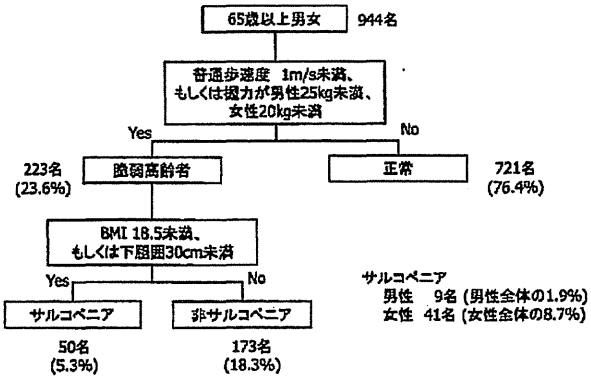

図3　サルコペニアの簡易基準案と，一般住民での分布

が小さいほど，つまりやせているほど身体機能は良くなっており，カットオフ値は決められなかったが，男性では19 kg/m²がカットオフ値であった．下腿囲も同様に女性ではカットオフ値は決められなかったが男性では30 cmであった．

サルコペニアの簡易基準の作成

サルコペニアの簡易基準の作成は，体力や身体計測値から中強度の身体機能に支障が生じる可能性のある集団を捉えることを目指した．判定に使用する項目は，簡便な器具で簡単に測定できるものとした．さらに，Muscle performanceとmuscle volumeを分けて考えることとし，Muscle performanceは普通歩速度と握力で評価し，Muscle volumeは測定に高額で放射線被曝を伴う機器が必要なSMIの代わりにBMIと下腿囲で評価することとした．また，各指標のカットオフ値は中強度の身体機能との関連で決めることとし，女性で上記の基準で決められない場合には，従来のやせの基準値や男性の値を参考に決めることとした．

European consensus[5]によるサルコペニアの簡易基準を参考に，日本人高齢者におけるサルコペニアの簡易基準の作成を試みた．図3に示すように，まず普通歩速度1 m/sec未満，もしくは握力が男性25 kg未満，女性20 kg未満である場合には脆弱高齢者と判断し，脆弱高齢者のうち，BMI 18.5 kg/m²未満もしくは下腿囲30 cm未満である場合をサルコペニアとした．

今回の検討での対象者についてこの基準を当てはめてみると，65歳以上の男女944名のうち23.6パーセント(223名)が脆弱高齢者であり，さらに全体の5.3パーセント(50名)がサルコペニアと診断された．その内訳は男性9名(男性全体の1.9パーセント)，女性41名(女性全体の8.7パーセント)と女性で割合が高くなっていた．

ここに示したサルコペニアの簡易基準案は，身長，体重，握力計とメジャー，ストップウォッチがあれば実施することができる．スクリーニング検査として有用と思われるが，さらに縦断的なデータを用いて，妥当性の検討を行っていきたい．

ま と め

40歳以上の地域住民2,419名を対象としたDXAによる判定では男性の25.0パーセントが，女性の24.2パーセントがサルコペニアに分類された．男性では加齢とともにサルコペニアの割合は増加していたが，女性では加齢による変化はなかった．サルコペニアの簡易基準の作成は，体力や身体計測値から中強度の身体機能に支障が生じる可能性のある集団を捉えることを目指した．その結果，普通歩速度1 m/sec未満もしくは握力が男性25 kg未満，女性20 kg未満である場合には脆弱高齢者と判断し，脆弱高齢者のうちBMI 18.5 kg/m²未満もしくは下腿囲30 cm未満である場合をサルコペニアとした．65歳以上の男女の5.3パーセントがサルコペニアとされた．

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Association of daily physical performance with muscle volume and strength

Hiroshi Shimokata[1] and Fujiko Ando[2]

Abstract

Sarcopenia disturbs the daily life of elderly people, and hinders healthy aging. We studied the association of daily physical performance with muscle volume and muscle strength in a randomly selected community-living population. Results: Grip power and leg muscle strength decreased about 1% per year after age 40 in both men and women. Muscle strength was greater in men than in women at every age by decade, and muscle strength in men in their 80s was similar to that in women in their 40s. Therefore, the effect of a decrease in muscle strength on daily physical performance was greater in women than men. On the other hand, the muscle volume of all limbs decreased with age in men, but there was almost no decrease in muscle volume in women. These results indicate that qualitative change in muscle was more significant than quantitative change in muscle in women. Daily physical performance was influenced by muscle performance and could be assessed based on grip power and walking speed. To prevent frailty, it may be important to determine the high-risk group for frailty using these assessments.

Key words: *Sarcopenia, Daily physical performance, Muscle volume, Muscle strength, Aging*
(Nippon Ronen Igakkai Zasshi 2012; 49: 195–198)

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認知症の実態と予防の重要性

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第18回日本未病システム学会学術総会

●シンポジウム4「認知症予防の最前線―現在そして将来，どこまでできるか―」

認知症の実態と予防の重要性

下方　浩史[1)]
安藤　富士子[2)]

1. はじめに

認知症にはまだ根本的な治療はなく，病状は長期にわたって慢性に進行して重症に至ることが多い．進行すると徘徊や暴力などの問題行動もみられ，末期には寝たきりとなり，誤嚥性肺炎や褥創などの合併症も生じて，経済的，社会的な負担がきわめて多い．認知症の出現頻度は高齢になるほど高くなるので，わが国の社会の高齢化に伴って今後急速に患者数が増大し，介護や医療への費用負担が急騰することが予想される[1-5]．このため，認知症罹患の実態を把握し，認知症の予防を目指すことはわが国にとっての緊急の課題となっている．

2. 認知症の有病率

認知症の有病率や罹患率に関しての疫学統計が，今後の医療費予測や高齢者の介護・福祉のあり方，医療政策に関して，重要な意味を持つと思われる．しかし，今まで認知症の疫学調査は十分には行われてこなかった．それは認知症という疾患の持つ特殊性により，調査に多くの困難を伴うためである[1-4]．

認知症の有病率は比較的低いので正確な統計データを得るためには対象人数を多くしなければならない．65歳以上の高齢者は日本全体では現在約3,000万人であり，推定有病率の1％の違いが患者数推計では30万人の差となる．例えば，有病率15％を14～16％の信頼区間で得るためには4,898名の対象者が必要である．また，アルツハイマー病，血管性認知症，レビー小体型認知症，前頭側頭葉脳変性などの病型別有病率についての検討を加えるためには，さらに多くの対象者が必要である．

認知症の診断を行うためには専門的知識が必要であり，場合によってはMRIやPETなどの検査や剖検が診断のためには必要となる．認知症患者やその家族は調査に対して消極的なことが多い．認知症は高齢者に多いため，身体機能の低下を認める者が少なくなく，訪問による検査などが必要で，実際の調査が思うようにいかないことも多い．また，認知症の有病率を調べる場合，調査地域の高齢者の年代分布によって有病率が異なる可能性がある．地域在住者を調査しても，問題行動のある認知症患者は施設に入所しているために，有病率が低く出てしまうことも考えられる．

認知症の有病率については1970年代から全国のさまざまな地域において疫学調査が行われてきたが，調査は県や市町村の地域ごとに行われており，最近まで全国規模での調査は行われていなかった．日本初の全国調査は，厚生労働省認知症対策総合事業「認知症の実態把握に向けた総合的研究」として実施された[6]．まず2009年から2010年にかけて全国7ヵ所で65歳以上の住民を対象として行われた（図1）．訪問調査員による1次調査と専門医による2次調査を基本として，さらに頭部MRIによる脳萎縮や血管性病変の評価なども行い，精度の高い診断を目指した．全国での調査結果から2008年の日本の人口を基準にして推定された有病率は12.4～20.2％（平均14.4％）であった．2008年度の65歳以上の全国人口2,822万人から，認知症患者数は406万人と推定された．しかし，施設入所者などを加えればこれよりも患者数はさらに多い可能性がある．従来の方法での患者数推計では208万人とされていたが，患者数は少な

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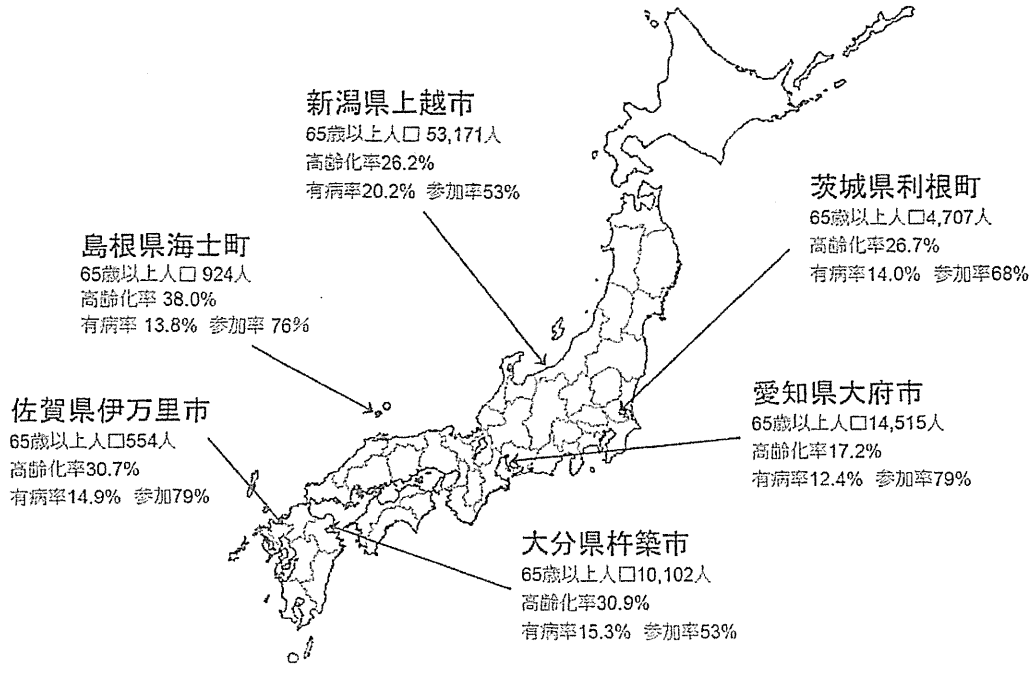
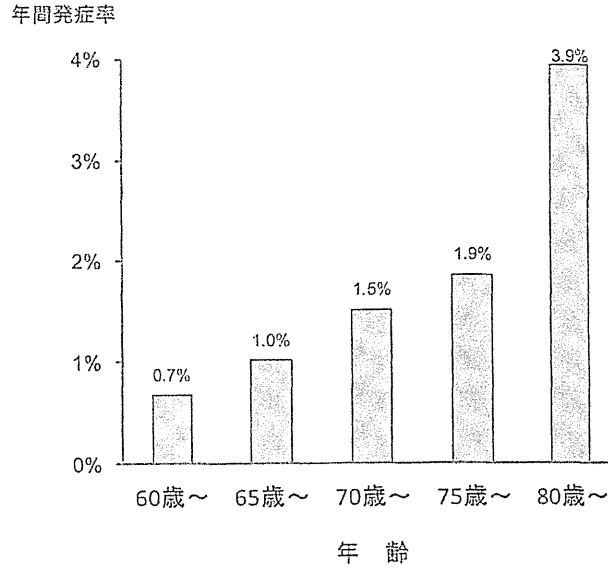


■図 1　認知症有病率全国調査結果（2008 年度日本全国の人口構成に基づく）

くともその約 2 倍存在することになる．

3. 認知症の発症率

発症率を推定するためには，同一対象集団について複数年にわたっての繰り返しの調査が必要であり，有病率の推定よりも難しく，わが国の疫学調査の結果では認知症の発症率の推定はほとんど行われていない．われわれは，無作為抽出された地域住民を長期にわたって追跡した「国立長寿医療研究センター・老化に関する長期縦断疫学研究（NILS-LSA）」[7] のデータを用いて 8 年間の縦断的な検討から認知症の発症率の推定を行った（図 2）．その結果では，60 歳以上の地域住民の 1.5 %が毎年認知症となっていた．年齢が高くなるほど発症率は上昇し，80 歳以上では毎年 3.9% が認知症となっていたという結果であった．



■図 2　認知症の年間発症率（「国立長寿医療研究センター・老化に関する長期縦断疫学研究（NILS-LSA）」の 8 年間の縦断的観察から）

4. 将来推計

人口の高齢化に伴う認知症患者数の将来推計を行ってみた．性別・年齢別の認知症有病率は今回の全国調査の結果を用い，人口推計は国立社会保障・人口問題研究所の平成 24 年度 1 月推計を用いた．2010 年度の 65 歳以上の認知症推定患者数は全体として 415 万人で，

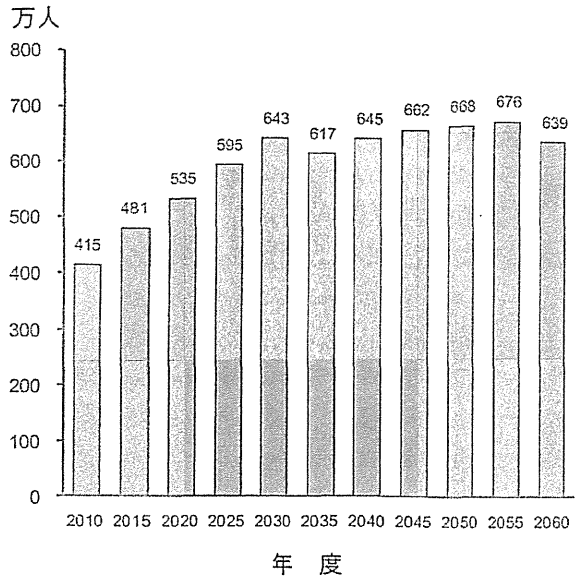


図3 認知症患者数の将来推計（人口推計は国立社会保障・人口問題研究所の平成24年度1月推計を用いた）

有病率は約14.1パーセントであると推定される．今後，高齢者人口，特に後期高齢者の人口が急増し，患者数は2020年度に535万人，2030年度には643万人と，これからの20年間にアルツハイマー病の患者数は1.5倍に大きく増加すると予測される（図3）．

5. 認知症の経過と予後に関する統計

認知症は長期にわたって慢性に進行していくことが多い．このことが社会に大きな負担となる要因のひとつである．わが国の在宅認知症患者の5年後生命予後調査では，66％～86％の生存率が報告されており[3]，認知症の発症から死亡までの全経過は現在のところ7年から10年程度だと思われる．米国での認知症患者の大規模な追跡調査では，発症からの生存年数は10.5年，診断からの生存年数は5.7年であった[8]．他の研究でも認知症患者の診断後の生存年数は5年から9年であった[9-12]．米国の国立老化研究所（NIA）からの報告では，生存期間は年齢によっても大きく異なり，75歳までに診断されたアルツハイマー病患者の生存年数は診断後7年から10年であったが，85歳以降に診断された場合は3年未満の生存期間であった[13]．しかし今後，介護技術，医療の進歩により死亡までの期間は長くなっていくと思われる．

6. 認知症予防とのその重要性

世界有数の長寿の国であるわが国は急速に高齢化が進み，それとともに認知症患者の数も増大していく．今後15年間で認知症にかかわる介護費用は大きく増加し，年間10兆円に達するとも予想される．高齢化が進む一方で，少子化も進み，介護にかかわることのできる労働人口は激減する．このままでは認知症によって日本の社会が崩壊すると言っても過言ではない．認知症を予防していくことが，今後の日本にとっては極めて重要であろう．

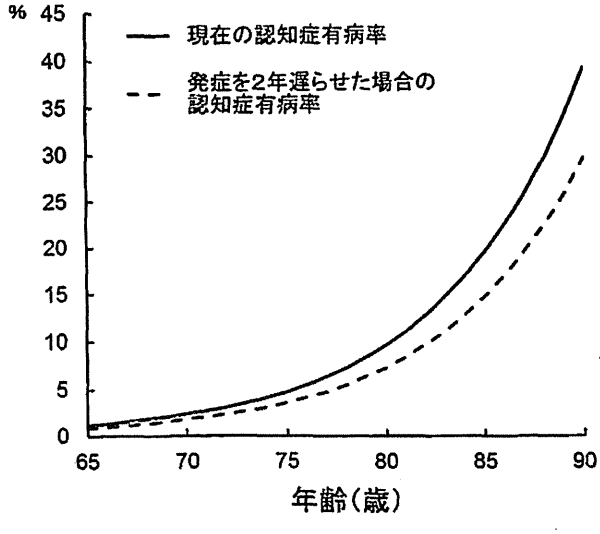
アルツハイマー病予防の切り札としてワクチンの開発が進められている．ワクチンはアルツハイマー病を引き起こすアミロイドβ蛋白の蓄積を予防するような作用を持つとされるが，脳炎などの重篤な副作用も報告されている[14]．また中年以降ではすでにアミロイドβ蛋白は蓄積されてしまっており，ワクチンは30歳以前に使用しなければ効果はないという．たとえワクチンが開発されたとしても，50年後の認知症発症を予防するために，有効性が不明でしかも脳炎などの副作用のリスクがあるワクチンを若者が使用するかどうかは疑問である．

認知症は生活習慣病でもあり，生活習慣の改善である程度の予防が可能である．生活習慣は血管性認知症だけでなくアルツハイマー病の発症と関連している可能性がある．特に食事は毎日の生活の中で繰り返され，影響が大きい．認知症の予防にはビタミンE，ビタミンC，カロテノイドのような抗酸化ビタミンが有用であり，中でも抗酸化作用を持つビタミンEが期待される[15,16]．葉酸やビタミンDの認知症予防作用も明らかにされてきている[17,18]．多価不飽和脂肪酸，特にn-3系のドコサヘキサエン酸（DHA），エイコサペンタエン酸（EPA）は認知症の予防に有用であり[19,20]，またアラキドン酸についても有用性の研究が進んでいる[21]．食事のパターンとしては野菜や魚類をバランス良く摂ることが重要である．適度な飲酒，特にワインが認知症の予防に有用であり[22]，喫煙は多くの研究で認知症の危険因子となることが報告されている[23]．運動によって認知症やアルツハイマー病のリスクを下げることは多くの論文で報告されている[24]．運動が糖尿病，脂質異常症，高血圧症を

予防し，その結果，動脈硬化の進行を遅らせて認知症の発症リスクを下げると考えられるが，運動自体が脳神経のネットワーク機能を強化し，認知症の発症を防ぐという直接的な効果も推測されている．

認知症の素因としての遺伝子多型の研究も進み始めている．しかし危険因子間の相互作用，特に遺伝子と生活習慣との相互作用についてはほとんど研究が進んでいない．例えば食塩の摂取により血圧が高くなる遺伝子多型は，塩分感受性遺伝子多型として知られている．特定の遺伝子多型を持つ人は塩分を多く摂ると高血圧症になりやすく，それが認知症のリスクとなる．このような遺伝子多型とライフスタイル，環境因子との相互作用は数多い．認知症に関連する遺伝子多型は直接に認知症を引き起こすわけではなく，むしろライフスタイルや環境因子の影響を修飾することで認知症の発症に関与するものと考えられる．特定の遺伝子多型の認知症発症寄与率は集団全体の生活習慣などによって異なると考えられ，このために集団が異なれば結果も異なることになり，遺伝子多型の影響について一定の結果が得られにくい．こうした，危険因子相互の作用について明らかにしていくには，大規模な一般住民で追跡を行い，生活習慣や認知機能の変化を継続的に観察する縦断的研究が必要である[25]．

医薬品の開発などで認知症の発症を完全に予防できなくても，仮に2年間だけでも遅らせるようなことが出来れば，各年齢の認知症の有病率は，2歳若い年齢に相当する有病率になると期待できる（図4）．65歳以上の全人口に対して，実際の年齢よりも2歳若い年齢の有病率を使って患者数を計算すると期待患者減少数は33万人，医療費削減効果は2,000億円，介護費用削減効果は7,700億円となる．さらに，家族が介護のために職につけなかったり，本人が病気のため社会参加が出来なかったりした損失も加えると合計の費用削減効果は，年間約2兆円にも達する．こうした経済的な効果を考えると，認知症性疾患の基礎研究，臨床研究へのわが国における研究費の支出は驚くほど少ない．



■図4　年齢別にみた認知症の有病率と認知症の発症を2年遅らせた場合の有病率
期待患者減少数は33万人，医療費削減効果は2,000億円，介護費用削減効果は7,700億円と推定される．

7. 最後に

世界でも類をみない速度で高齢化が進んでいるわが国にとって，認知症患者の増加は大きな社会問題である．今後15年間で認知症にかかわる介護費用は倍増し，年間10兆円に達するとも予想される[5]．高齢化が進む一方で，少子化も進み，介護にかかわることのできる労働人口は激減する．このままでは認知症によって日本の社会が崩壊すると言っても過言ではないかも知れない．一方で，認知症の発症を2年遅らせることができれば，それだけで年間2兆円もの費用が削減できる可能性がある．

日本人で比較的多いと言われる血管性認知症は，喫煙や高脂血症，高血圧，糖尿病などが要因となっており，禁煙や減塩，身体活動，食生活の改善などである程度予防することが可能である．最近ではアルツハイマー病も生活習慣病であると言われ始めており，生活習慣の改善である程度の予防が可能であろう．認知症の素因としての遺伝子多型の研究も進み始めている．こうした研究の推進により高齢者の知的機能を守り，高齢者の社会参画を可能にしていくことが是非とも必要であろう．

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Review Article

Aging-related Genes

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Abstract

Genetic factors affect an individual's maximum possible lifespan. In humans, the average lifespan is about 40 years shorter than the maximum lifespan. Any gene that influences the development of a disease is called a disease-susceptibility gene. The impacts of disease-susceptibility genes on aging and average lifespan would be much stronger than the impacts of aging genes on maximum lifespan. Multiple genes are associated with the aging process and age-related diseases, and gene-to-gene interactions are important, as are gene-environment interactions; the interactive effects of lifestyle are especially important. A broad-scale, long-term longitudinal study that includes detailed examinations of medicine, nutrition, physical activity, and psychology in a community-dwelling population is necessary for comprehensive genetic epidemiological study of aging and age-related diseases. Risk of disease to individuals can be more effectively assessed with data on genetic, lifestyle, and environmental factors. The most appropriate health education, lifestyle modifications, and health examination protocols could be then implemented in an individualized manner to prevent diseases and aging processes based on these personalized risk assessments.

KEY WORDS: aging, gene, epidemiology, longitudinal study, lifespan

Aging and genes

Japan is the world leading country with long living poeple. Nevertheless, until recently, few Japanese people lived more than 100 years. However, the number of centenarians has recently begun to increase rapidly; in 2012, there were 51,376 men and women aged 100 years or older in Japan. It is no longer inconceivable for a regular person to live for 100 years or more.

The lifespan of individual organisms varies based on species. The maximum lifespan for humans is currently 120 years, at most. The maximum lifespan in each species is determined by genes. Do longevity genes that increase maximum life-span exist? If such longevity genes exist, what is the function of these genes in the human body? Perpetual youth and longevity is a dream of people worldwide, and extensive research is currently being performed to clarify the mechanism of aging using new molecular and genetic methodologies [1] to identify for longevity genes.

Search for an aging gene

Progeria (Hutchinson–Gilford progeria syndrome) is a rare genetic disease with symptoms that resemble the acceleration of the regular aging process [2]. The first symptoms manifest in neonates and infants. In one year, a patient with progeria undergoes physical aging equivalent to that requiring over 10 years in an unaffected person. The average lifespan of patients with progeria is about 13 years. The incidence of progeria is very low, at only 1 person in every 4 to 8 million live births. The typical symptoms of progeria are growth insufficiency, a localized scleroderma-like skin condition, wrinkled skin, loss of eyesight, hair loss, atherosclerosis, cardiovascular disease, and renal failure. However, cognitive development and function are usually normal. A point mutation in position 1824 of the lamin A (LMNA) gene has been identified as the cause of progeria [3].

Werner syndrome, also called adult progeria or progenoid syndrome, is another very rare genetic disease characterized by the appearance of premature aging. Symptoms of Werner syndrome are short stature, low body weight, absence of a teenage growth spurt, graying of hair, bilateral cataracts, hoarseness of the voice, and thickening of the skin. These symptoms appear after the age of 10. Patients with Werner syndrome generally die of atherosclerotic disease or cancer sometime between the ages of 40 and 60. In humans, Werner syndrome is an autosomal recessive disorder caused by a point mutation in the WRN gene on chromosome 8 [4]. About 1,200 cases have been reported, and 80% of these patients are Japanese.

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The incidence of Werner syndrome is 3 per 100,000 live births in Japan.

The LMNA and WRN genes, which are responsible for progeria and Wener syndrome respectively, cause pathological aging processes, but do not regulate normal aging processes. The frequency of genotypes unrelated to lifespan did not differ between younger people and older people in a cross-sectional study [5] (***Fig. 1-A***). However, the frequency of certain genotypes changes with aging. A genotype with a high frequency among older people could represent a "longevity genes" that serves to prolong lifespan or to protect against age-related diseases (***Fig. 1-B***). In contrast, a genotype with a lower than average frequency among older people could represent an "aging gene" or a "gene resulting in shorter life expectancy" (***Fig. 1-C***).

Table 1 shows a list of genes associated with longevity based on the findings of a cross-sectional study of age difference in genotype frequency [5]. Most of these genes are related to a molecular pathway involved in nutrient metabolism, especially lipid or glucose metabolism, or in endocrine regulation.

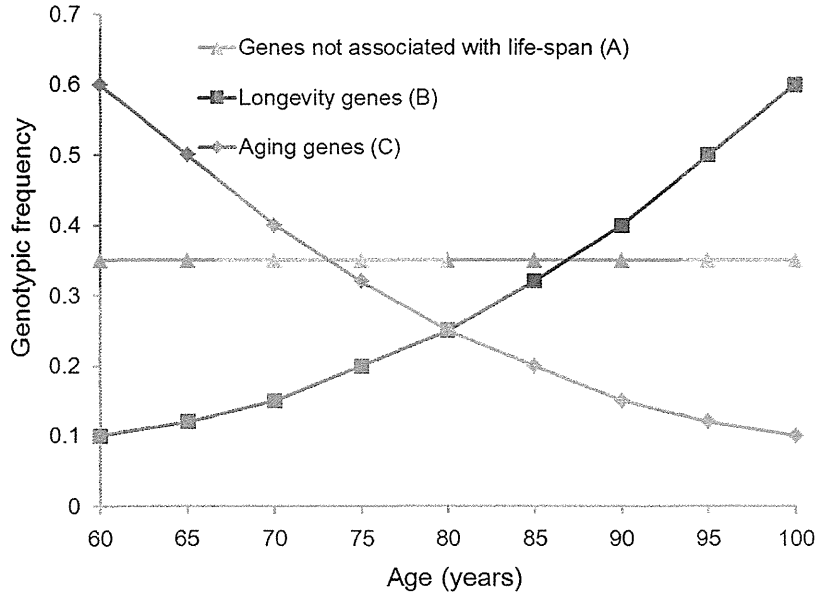

Fig. 1. **Genotypic frequency by age in genes not associated with lifespan (A), longevity genes (B), and aging genes (C) (Modified form Barzilai *et al.*, 2010 [5]).**

Table 1 Genes associated with longevity

Gene	Longevity	Relevant biological action	Chromosomal loci
Klotho (KL gene)	+	Insulin sensitivity, modulation of IGF-I and vitamin D	13q12
Silent mating type information regulation 2 homolog 1 (SIRT1)	+	Regulates epigenetic gene silencing and suppresses recombination of rDNA, associated with insulin action/sensitivity	10q21.3
Catalase (CAT)	+	Antioxidant that protects cells from hydrogen peroxide	11p13
Mammalian target of rapamycin (mTOR)	−	Modulates insulin, IGF, and mitogen function	1P36
IGF-I/insulin (FOXO)	−	Transcription factors that take part in cell growth and differentiation	12q23–23
GH	−	Stimulates growth, production of IGF-I	17 q22-q24
TSHβ	+	Production of TSH	1p13
Thyrotropin receptor (TSHR)	+	Production of T4 and T3	14q31
CETP	+	Facilitates the transport of cholesteryl esters and triglycerides between the lipoproteins	16q21
APOC-3	+	Inhibits lipoprotein lipase and hepatic lipase	11q23.1-q23.2
Adiponectin (AdipoQ)	+	Modulates glucose and fatty acid metabolism	3q27

Modified form Barzilai *et al.*, 2010 [5]

Aging genes and disease susceptibility genes

It is very rare for a human being to live 120 years; most people die from one of many diseases before reaching 120 years of age. Currently, the average human lifespan is thought to be about 40 years shorter than the maximum lifespan. Several lifestyle-related diseases, such as dyslipidemia, hypertension, diabetes, atherosclerosis, and cardiovascular disease, accelerate the aging process. The relationship between atherosclerosis and aging is particularly strong, as indicated by "a man is as old as his arteries". Susceptibility to lifestyle-related disease is influenced by genetic factors. Any gene that influences the development of disease is known as disease-susceptibility gene. The impact of disease-susceptibility genes on aging and average lifespan is thought to be much larger than the impact of aging genes on maximum lifespan.

Although disease-susceptibility genes determine the susceptibility of an individual to disease, including lifestyle-related diseases, a person with a specific disease-susceptibility gene does not always have the disease. Lifestyle or environmental factors might have much stronger effects on pathogenesis than any of the direct effects of the gene. For example, it should be possible to develop a new method for preventing a disease by investigating differences in lifestyle or environmental factors between individuals with and without disease in a group with a specific disease susceptibility allele. Moreover, investigation of longitudinal changes in modifiable risk factors such as lifestyle should be useful. A better understanding of changes in the incidence of a disease should be helpful for preventive genetic counseling; for example, a person with a specific disease-associated genotype may be able to reduce their personal risk of developing the respective disease if they double their physical activity.

Molecular epidemiology of aging

Genotypes related to aging or age-related disease are, in most cases, not single but multiple, and effects of genotypes are influenced by gene-to-gene interactions and gene-environment interactions. Thus, the analysis of genotypes is often difficult [6].

Case-control or association studies of genetic factors that affect aging or age-related diseases compare the frequency of genotypes in a group of cases with those in a control group. Usually, a relatively small number of cases and controls are examined in a case-control study. To date, many association studies have been conducted to identify genetic factors that affect or cause diseases and clinical condition. However, in most of these studies, gene-gene interactions and gene-environment interactions were not examined.

Affected sib-pair linkage analysis is a type of genome-wide analysis in which researchers study sib-pairs that are affected by a specific disease to identify disease-causing alleles [7]. Although significant linkage can be located in specific loci, identification of the actual disease-causing allele is usually difficult.

Calpain-10A, a member of the calpain-like cysteine protease family, was identified as a type 2 diabetes susceptibility gene in a genome-wide screen of affected sib-pairs of Mexican-American descent [8]. However, findings from other studies indicate that no association between the calpain-10 gene and diabetes exists in other population [9,10]. The results often differ based on the quality of the cohorts, especially for diseases such as diabetes, as numerous genes are related to glucose metabolism and obesity.

Findings based on affected sib-pair linkage analysis can be highly problematic. Collecting a large sample of sib-pair cases is often difficult, environmental factors are usually excluded, and the required genome-wide analyses are very costly. Association studies are better suited for the investigation of aging and age-related diseases because these involve many genotypes and many environmental factors. A large cohort is necessary for such analyses because each disease-related genotype may contribute a small amount to the onset of disease and because there are usually significant interactions with lifestyle and environmental factors. For example, in the analysis of dyslipidemia, contribution of genotype should be controlled for age, body size, diet, physical activity level, and among other factors. Multivariate and longitudinal analyses that account for changes in many examination results are essential in large cohort studies.

Epidemiologists and biostatisticians with experience in clinical medicine and human genome studies should develop methodologies for comprehensive and systematic assessments of many genotypes, lifestyles, and environmental factors in studies of molecular epidemiology. A large number subjects are necessary in epidemiological analyses of the associations between a disease and combinations of relevant genotypes. For example, in the case of combination of two genotypes with 10 percent mutation rate, the subject with both mutations is only 1 percent. To assess interactions between rare mutations at two different genes, a larger number of subjects are necessary than single mutation.

Based on whole-genome sequencing, the human genome encodes 30,000 genes, and in many cases, a single gene is highly pleiotropic because it has multiple roles and functions in multiple organs. For example, variants in the apolipoprotein ε4 gene are associated with lipid metabolism and atherosclerosis [11], and with Alzheimer's disease [12] and with osteoporosis [13]. A single allele of a gene may influence the aging process as well as the incidence of multiple age-related diseases, and the effect of the allele may be influenced by lifestyle, environmental factors, or both.

For the above-mentioned reasons, at least 2,000 middle-aged or elderly men and women should be selected, if possible, from a community-dwelling population as a basic cohort for a genetic epidemiological study of aging and age-related disease. Many alleles and candidate genes should be genotyped or, if possible, a genome-wide analysis of single nucleotide polymorphisms should be performed, and various life and environmental factors, medical findings, and disease markers should be assessed in a systematic way for each individual in the cohort. Moreover, for the assessment of time-dependent changes in lifestyle choices and environment factors, a comprehensive longitudinal study in which the subjects are observed repeatedly over time is desirable.

Research on the association of genotypes with common age-related diseases or disabilities that is controlled for many background factors can be accomplished with a nested case-control study design in which subjects with and without disease or disability are in the basic cohort. Research on genetic associations with differences in clinical parameters such as blood pressure, serum cholesterol level, and bone mineral density are also possible. For important geriatric diseases including Alzheimer's disease, Parkinson's disease, and femoral neck fracture, it is difficult to recruit enough affected patients from a single community-dwelling population to conduct a genetic association study. However, case-control study design is feasible if the patient group with the disease is recruited from collaborating hospitals and the control group without the disease is selected from the basic cohort.

Longitudinal epidemiological studies

Accumulation of basic data on aging is indispensable for the molecular epidemiological study of aging and age-related disease. The National Center for Geriatrics and Gerontology (NCGG) Research Institute (former National Institute for Longevity Sciences: NILS) is the leading national research center for aging and geriatrics; it is located in Obu City in the suburbs of Nagoya, Japan. In 1996, the Laboratory of Long-term Longitudinal Studies was established within the Department of Epidemiology, NILS; the initiative was focused on a new longitudinal study of aging in Japan. In October 1997, a trial run of the examinations was conducted, and in November 1997, we started the NILS-Longitudinal Study of Aging (NILS-LSA), a large-scale and comprehensive longitudinal study of aging in Japan [14]. Every day, six to seven participants were examined at the NILS-LSA Examination Center (***Fig. 2***). The first wave of the examinations finished in April 2000, and 2,267 participants (both male and female) had completed the examinations. The participants were examined every 2 years, and in July 2012, the seventh wave of examinations was completed.

The research area was defined as the neighborhood of NCGG, which included Obu City (population 79,000) and Higashiura Town (population 48,000). This area is located south of Nagoya, and is a bedroom town and also an industrial area of the Toyota group, and the area has many orchards and farms; therefore, the research area included both urban and rural characteristics. The research area is located at the center of Japan, and the climate is close to the average for all of Japan. We examined how representative this area is of Japan by conducting a national postal questionnaire of prefecture-stratified random samples of 3,000 households from all prefectures in Japan, and found that the lifestyle choices in the research were typical of all areas in Japan. Therefore, we expected that the results of the examinations in this area will be representative of Japan.

The participants in the baseline examinations of the NILS-LSA were males and females aged 40 to 79 years old. The population of Obu City and Higashiura Town was stratified by both age and gender, and participants were randomly selected from resident registrations in cooperation with the local governments. To test sex differences, the study cohort included equal numbers of males and of females; moreover, the numbers of participants within each decade (40s, 50s, 60s, 70s) were also to be equal. There are some dropout participants in each wave of the examination. These dropout participants were replaced newly recruited age- and sex-matched samples randomly selected from the resident registration except the participants over 79 years old. And, new participants, males and females aged just 40 years, were recruited every year. Recruitment and follow-up are expected to be much easier with volunteers than with randomly selected participants. However, because samples comprising volunteers generally tend to be interested in health, findings from samples comprising volunteers would produce biased results. Consequently, samples should comprise randomly selected participants in order observe the aging process of ordinary Japanese who live ordinary lives.

The participants were examined from 8:50 am to 4:00 pm at a special examination center within a facility at the NCGG. To examine 2,400 males and females in 2 years, that is, 1,200 males and females per year, six or seven participants were to be examined each day, 4 days a week, from Tuesday to Friday, 200 days (50 weeks) a year. We took advantage of the fact that all participants could be examined at the center; therefore, we could conduct detailed examinations that included medical evaluations as well as examinations of exercise physiology, body composition, nutrition, and psychology. Each examination was to be extensive and the most up-to-date, aiming at the internationally highest level in geriatrics and gerontology.

From the beginning of the study, blood samples for gene analysis were collected from almost all participants. There would be no other accumulation of DNA specimens with very detailed back ground information in a community-dwelling population in Japan and other countries. To date, 230 genotypes have been examined, and the associations between genotypes with age-related diseases and parameters of aging controlling for various background factors including nutrition and physical activity have been investigated.

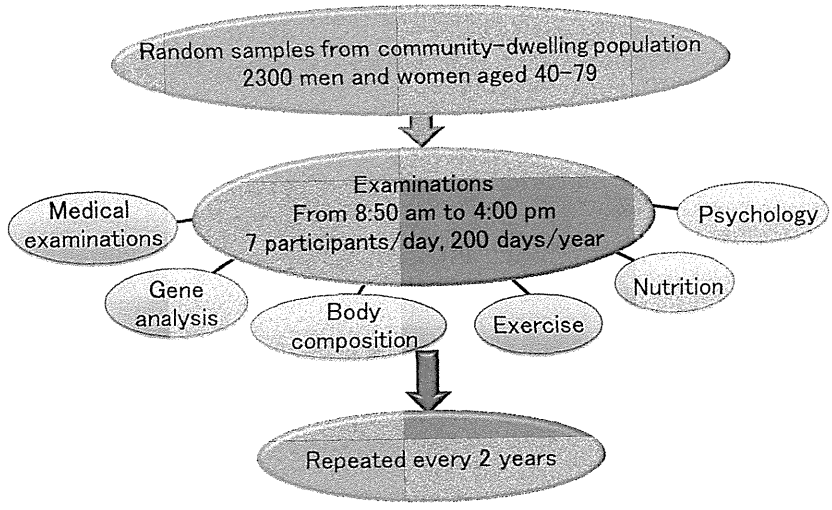

Fig. 2. **Implementation of the National Institute for Longevity Sciences, Longitudinal Study of Aging (NILS-LSA).**

Genotype and bone mineral loss with aging

Age-related changes in bone mineral density (BMD) were examined via dual-energy x-ray absorptiometry (DXA) and a peripheral quantitative CT (pQCT) in the NILS-LSA. We found 31 genotypes that were associated with BMD (***Table 2***). These are results from association studies between genotypes of candidate genes and BMD by DXA or pQCT.

Fig. 3 shows the effects of the estrogen receptor (ERα) XbaI genotype on the relationship between BMD and lean body mass in post-menopausal women [30]. BMD tends to be higher with more muscle mass estimated as lean body mass, and the effect of lean body mass is larger in AG/GG type than in AA type of ERα XbaI genotype. We suspect that, for the purpose of preventing osteoporosis, an increase in muscle mass is more effective in people with the AG/GG type than in those with the AA type.

BMD is higher in AA type in a cohort with low muscle mass, but BMD is lower in AA type in a cohort with large muscle mass. Findings from analyses of cohorts with different muscle mass reveal that there may be an inverse association between genotype and BMD. Lack in analysis of interaction between gene and life-style would be one of the causes of poor reproducibility in genome research. Thus, comprehensive analyses of the interaction with detailed data from nutrition surveys and lifestyle examinations including smoking, alcohol drinking, and physical activity are essential in the study of Anti-Aging and disease prevention.

Gene and age-related cognitive impairment

Many genes are likely to influence cognitive function, but the associations between genetic polymorphisms and age-related cognitive impairment are unclear. There are significant differences in age-related cognitive decline among individuals.

Klotho is a type I membrane protein that shares sequence similarity with members of the glycosidase family [31], and it

Table 2 *Newly found or confirmed associations between genotypes and bone mineral density (BMD) based on NILS-LSA findings*

Genes and genotypes		Effects on BMD	Ref.
Calcium metabolism related hormones and receptors			
VDR	Vitamin D receptor (A-3731G)	Femoral neck BMD is high in men with CC type	15
ESR1	Estrogen Receptor α (PP/pp)	BMD is low in elderly women with CC type	16
ESR1	Estrogen Receptor α(XX/xx)	BMD is low in elderly women with GG type	16
OST	Osteocalcin (C298T)	BMD is low in premenopausal women with TT type	15
ADR	Androgen receptor (CAG repeat)	BMD is low in premenopausal women with frequent CAG repeat	17
CYP17A1	Cytochrome P450,family 17, subfamily A, polypeptide 1 (T-34C)	BMD is low in postmenopausal women with CC type	18
Cytokines growth hormones and receptors			
IL6	Interleukin-6 (C-634G)	Radial BMD is low in postmenopausal women with GG type	15
TGFB	Transforming growth factor-β1 (T29C)	Radial BMD is high in elderly women with CC type	19
OPG	Osteoprotegerin (T950C)	Radial BMD is low in premenopausal women with CC type	20
OPG	Osteoprotegerin (T245G)	Femoral neck BMD is low in pastmenopausal women with GG type	20
CCR	Chemokine receptor 2 (G190A)	BMD is high in postmenopausal women and middle-aged men and with AA type	21
Bone matrix related protein			
MMP1	Matrix metalloproteinase-1 (1G/2G at-1607)	Radial BMD is low in postmenopausal women with 2G/2G type	22
MMP9	Matrix metalloproteinase-9 (C-1562T)	BMD is low in men with CT/TT type	23
COL	Collagen typeI (G-1997T)	BMD is low in postmenopausal women with GG type	24
ICAM1	Intercellular adhesion molecule-1 (Lys469Glu)	BMD is low in postmenopausal women with AA type	25
PLOD1	Procollagen-lysine 2-oxyglutarate 5-dioxygenase (Ala99Thr)	BMD is low in pre and postmenopausal women with GA/AA type	25
CX37	Connexin 37 (Pro319Ser)	BMD is low in men with TT type	25
Others			
KLOT	Klotho (G-395A)	BMD is low in pre and postmenopausal women with GG type	17
MTP	Microsomal triglyceride transfer protein (G-493T)	BMD is high in premenopausal women with TT type	18
VLDLR	VLDL receptor (triplet repeat)	BMD is high in men with more than 8 CGG repeat	18
ALAP	Adipocyte-derived leucine aminopeptidase (Lys528Arg)	BMD is high in premenopausal women with GG type	25
LIPC	Hepatic lipase (C-514T)	BMD is low in postmenopausal women with TT type	25
CNR2	Cannabinoid receptor 2 gene (A/G, rs2501431)	BMD is low in pre and postmenopausal women with AA/AG type	25
PON1	Paraoxonase-1 (Gln192Arg)	BMD is low in postmenopausal women with GG type	26
PON1	Paraoxonase-1 (Met55Leu)	BMD is low in postmenopausal women with TT type	26
PON2	Paraoxonase-2 (Cys311Ser)	BMD is low in postmenopausal women with CC type	26
DRD4	Dopamine D4 Receptor (C-521T)	BMD is low in men with CC type	27
FOXC2	Forkhead box C2 (C-512T)	BMD is low in men and women with T allele	28
PLN	Perilipin (C1243T)	BMD is low in men with C allele	28
MAOA	Monoamine oxidase A (uVNTR)	BMD is low in women with repeat less than 4	29
SH2B1	Src-homology-2-B (Ala484Thr)	BMD is low in women with A allele	29

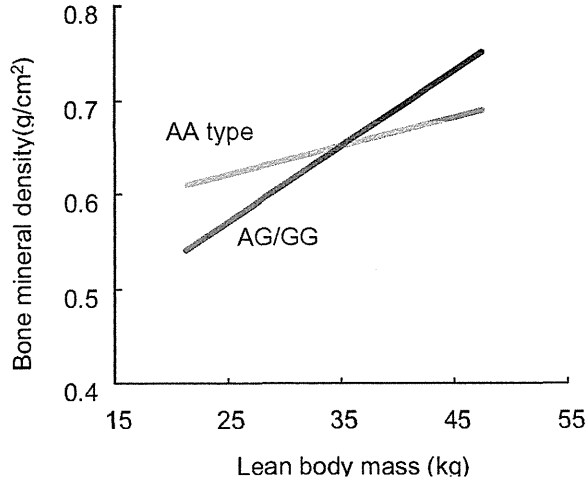

Fig. 3. **The effects of the estrogen receptor (ERα) XbaI genotype on the relationship between BMD and lean body mass in post-menopausal women. The BMD tends to be higher in women with more muscle mass as estimated as lean body mass, and the effect of lean body mass is larger in AG/GG type than in AA type of ERα XbaI genotype (modified from Kitamura *et al.*, 2007 [30]).**

is a fundamental regulator of aging in mice [32]. Mice lacking this protein exhibit multiple aging phenotypes and age-related disorders, including a shortened lifespan, reduced spontaneous activity, arteriosclerosis, infertility, skin atrophy, premature thymic involution, pulmonary emphysema, and osteopenia, although the function of klotho remains to be determined [31,33]. A human homolog of the mouse klotho gene was isolated and its structure was determined [34]. Cognitive impairment was previously shown in klotho gene mutant mice aged seven weeks or over [35]. The klotho gene may be mediate age-related changes in cognitive function in humans.

The effects of klotho gene genotype on cognition were examined in the NILS-LSA [36]. The subjects comprised 2,234 participants in the NILS-LSA aged 40 to 79 years. The klotho gene promoter polymorphism G-395A was identified, and cognitive function was assessed using the Japanese Wechsler Adult Intelligence Scales - Revised Short Forms (JWAIS-R SF) and Mini Mental State Examination (MMSE). The differences in cognitive function were compared between the GG type and GA/AA type of the klotho gene G-395A polymorphism. There was no significant difference in IQ between the GG type and GA/AA type in the subjects aged 40 to 59 years. However, the IQ level was significantly different in terms of the klotho genotype for subjects aged 60 to 79 years (p=0.004). The mean and SE of IQ levels of the subjects with the GG type and the GA/AA type at nucleotide –395 were 99.8 ± 0.5 and 102.6 ± 0.8, respectively. There were also significant differences in three subtests within the JWAIS-R SF: Information, Similarities, and Picture Completion for subjects aged 60 to 79 years. Also, the MMSE score was slightly lower for the GG type than for the GA/AA type (p=0.099).

There were statistically significant differences in cognitive function for klotho gene promoter polymorphism G-395A only in subjects aged 60 or over. This polymorphism may be associated with age-related cognitive impairment, and not associated with cognitive development during childhood to adolescence.

A new genetic strategy for Anti-Aging and prevention of age-related disease

The impact of genetic surveys could be enormously helpful for preventive treatments of geriatric disease as well as Anti-Aging. Previously, associations between disease and genotype were usually investigated by association studies of a specific genotype and a specific disease in molecular epidemiology research. However, we should clarify the following to apply results of epidemiological study to Anti-Aging medicine and preventive medicine: 1) the penetration rates of the genotypes in Japanese; 2) contribution rate to incidence of disease by each susceptibility genotype; 3) factors associated with development of disease in carriers of disease susceptibility genotype; 4) interactive effects with other genotypes; and 5) other physiological effects of the genotype.

These can be investigated in community-dwelling populations and patient cohorts that have detailed background data. Risk of disease can be estimated with the aid of accumulated data. The best-suited education and modification of lifestyles and the content and frequency of examinations for each individual can be determined based on the risk estimation can be applied for disease prevention and Anti-Aging.

Conflict of interest statement

The authors declare no financial or other conflicts of interest in the writing of this paper.

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Relationship between Physical Activity and Brain Atrophy Progression

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ABSTRACT

YUKI, A., S. LEE, H. KIM, R. KOZAKAI, F. ANDO, and H. SHIMOKATA. Relationship between Physical Activity and Brain Atrophy Progression. *Med. Sci. Sports Exerc.*, Vol. 44, No. 12, pp. 2362–2368, 2012. **Introduction**: Brain atrophy is associated with impairment in cognitive function and learning function. The aim of this study was to determine whether daily physical activity prevents age-related brain atrophy progression. **Methods**: The participants were 381 men and 393 women who had participated in both the baseline and the follow-up surveys (mean duration = 8.2 yr). Magnetic resonance imaging of the frontal and temporal lobes was performed at the time of the baseline and follow-up surveys. The daily physical activities and total energy expenditures of the participants were recorded at baseline with uniaxial accelerometry sensors. Multiple logistic regression models were fit to determine the association between activity energy expenditure, number of steps, and total energy expenditure variables and frontal and temporal lobe atrophy progression while controlling for possible confounders. **Results**: In male participants, the odds ratio of frontal lobe atrophy progression for the fifth quintile compared with the first quintile in activity energy expenditure was 3.408 (95% confidence interval = 1.205–9.643) and for the number of steps was 3.651 (95% confidence interval = 1.304–10.219). Men and women with low total energy expenditure were at risk for frontal lobe atrophy progression. There were no significant differences between temporal lobe atrophy progression and physical activity or total energy expenditure. **Conclusion**: The results indicate that physical activity and total energy expenditure are significant predictors of frontal lobe atrophy progression during an 8-yr period. Promoting participation in activities may be beneficial for attenuating age-related frontal lobe atrophy and for preventing dementia.
Key Words: LONGITUDINAL STUDY, MIDDLE AGED AND ELDERLY, ACCELEROMETRY SENSORS, MRI

Atrophy of brain structures is associated with impairment in cognitive function and learning function (the extreme case is Alzheimer disease) (21). Brain atrophy progresses with aging (17). The gray matter volume decreases by approximately 15%, from the 20s through the 70s (38). A previous study reported that a decline in cognitive function is associated with the progression rate of brain atrophy for 6 yr in normal elderly people (33). Thus, preventing brain atrophy may be a promising strategy for preventing cognitive impairment and decline.

Physical exercise appears to induce neurogenesis in the brain not only in animals but also in humans (11). The practice of juggling for 3 months increases the volume of gray matter in the bilateral midtemporal area and in the left posterior intraparietal sulcus in young people (10). Similarly, the increase in brain volume in the anterior cingulate gyrus and frontal pole caused by juggling occurs in elderly people (3). In particular, aerobic exercise appears to suppress global and regional brain atrophy to effectively increase brain volume (14). Relatively little brain structural atrophy is seen in elderly people with high aerobic capacity (7). Six months of aerobic exercise increases the volume of the frontal lobe, temporal lobe, and hippocampus (8). Aerobic capacity is correlated with the preservation of gray matter in the medial–temporal, parietal, and frontal areas in elderly people (18). Aerobic quick-step walking suppresses hippocampal atrophy and improves cognitive function in elderly people (15). These reports suggest the possibility that aerobic exercise prevents brain atrophy.

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We hypothesized that brain atrophy progression can be prevented in middle-age and elderly people with a high level of daily physical activity. Daily physical activities are correlated with aerobic capacity in middle-age and elderly people (2,6). In cross-sectional studies, high physical activity levels are related to larger superior frontal volumes (5). Increased physical activity is associated with greater average brain tissue volumes in the white matter of the corona radiata, extending into the parietal–occipital junction (19). Although daily physical activities may prevent brain atrophy progression, there has been no specific longitudinal analysis showing that daily physical activity maintained at a high level prevents brain atrophy. Recent longitudinal studies have reported that elderly people with high levels of daily physical activity have a low risk of decline in cognitive function (26,34). A demonstration of the prevention of brain atrophy progression by high levels of physical activity in a longitudinal study may support the association between daily physical activity and cognitive function.

The aim of this study was to determine whether high levels of daily physical activity prevent brain atrophy progression with aging. We assessed the progression of frontal and temporal lobe atrophy with aging using 8-yr follow-up surveys and magnetic resonance imaging (MRI) of middle-age and elderly people. We also recorded the amount of physical activity (activity energy expenditure and number of steps) and total energy expenditure using a uniaxial accelerometry sensor. We evaluated the association between brain atrophy progression and daily physical activity and total energy expenditure in 774 community-living, middle-age, and elderly Japanese people using longitudinal analysis.

METHODS

Participants. The participants in this study were derived from the National Institute for Longevity Sciences, Longitudinal Study of Aging (NILS-LSA), which involves ongoing population-based biennial examinations of a cohort of approximately 2300 persons. The participants in the NILS-LSA were randomly selected from resident registrations and stratified by both decade of age and sex. The NILS-LSA is a comprehensive and interdisciplinary study to observe age-related changes and consists of various gerontological and geriatric measurements, including medical examinations, blood chemical analysis, body composition, anthropometry, nutritional analysis, psychological tests, physical function, and physical activity. Details of the NILS-LSA have been described elsewhere (35).

The baseline participants of this study were 1526 middle-age and elderly people (773 men and 753 women) who completed the second wave examinations of NILS-LSA between April 2000 and May 2002. Of these, 942 (61.6%, 481 men and 461 women) participated in the 8-yr follow-up surveys (NILS-LSA sixth wave examination from July 2008 to July 2010). The dropouts were 584 participants (292 men and 292 women). In male and female participants, the age at baseline of the dropouts was significantly higher than that of the participants who completed both examinations (*t*-test, $P < 0.0001$). In male participants, the ratios of stroke and ischemic heart disease histories in dropouts were significantly higher than those in participants who completed both examinations (chi-square test: stroke, $P = 0.0002$; ischemic heart disease, $P = 0.0019$). In female participants, there were no differences in the ratios of stroke and ischemic heart disease histories between the dropouts and the participants who completed both examinations. In male and female participants, the ratio of diabetes histories in dropouts was significantly higher than that in participants who completed both examinations (chi-square test: men, $P = 0.0077$; women, $P = 0.0369$). There were no differences in the ratios of hypertension and hyperlipidemia histories between the dropouts and the participants who completed both examinations in men or women. There were no differences in the ratios of severe atrophy in the frontal and temporal lobe between the dropouts and the participants who completed both examinations in men or women.

Participants with severe atrophy in the second wave examination were excluded because severe atrophy was of a high-end grade that cannot be used to determine further atrophy progression. Participants in their 40s were also excluded because few participants of this age show brain atrophy progression. Participants with a current medical history of Parkinson disease, dementia, or open head surgery were also excluded. Finally, the participants for this study were 381 men and 393 women.

The study protocol was approved by the Ethics Committee of the National Center for Geriatrics and Gerontology, and written informed consent was obtained from all participants.

Brain MRI examination. Brain MRI was performed on participants at the second and sixth wave examinations using a 1.5-T scanner (Toshiba Visart, Tokyo, Japan) at the National Center for Geriatrics and Gerontology. Each participant's head was oriented in the scanner and stabilized during the scanning procedure by a head support. To establish slice orientation, the first scanning sequence consisted of a T1-weighted sagittal series (repetition time (TR) = 500 ms, echo time (TE) = 15 ms, 256 × 256 matrix) centered along the midline to define the orbitomeatal line. The second series of T1-weighted axial images (TR = 500 ms, TE = 15 ms, thickness = 8 mm, gap = 1.5 mm, 256 × 256 matrix) and T2-weighted axial images (TR = 4000 ms, TE = 120 ms, thickness = 8 mm, gap = 1.5 mm, 320 × 320 matrix) were oriented parallel to the orbitomeatal line. Fourteen slices were taken during each examination.

The presence and the degree of brain atrophy in the frontal and temporal lobes were assessed as no atrophy (I), mild atrophy (II), moderate atrophy (III), and severe atrophy (IV) (25,36). The participants were divided into two groups on the basis of results from the MRI in the second wave examination and sixth wave examination: the brain atrophy progression group (progress: degree of brain atrophy in the second wave < sixth wave) and the brain atrophy non-progression group.

Daily physical activities and total energy expenditure assessments. We recorded the daily physical activities and total energy expenditures of the participants at the second wave examinations using a uniaxial accelerometry sensor (Lifecorder; Suzuken, Aichi, Japan). Lifecorder can assess two types of activity energy expenditure by activity level: energy expenditure of activities (with body movements) and energy expenditure of minor activities (working at a desk or reading a book). In this study, the activity energy expenditure was estimated as the energy expenditure of both types of activities. The total energy expenditure was determined as the sum of basal metabolism, energy expenditure of activities, energy expenditure of minor activities, and thermic effects of food. Participants wore the Lifecorder constantly (except while sleeping or bathing) for a 7-d period. We calculated the mean activity energy expenditure, the number of steps, and the total energy expenditure from 5 d of records (the maximum and the minimum records were excluded).

Other parameters. Body height and weight were measured using a digital scale. Body mass index (BMI) was calculated as weight divided by height squared ($kg \cdot m^{-2}$). Body fat mass was assessed by dual x-ray absorptiometry (QDR-4500A; Hologic, Bedford, MA). Lifestyle factors (including alcohol intake, smoking habit, and education levels), medical history, and use of medications were assessed with questionnaires. These questionnaires were confirmed by a physician at the medical examinations. All prescribed and nonprescribed medications used during the previous 2 wk were documented and brought by the participants; the physicians confirmed and coded them. Users of antihypertensive, antilipemic, or hypoglycemic medications were considered participants with hypertension, hyperlipidemia, and diabetes histories, respectively.

Statistical analysis. The results are shown as the mean ± SD or mean ± SE. Differences in continuous and class variables between the progression and the nonprogression groups were assessed with *t*-tests and chi-square tests, respectively. Cochran–Mantel–Haenszel statistics were used to examine the relationship between the age group and the brain atrophy progression. Multiple logistic regression models were fit to determine the associations of activity energy expenditure, number of steps, and total energy expenditure variables with frontal and temporal lobe atrophy progression while controlling for the baseline decade of age group (38), BMI (19), education history (19), medical history (stroke, ischemic heart disease, hypertension, hyperlipidemia, and diabetes) (4,12,24), and current smoking and alcohol intake as possible confounders (9,37). Activity energy expenditure, number of steps, and total energy expenditure were modeled as sex-specific quintiles. Statistical testing was performed using the Statistical Analysis System release 9.1.3 (SAS Institute Inc., Cary, NC). Significant probability levels were considered to be less than 0.05.

RESULTS

Characteristics of the participants. Table 1 shows elementary statistics of the study variables in male and female participants. The mean follow-up durations of all participants were 8.2 ± 0.3 yr. There were no significant differences in baseline age, BMI, or number of steps between male and female participants. Body height and weight, alcohol intake, and education history were significantly higher in male participants than those in female participants (each, $P < 0.0001$). The percentage of body fat in female participants was significantly higher than that in male participants ($P = 0.0126$). The activity and total energy expenditures in men were significantly higher than those in women (each, $P < 0.0001$). There were no sex differences in the ratios of stroke, ischemic heart disease, and hypertension histories. The ratio of hyperlipidemia history in female participants was significantly higher than that in male participants ($P = 0.0060$). The ratios of diabetes history and smoking habits in male participants were significantly higher than that in female participants (diabetes history, $P = 0.0126$; smoking habits, $P < 0.0001$).

TABLE 1. The characteristics of participants at the time of the second wave examination of the NILS-LSA, 2000–2002.

	Male ($n = 381$)	Female ($n = 393$)	*P*
Mean follow-up (yr)	8.2 ± 0.3	8.2 ± 0.3	0.5777
Age (yr)	60.4 ± 7.3	60.8 ± 7.6	0.5421
Body height (cm)	164.7 ± 5.4	152.2 ± 5.2	<0.0001
Body weight (kg)	62.5 ± 7.1	52.7 ± 7.0	<0.0001
BMI ($kg \cdot nm^{-2}$)	23.0 ± 2.4	22.7 ± 2.9	0.1279
% body fat	21.0 ± 4.0	31.3 ± 4.9	<0.0001
Alcohol intake ($g \cdot d^{-1}$)	16.6 ± 20.9	2.7 ± 6.1	<0.0001
Education (yr)	12.3 ± 2.7	11.4 ± 2.3	<0.0001
Activity energy expenditure ($kcal \cdot d^{-1}$)	215.1 ± 78.5	175.1 ± 64.8	<0.0001
No. of steps per day	7993.2 ± 2588.0	7925.6 ± 2297.1	0.7011
Total energy expenditure ($kcal \cdot d^{-1}$)	1932.3 ± 168.5	1607.5 ± 150.0	<0.0001
With medical history, *n* (%)			
Stroke	14 (3.7%)	7 (1.8%)	0.1050
Ischemic heart disease	13 (3.5%)	19 (4.8%)	0.3203
Hypertension	40 (10.5%)	40 (10.2%)	0.8836
Hyperlipidemia	61 (16.0%)	94 (23.9%)	0.0060
Diabetes	32 (8.4%)	16 (4.1%)	0.0126
Smoking habit	102 (26.8%)	27 (6.9%)	<0.0001

Values are presented as mean ± SD. *P* values were obtained using the *t*-test for continuous data and the chi-square test for categorical data.

TABLE 2. The ratio of frontal and temporal lobe atrophy progression in participants from the second (2000–2002) to the sixth (2008–2010) wave examination of the NILS-LSA.

	Frontal Lobe Atrophy			Temporal Lobe Atrophy		
	Nonprogression	Progress	Trend *P*	Nonprogression	Progress	Trend *P*
Male, *n* (%)						
Age group						
50s	176 (95.1%)	9 (4.9%)	<0.001	156 (84.3%)	29 (15.7%)	<0.001
60s	112 (79.4%)	29 (20.6%)		87 (61.7%)	54 (38.3%)	
70s	38 (69.1%)	17 (30.9%)		38 (69.1%)	17 (30.9%)	
Total	326 (85.6%)	55 (14.4%)		281 (73.8%)	100 (26.3%)	
Female, *n* (%)						
Age group						
50s	191 (96.0%)	8 (4.0%)	<0.001	188 (94.5%)	11 (5.5%)	<0.001
60s	117 (90.0%)	13 (10.0%)		92 (70.8%)	38 (29.2%)	
70s	50 (78.1%)	14 (21.9%)		35 (54.7%)	29 (45.3%)	
Total	358 (91.1%)	35 (8.9%)		315 (80.2%)	78 (19.8%)	

The trend *P* values were obtained using the Cochran–Mantel–Haenszel test.

Progress of frontal and temporal lobe atrophy. Table 2 shows comparisons of the incidence of frontal and temporal lobe atrophy progression in each age group. Frontal lobe atrophy progression from the second wave examination to the sixth wave examination was present in 55 (14.4%) of 381 male participants and 35 (8.9%) of 393 female participants. The ratio of participants with frontal lobe atrophy progression in male participants was significantly higher than that in female participants ($P = 0.0213$). Aging raised the percentage of participants with frontal lobe atrophy progression in men and women (P trend <0.0001).

Temporal lobe atrophy progression from the second wave examination to the sixth wave examination was present in 100 (26.3%) of 381 male participants and 78 (19.8%) of 393 female participants. The ratio of participants with temporal lobe atrophy progression in male participants was significantly higher than that in female participants ($P = 0.0344$). Aging raised the percentage of participants with temporal lobe atrophy progression in men and women (P trend <0.0001).

Brain atrophy progression and physical activity level. Table 3 shows the activity energy expenditure, number of steps, and total energy expenditure in the frontal and temporal lobe atrophy progression and nonprogression groups. In the frontal lobe, activity energy expenditure ($P = 0.0095$), number of steps ($P = 0.0131$), and total energy expenditure ($P < 0.0001$) were significantly higher in the male nonprogression group than the progression group. In female participants, total energy expenditure was significantly higher in the nonprogression group than that in the progression group ($P = 0.0097$). There were no differences in the activity energy expenditure or number of steps between the female nonprogression and progression groups.

In the temporal lobe, there were no differences in the activity energy expenditure or number of steps between the nonprogression and the progression groups in male or female participants. The total energy expenditure was significantly higher in the nonprogression group than that in the progression group in male ($P = 0.0028$) and female ($P = 0.0096$) participants.

Risk of brain atrophy progression according to physical activity level differences. The results of multiple logistic regression analyses for risk of brain atrophy progression according to differences in the physical activity level in men and women are shown in Tables 4 and 5, respectively. In male participants, the odds ratio of frontal lobe atrophy progression for the comparison between the fifth quintile in activity energy expenditure and the first quintile was 3.408 (95% confidence interval (CI) = 1.205–9.643). The odds ratio of frontal lobe atrophy progression for the comparison between the fifth quintile in number of steps and the first quintile was 3.651 (95% CI = 1.304–10.219). The odds ratios of frontal lobe atrophy progression for the comparison between the fifth quintile in total energy expenditure and the first and third quintiles were 4.816 (95% CI = 1.037–22.376) and 4.639 (95% CI = 1.191–18.067), respectively.

In female participants, there were no significant differences between frontal lobe atrophy progression and physical activity parameters. The odds ratios of frontal lobe atrophy progression for the comparison between the fifth quintile in total energy expenditure and the first to the third quintiles

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TABLE 3. Mean activity energy expenditure, number of steps, and total energy expenditure per day in each group.

	Frontal Lobe Atrophy			Temporal Lobe Atrophy		
	Nonprogression	Progress	*P*	Nonprogression	Progress	*P*
Male (*n*)	326	55		281	100	
Activity energy expenditure (kcal·d^{-1})	219.3 ± 4.4	189.7 ± 9.9	0.0095	217.3 ± 4.6	208.8 ± 8.1	0.3503
No. of steps per day	8128.0 ± 143.6	7194.3 ± 327.4	0.0131	7983.1 ± 155.1	8021.8 ± 256.6	0.8979
Total energy expenditure (kcal·d^{-1})	1947.0 ± 9.2	1845.22 ± 1.2	<0.0001	1945.6 ± 10.1	1895.0 ± 15.9	0.0097
Female (*n*)	358	35		315	78	
Activity energy expenditure (kcal·d^{-1})	176.4 ± 3.4	161.6 ± 10.1	0.1965	176.7 ± 3.7	169.4 ± 6.9	0.3664
No. of steps per day	7984.9 ± 121.8	7318.7 ± 365.6	0.1016	7997.4 ± 130.1	7699.5 ± 254.6	0.3043
Total energy expenditure (kcal·d^{-1})	1614.5 ± 7.9	1535.4 ± 21.8	0.0028	1616.5 ± 8.3	1567.7 ± 17.8	0.0096

Values are presented as means ± SE. The *P* values were obtained using the *t*-test.

TABLE 4. Adjusted odds ratios of frontal and temporal lobe atrophy progression in male participants distributed into quintiles of physical activity and total energy expenditure data.

	Odds Ratio, 95% CI				
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Frontal lobe (*n*)	76	76	76	76	77
Activity energy expenditure (kcal·d^{-1})	3.408, 1.205–9.643 (<143.2)	1.054, 0.321–3.462 (143.2 to <184.4)	1.623, 0.523–5.035 (184.4 to <226.2)	2.054, 0.691–6.904 (226.2 to <284.4)	1.00, referent (≥284.4)
No. of step per day	3.651, 1.304–10.219 (<5736.0)	1.216, 0.383–3.863 (5736.0 to <6955.0)	1.487, 0.471–4.689 (6955.0 to <8261.4)	2.403, 0.819–7.052 (8261.4 to <10,407.4)	1.00, referent (≥10,407.4)
Total energy expenditure (kcal·d^{-1})	4.816, 1.037–22.376 (<1771.4)	2.758, 0.652–11.672 (1771.4 to <1897.4)	4.639, 1.191–18.067 (1897.4 to <1983.4)	2.275, 0.553–9.358 (1983.4 to <2091.2)	1.00, referent (≥2091.2)
Temporal lobe (*n*)	76	76	76	76	77
Activity energy expenditure (kcal·d^{-1})	1.015, 0.473–2.178 (<143.2)	1.293, 0.617–2.708 (143.2 to <184.4)	0.800, 0.364–1.756 (184.4 to <226.2)	0.845, 0.390–1.833 (226.2 to <284.4)	1.00, referent (≥284.4)
No. of step per day	0.938, 0.435–2.024 (<5736.0)	1.100, 0.519–2.330 (5736.0 to <6955.0)	1.142, 0.538–2.425 (6955.0 to <8261.4)	1.123, 0.528–2.389 (8261.4 to <10,407.4)	1.00, referent (≥10,407.4)
Total energy expenditure (kcal·d^{-1})	1.045, 0.388–2.816 (<1771.4)	1.303, 0.554–3.065 (1771.4 to <1897.4)	1.229, 0.537–2.810 (1897.4 to <1983.4)	1.006, 0.439–2.307 (1983.4 to <2091.2)	1.00, referent (≥2091.2)

Odds ratios were controlled for age, BMI, education history, medical history (stroke, ischemic heart disease, hypertension, hyperlipidemia, and diabetes), current smoking, and alcohol intake in a multinomial logistic regression model.

were 12.363 (95% CI = 1.029–148.594), 12.743 (95% CI = 1.292–125.792), and 21.539 (95% CI = 2.381–194.839), respectively.

We also evaluated temporal lobe atrophy progression using the adjustment model, similar to the frontal lobe atrophy progression analysis. There were no significant differences between temporal lobe atrophy progression and physical activities or total energy expenditure (Tables 4 and 5) in any groups of participants.

DISCUSSION

Using longitudinal analyses, we showed that a high level of physical activity and total energy expenditure suppressed the frontal lobe atrophy progression that is induced by aging.

An inactive daily life appears to be a risk factor for frontal lobe atrophy progression. In male participants, those with the lowest activity energy expenditure (first quintile, <143.2 kcal) had a 3.408-fold risk of frontal lobe atrophy progression compared with those with the highest activity energy expenditure (fifth quintile, ≥284.4 kcal) (Table 4). Similarly, men with the fewest number of steps (first quintile, <5736.0 steps) had a 3.651-fold risk of frontal lobe atrophy progression compared with those with the most number of steps (fifth quintile, ≥10,407.4 steps) (Table 4). An activity energy expenditure of 143.2 kcal is equivalent to activity in 4 METs (e.g., raking the lawn and table tennis) for 33 min in 62.5-kg men (1). Thirty minutes of middle-intensity or greater activities per day, such as 5700 steps or more walking per day, may be necessary to reduce the risk of frontal lobe atrophy progression. In addition, daily physical activity decreases with aging (27). An increase in planned physical activities may be necessary to prevent frontal lobe atrophy progression in older people.

Not only the expenditure of energy with physical activity but also the energy metabolic rate of the whole body appears to be associated with frontal lobe atrophy. Low total energy expenditure tended to be a risk for frontal lobe atrophy in male and female participants (Tables 4 and 5). In a study of prosimians and anthropoid apes and humans, brain volume is correlated with basal metabolism (23). The amount of basal metabolism may determine frontal lobe atrophy progression. It is well known that basal metabolism decreases with aging (32). Age-related skeletal muscle loss (sarcopenia) may be a risk factor for frontal lobe atrophy progression due to decreasing basal metabolism. Physical activity may compensate for a reduction in basal metabolism in the elderly.

TABLE 5. Adjusted odds ratios of frontal and temporal lobe atrophy progression in female participants distributed into quintiles of physical activity and total energy expenditure data.

	Odds Ratio, 95% CI				
	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Frontal lobe (*n*)	78	79	78	79	79
Activity energy expenditure (kcal·d^{-1})	1.442, 0.421–4.945 (<119.6)	1.422, 0.435–4.644 (119.6 to <148.4)	0.610, 0.148–2.520 (148.4 to <182.8)	1.233, 0.362–4.199 (182.8 to <226.4)	1.00, referent (≥226.4)
No. of step per day	1.559, 0.420–5.791 (<5825.2)	2.269, 0.627–8.209 (5825.2 to <7090.0)	0.826, 0.181–3.769 (7090.0 to <8374.0)	1.887, 0.505–7.053 (8374.0 to <9910.4)	1.00, referent (≥9910.4)
Total energy expenditure (kcal·d^{-1})	12.363, 1.029–148.594 (<1495.6)	12.743, 1.292–125.792 (1495.6 to <1570.2)	21.539, 2.381–194.839 (1570.2 to <1639.6)	4.261, 0.430–42.214 (1639.6 to <1722.0)	1.00, referent (≥1722.0)
Temporal lobe (*n*)	78	79	78	79	79
Activity energy expenditure (kcal·d^{-1})	0.978, 0.362–2.645 (<119.6)	1.023, 0.400–2.614 (119.6 to <148.4)	1.569, 0.591–4.162 (148.4 to <182.8)	1.547, 0.617–3.876 (182.8 to <226.4)	1.00, referent (≥226.4)
No. of step per day	0.879, 0.355–2.178 (<5825.2)	0.789, 0.311–2.005 (5825.2 to <7090.0)	0.825, 0.317–2.147 (7090.0 to <8374.0)	1.206, 0.489–2.974 (8374.0 to <9910.4)	1.00, referent (≥9910.4)
Total energy expenditure (kcal·d^{-1})	0.881, 0.260–2.984 (<1495.6)	1.127, 0.405–3.138 (1495.6 to <1570.2)	0.948, 0.337–2.668 (1570.2 to <1639.6)	1.285, 0.499–3.305 (1639.6 to <1722.0)	1.00, referent (≥1722.0)

Odds ratios were controlled for age, BMI, education history, medical history (stroke, ischemic heart disease, hypertension, hyperlipidemia, and diabetes), current smoking, and alcohol intake in a multinomial logistic regression model.