associations between IMAT and double support phase characteristics. This indicated that as IMAT in the psoas decreased variability in double support loading and unloading increased. Both the psoas major and the hip abductors assist in stabilizing the hips during gait [27]. We speculate that, compared with the hip abductors, the difference we found in the relationship between gait variability and psoas composition may be related to the nearly constant use of psoas during functional activities with resulting lower IMAT accumulation compared to other hip muscles [28, 29]. The psoas major is a major stabilizer of the spine and co-contracts with muscles of the diaphragm, pelvic floor and deep fibers of multifidus, indicating that it is constantly being activated [28]. Moreover, during bedrest, while other muscles atrophy, muscle cross-sectional of the psoas increases [28]. This is consistent with others observations that the differential increase of IMAT in the gastrocnemius compared to the soleus is due to different activation levels of the muscles [14], implying that increased neuromuscular activity in older adults may guard against the accumulation of IMAT [30-32].

Among this study's limitations are the relatively small sample size, the relatively small number of steps measured for gait variability, and the small but significant age difference noted between our variability groups. Although we repeated overground walking for four trials and an average of 36 steps were taken, consistent with other studies, [7, 26] it was still a relatively small number of steps and due to our sample size we were unable to conduct any regression analysis to assist in identifying the most important predictor variables in gait variability. By limiting our study sample to non-obese healthy older adults, we also recognize that our findings may not be broadly generalizable. It is probable that our observations are conservative as it is conceivable that older adults with mobility limitations or who are obese would have both greater gait variability and IMAT.

In conclusion, our results indicate that community dwelling older adults with increased gait variability have increased accumulation of IMAT within their hip muscles that is related to both balance and mobility function adults. These findings have direct clinical implications for designing exercise and weight loss interventions to improve muscle quality and function related to gait mobility. While the mechanisms behind the observed relationships are currently not known, this study suggests that IMAT in the hip gluteal muscles may be more detrimental to balance and mobility function than IMAT in the more distal thigh muscles. Additional studies are needed to further delineate the relationship of IMAT in the more proximal hip muscles with balance and mobility impairment. Future research should also examine the relationship of gait variability and muscle composition in older adults with mobility limitations, and determine the effects of exercise and balance interventions on muscle composition and gait variability.

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LIST OF ABBREVIATIONS

Add	Adductor Magnus and Longus
BBS	Berg Balance Scale
CT	Computed tomography
DGI	Dynamic Gait Index
Gmax	Gluteus maximus
Gmed/min	Gluteus medius/minimus
Ham	Hamstrings
HDL	High density lean
HU	Hounsfield units
IMAT	Intramuscular Adipose Tissue
LDL	Low density lean
mFAT	intramuscular fat
PS	Psoas
VL	Vastus Lateralis

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Fig. (1).

A comparison of muscle composition of the gluteal muscles (Gluteus maximus and Gluteus medius/minimus) in those with high and low gait variability. HDL (high density lean) is a measure of the % of lean tissue and both LDL (low density lean) and mFAT (muscle fat) are measures of the % IMAT. Gait variability was determined by adding the z-scores for stride time, stance time, swing time, and double support time, high and low variability represent those in the high and low tertiles for variability. *= $p < 0.05$.

Fig. (2).

Schematic diagram illustrating how IMAT may be related to increased gait variability and falls in older adults. Disease, obesity, injury, age and inactivity may all contribute to increased IMAT levels in skeletal muscle. High levels of IMAT may result in impaired muscle strength, activation and muscle quality which may result in increased levels of gait variability and increased fall risk.

Table 1

Subject Characteristics

Characteristics Mean (SEM)	Total (N=48)	High Variability (n=16)	Low Variability (n=16)
Gender (Male/Female)	20/28	8/8	6/10
Age (years)	74.4 (1.0)	76.6 (1.8)	71.3 (1.5) *
BMI (kg/m ²)	25.9 (0.4)	25.3 (0.8)	26.5 (0.6)
BBS	54.1 (0.4)	53.4 (0.8)	54.9 (0.4)
DGI	20.7 (0.4)	19.8 (0.8)	22.3 (0.6) *
Gait speed (cm/sec)	108.3 (2.9)	98.0 (5.3)	122.2 (4.1) *

* P<0.05, BMI=Body Mass Index, BBS=Berg Balance Scale, DGI=Dynamic Gait Index.

Table 2

Average Intra-Individual Gait Variability

Gait Variability Measure	Intra-individual Standard Deviation Mean (SEM) (N=48)
Stride Width (cm)	2.1 (0.1)
Step Time (ms)	32.6 (2.6)
Stride Time (ms)	66.6 (4.1)
Swing Time (ms)	23.2 (2.1)
Stance Time (ms)	36.1 (3.3)
Double Limb Support Time (ms)	28.3 (2.2)
Double Support Loading Time (ms)	17.8 (1.2)
Double Support Unloading Time (ms)	17.6 (1.2)