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Obesity, functional mobility and quality of life

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Obesity is a health condition that, through a complex interaction of biopsychosocial and environmental factors, is associated with mobility disability. The mobility disability experienced by persons with obesity is associated with reduced health related quality of life (HRQoL) compared to persons without obesity. This paper will review and discuss functional mobility and its relationship to HRQoL for persons living with obesity. This will be done by conducting a review of the literature in the area of obesity and functional mobility and it's association with HRQoL. Recommendations to address the known factors that contribute to mobility disability and reduced quality of life are outlined while suggestions for research to contribute to best practice to enable mobility for persons with obesity are made.

Introduction

Patients with obesity are routinely advised by their health care provider to become more physically active for the purpose of losing weight and reducing cardiovascular and metabolic risk profiles. Although such advice is well intended to promote health and wellness, changes to physical activity levels and the associated benefits are illusive unless issues related to functional mobility are addressed. Understanding the determinants of functional mobility in persons with obesity will help practitioners to improve health related quality of life in their patients by developing treatments to address their co-

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occurrence. If a patient with obesity is not able to move around at an intensity and frequency required to lose weight or prevent weight gain they are at greater risk of experiencing mobility disability and those patients with impaired mobility will continue to experience restrictions in activities at home, work, school and in the community thereby having a negative impact on their health related quality of life.

Functional mobility is defined as the manner in which people are able to move around in the environment in order to participate in the activities of daily living and, move from place to place. Movements include standing, bending, walking and climbing. Functional mobility provides opportunities for a person to engage in physical activities at home, school and in the community thereby contributing to health related quality of life. Such engagement is labeled as participation in the International Classification of Functioning and Disability (ICF).[1] The ICF was developed by the World Health Organization (WHO) to provide a universal framework to describe how people live with a health condition such as obesity.[1] The use of the ICF to explore the impact of obesity on functional mobility provides a framework to consider how body functions and structural impairments and personal and environmental factors contribute to functional mobility and health related quality of life.[2,3] The ICF framework will be used to organize this review of factors that contribute to functional mobility and influence participation in physical exercise and activity for patients with obesity and thereby quality of life and to identify gaps in knowledge. Fig. 1 illustrates how mobility disability and functioning are viewed as an outcome of the interactions between obesity, body functions and structures and personal factors and environmental factors.

The ICF is useful to identify factors that may contribute to functional mobility however it does not provide a way in which to quantify functional mobility. Classification systems exist to describe functional mobility in children with neurological disorders such as cerebral palsy[4] and in adults with musculoskeletal disorders such as rheumatoid arthritis.[5] The Timed Up and Go (TUG) Test is commonly used to classify mobility function and has been shown to be a valid predictor of performance in activities of daily living[6] however the body mass of participants in that study was not reported therefore it is not known if the cut points used on the TUGS could be applied to patients with obesity. Existing mobility classification systems have not been validated for use by children or adults with obesity nor has a system been developed to assess functional mobility for persons with obesity despite the fact that functional mobility is included in emerging obesity staging systems designed to guide clinical decisions in the treatment of obesity.[7,8] A unique feature for some patients with obesity and for those who have experienced massive weight loss is the presence of excessive tissues in the upper and

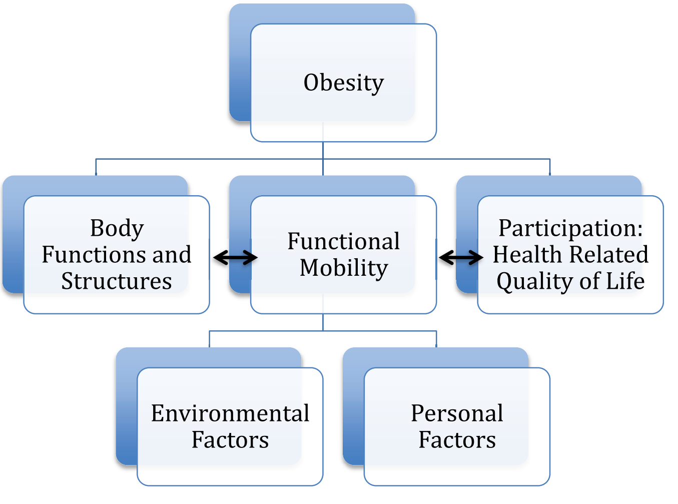

Fig. 1. Illustration of how mobility disability and functioning and health related quality of life are viewed as an outcome of the interactions between obesity, body functions and structures, environmental factors and personal factors. Adapted from the WHO.[1]

lower extremities and abdominal region (hereby referred to as an abdominal pannus) that could restrict functional mobility. Although no studies on the effect of excessive tissue, skin folds and an abdominal pannus on mobility were found, practitioners recognize the potential of such features to restrict performance of daily activities including functional mobility.[8] This has resulted in the development of a classification system for use by practitioners to guide decisions about surgical interventions to address functional impairments caused by excessive tissue.[8] To date, this classification system is not widely used or recognized. Industry produced guidelines to enable safe lifts, transfers and mobilization of patients with obesity using assistive devises exist, however these recommendations are based on in-house industry standards. If evidence from clinical trials was used to develop these recommendations the source of such evidence was not identified. In order to make recommendations to address limitations to functional mobility in persons with obesity a better understanding of the mechanisms and process of mobility disability and function as outcomes associated with obesity is needed.

Body functions and structures

Body functions are defined as the physiological functions of the body systems and body structures includes organs, limbs and their components. Evidence from studies of mobility that explore body functions and structures associated with functional mobility include topics related to gait, posture, bones and joints, neurocognitive function, and pain.

Postural control

Obesity is associated with reduced postural control and stability that could hinder the ability to adapt to changes in terrain or grades during walking. One of the reasons for this is the abnormal distribution of body fat in the abdominal area. This leads to a forward anterior posterior (AP) center of pressure; meaning that they carry their weight toward the front of their feet, and AP instability during static and dynamic balance.[9,10] Therefore, the changes to temporospatial gait parameters (distance between steps and number of steps per minute) have been interpreted as a compensatory mechanism for the instability created by abnormal body fat distribution.[11] However, these changes, while attempting to improve balance, may actually threaten the ability to recover when a loss of balance occurs leading to more cases of falls and injuries and perpetuate patterns of walking that lend themselves to falling such as tripping.[12]

Impact on bones and joints

Maintaining skeletal health particularly at the knee and hip joints could be another explanation for the differences in gait parameters between obese patients and non-obese patients. The altered walking pattern used by all ages of obese individuals leads to decreased knee torque and reduced impact on proximal leg joints (i.e. knee joint & hip joint) while walking.[13,14] The modified gait pattern acts as a mechanism to maintain skeletal health with the addition of extra body weight due to obesity.[13] While this mechanism may maintain skeletal health in the short term, chronic adjustments to the musculoskeletal system to accommodate excess body weight are a concern.

Over a period of 10 years or more, obese adults are more likely to develop knee osteoarthritis (OA) than normal weight adults.[15] There is a dose-response relationship between obesity and knee OA, meaning the greater an individual's body mass index (BMI), the greater the likelihood of developing knee OA.[15] The same prevalence and relationship between the two variables is seen among elderly obese individuals as well.[16–18] This cross-sectional data suggest that obesity or unknown factors associated with obesity cause knee OA.[16,17]

Existing evidence shows that a high BMI is associated with and increased risk of knee osteoarthritis, particularly in older adults (>65 years of age) that is likely caused by a higher weight exertion across the knees compared to that of the hips during weight bearing activities such as walking.[16,19] There is speculation that obesity precedes the presentation of OA and contributes to the development of OA as a result of chronic mechanical strain on weight-bearing joints.

Compromised bone strength is a musculoskeletal deficiency observed in children with obesity. Normally, more weight is linked to greater bone development, however once adjusted for maturational age, it has been shown that obese children have lower bone mass density (BMD) compared to normal weight children (Goulding et al., 2001). Physical activity may have something to do with these finding because it is a good predictor of bone mass. Obese children are less physically active than their normal weight counterparts and this decreased activity level contributes to their decrease in BMD and bone strength.[20] While this phenomenon has not been observed in the adult population there is one study that suggests excess weight due to fat mass could possibly be detrimental to adult bone health as well. A study with young adult females predicted bone failure in these individuals using the peripheral quantitative computed tomography (pQCT) method, which takes into account bone size, shape, and mineral density to determine bone strength.[21] After adjusting for muscle cross-sectional area, the percentage body fat was inversely related to pQCT scores.[21] High body weight due to fat mass is not advantageous to skeletal health and actually leads to lower overall bone strength. While this research in young adults did not find decreased BMD in obese individuals as has been seen in children, the end result is the same; bone strength in the obese population in compromised.

Neurocognitive function

Studies attempting to establish a connection between obesity and cognitive function (i.e. motor planning) are at their inception, but there is evidence that obesity negatively impacts performance on cognitive tasks across the life span. For example, obese children and adolescents (8–16 years old) perform significantly worse on cognitive tasks of visuospatial organization and global executive functioning than non-obese children of the same age and socioeconomic status.[22] Second, obese adults (specifically with BMIs >35) perform poorly on tasks of executive function involving planning and mental flexibility when compared to normal weight individuals.[23] Last, older obese adult males showed deficits in cognitive functioning when completing cognitive tasks evaluating learning and visual memory.[24] Each of the mentioned components of cognition effected by obesity are keys to motor planning and if impaired could result in a weakened ability to plan motor actions.

Due to the infancy of research in this area the reasons for the relationship between obesity and cognitive function remain unclear. However, possible causes include impaired metabolic processing that affects brain structures involved in planning and organization (i.e. cerebellum).[25] Recent imaging studies in children suggest that reduced cerebellar function may be related to obesity and perhaps the same may hold true for adults and the elderly.[26] Also, decreased oxygen flow to the brain due to the obese population's lack of physical activity could be responsible for impaired spatial abilities needed to motor plan.[27] Each of these suggestions could have a negative effect on the cognitive abilities (specifically motor planning) of obese individuals of all ages. These negative effects result in an inability to meet the cognitive demands required to adapt during movement. The failure to quickly and effectively adapt to change while walking can lead to injuries and poses a serious safety risk for obese people of all ages.

Pain

Increased OA and knee pain is associated with greater BMI scores; the higher the BMI the higher the degree of pain reported in the knee joint.[28] Pain in the lower extremities can cause gait abnormalities (e.g. limping). While OA is not of concern for obese children and adolescents because it usually takes years to form, joint pain from being over weight still is. Joint pain specifically located in the knee and hip is has been associated with higher BMIs in obese children; again the higher the BMI, the higher the degree of pain reported.[29] Therefore, for obese children, the case still stands that increased joint pain, specifically at the knee, could cause loss of stability and result in falling.

A review of evidence about the relationship between pain and obesity concluded that evidence from cross sectional studies show a relationship between obesity and conditions known to cause pain such as OA and low back pain (LBP).[30] Authors of the review also concluded that evidence from longitudinal studies show that obesity experienced in childhood increased the risk of developing OA or LBP.[30] Janke et al.[30] also concluded that the co-occurrence of pain and obesity has an additive effect on HRQoL based on a study of patients with obesity seeking treatment for chronic pain[31] and treatment for obesity.[32] Pain may mediate the relationship between BMI and functional mobility and thereby negatively influence HRQoL.

Activities and tasks: functional mobility

An activity is the execution of a task or action by an individual and for the purpose of this review will focus on activities and tasks such as walking and stability required for functional mobility.

Walking speed

Many of the impairments to walking related to obesity can be attributed to differences in temporospatial gait parameters observed between obese and normal weight populations. When walking at a self selected pace, obese individuals walk at a slower velocity with shorter stride length and spend more time with their feet contacting the ground via longer double support times (amount of time both feet are on the ground simultaneously while walking) and stance times (amount of time either one or both feet are in contact with the ground during walking).[33] Obese adults also walk at a slower cadence (steps per minute) with wider step widths and shorter swing times (amount of time foot swings in the air between steps).[11] Many of these same characteristics hold true for obese children. For example obese children also demonstrate a slower cadence, shorter swing time and increased double support and stance times while walking at preferred speeds.[34,35] There has been considerably less information done in this area with the older adult obese population. However, the work done indicates slower walking speeds, larger step widths, and longer stance times, which is consistent with what is seen in the younger populations.[14]

Stability

Obesity in all ages is associated with impairments in many aspects of body functions and structures involved in walking that affect adaptation, which can lead to falls and injuries.[36]

While it has not been directly investigated, increased knee pain from OA could result in a higher incidence of falls. For example, when knee pain is artificially induced in healthy adults, via saline injections into the knee joint postural control and stability is compromised during quiet standing.[37] When the induced pain is unilateral increased anterior–posterior (AP) displacement is observed, and when the pain is bilateral increased AP and medial–lateral (ML) sway displacement is seen.[37] Based on these findings, it can be argued that the pain felt by obese adults and older adults with OA could impair their postural control and stability putting them at risk for loss of balance and falls.

Obesity may also affect adaptation and mobility by limiting an individual's ability to motor plan, the ability to pre-plan a movement before the movement is executed. Poor motor leads to poor performance on tasks.[25] This could be a detriment to adaptation because adaptive behavior involves tailoring actions to variations in one's environment. Therefore motor plans need to be changed during motor actions.[38] In the obese population, poor motor planning and an inability to adapt motor plans during the course of action could lead to more frequent losses of balance or the inability to recover from unavoidable losses of balance.

Personal factors

Personal factors include sex, age, and past and current experience and for the purpose of this review will be considered in terms of their influence on how mobility disability is experienced by the individual. Age has been identified as a factor that contributes to mobility disability however, as previously mentioned, obesity early in life leads to an increased risk of mobility disability later in life. It has been suggested that maintaining a stable weight in older adults could be important in preventing functional mobility limitations.[39] Results of studies of obese elderly populations show no differences in the functional mobility (moving from sitting to standing) compared to healthy weight elderly counterparts however researchers have found differences in the anterior posterior acceleration time to reach the peak extension angular velocity from initiation and double support time between lean and obese groups of participants leading researchers to conclude that obese elderly may have more muscular impairments that could contribute to the higher prevalence of falls experience by obese elderly compared to health weight elderly.[36]

Environmental factors

Environmental factors include aspects of the physical, social and attitudinal environment in which people live. For the purpose of this review, the focus will be on aspects of the physical environment in which people mobilize.

Functional mobility is in part determined by factors in the environment that contribute to a person's ability to move around. Research in the area of environmental factors and functional mobility include walking on slippery surfaces, inclines and declines. Such studies have not specifically focused on persons with obesity so it is not known if persons with obesity would respond the same way to these factors. However, results from a cross sectional study on neighborhood walking among adults with obesity showed that bad weather, inadequate lighting, no shade, disconnected sidewalks, poor walking surfaces, and no benches were perceived as barriers to walking with participants who were classified as older adults reporting a fear of injury as an additional barrier to walking.[40]

Health related quality of life and mobility

Health related quality of life (HRQoL) is defined as the effect of a medical condition such as obesity on well-being and physical function. Information obtained to classify HRQoL has typically been collected via self-report in patients with obesity using various measures including the Rand 36-item Health Survey, Health Status Questionnaire-12, EuroQoL, the Impact of Weight on Quality of Life (IWQOL) and the Medical Outcomes Study 36-item Short Form (SF-36) Health Survey. Each of these measures includes items pertaining to functional mobility such as being able to rise from a sitting to standing position, lower from a standing to sitting position, rise from a lying to sitting position and to move around a defined space such the home, institutional or community environment. Evidence from studies of quality of life of persons with obesity consistently shows an inverse relationship between obesity severity and self-reported quality of life that includes functional mobility. Severe obesity, classified as a body mass index of $\geq$40 kg/m^2 is associated with poor HRQoL, specifically the sub scores related to mobility.[41]

Implications for clinical practice

Understanding and addressing the body functions and structures impairments associated with obesity along with the personal and environmental factors that influence functional mobility is key to developing safe and effective interventions that may increase participants ability to engage in physical exercise.

Existing evidence shows that patients with obesity adapt their gait in order to accommodate excess weight and temporarily protect bones and joints however by doing so put themselves at greater risk for damage to their knee joints and associated pain. Additionally, these differences in gait parameters put the patient with obesity at high risk for falls and resulting injuries. Emerging research suggests that in addition to impairments of the musculoskeletal system those patients with obesity may also have cognitive impairments that could interfere with motor planning and therefore also contribute to mobility disability. The age of the patient, distribution of body fat, and factors in the environment in which the person plans to be physically active must also be considered. Given the apparent multidimensional nature of factors contributing to mobility disability for patients with obesity, simply advising patients to move more is likely to be met with exercise non-adherence and interpreted as non-compliance to physician recommendations. In the absence of existing best practice guidelines to treat mobility disability for patients with obesity, it is suggested that the practitioner continue to suggest that a patient engage in physical exercise but to be mindful of the targets set for exercise. Public health messages promoting the frequency and duration of physical activity to promote health and prevent chronic disease do not consider the demands for physical activity for persons with obesity and therefore may not be applicable to patients with obesity. In fact, studies exploring the energy expenditure associated with walking in obese participants compared to non-obese participants show that groups of patients with obesity require twice as much energy to walk one kilometer and therefore it is possible that persons with obesity may not need to walk as far as their non-obese counterparts to burn the same amount of energy.[42]

In addition to recommending that patients exercise, practitioners need to go further to identify barriers to functional mobility and to target strategies to address the barriers through remediation of impaired body functions and structures where possible and through compensatory strategies such as the use of assistive devices and adaptations to physical exercise. Although the gait parameters differ between obese and non-obese persons it accounts for only 15% of the metabolic energy required per kilogram during a typical walking speed of 1.5 m/s leaving the remainder of the energy expenditure explained by factors other than those associated with functional mobility disability or adaptations to gait parameters.[43] Therefore interventions aimed at changing gait parameters may not increase energy expenditures for persons with obesity, they may be warranted in an effort to reduce the potential damage to bones and joints and associated pain. Interventions designed to address pain and protect joints have been shown to be effective for populations with chronic health conditions such as arthritis, cardiovascular disease and cancer. These interventions are classified as energy conservation strategies and include grading and pacing tasks required for functional mobility, use of mobility aids such as canes, walkers and wheelchairs and making changes to the home, school, work and community environments that create opportunities to reduce the demand for mobility and, when needed, enable safe mobility through design. Although such interventions have not been validated for use specifically by patients with obesity it is expected that patients with obesity were included in population studies however such studies did not stratify groups by obesity status. As the population ages and with increased in obesity rates so too will the demand for assistive devices such as canes and walkers[44] and the need to find effective strategies to enable functional mobility. Other interventions known to have a positive effect on postural control and walking stability such as falls prevention programs also need to be considered for use in obese populations of all ages.

It is not known if improvements to functional mobility translate to physical exercise contributing to weight loss however, it is known that improvements in functional mobility does have a positive effect on HRQoL. It is anticipated that targeted strategies to improve functional mobility will provide a foundation upon which to build a program of physical exercise including competencies and capacities to engage in exercise.

As with other chronic health conditions, interventions to enable functional mobility for patients with obesity will need to be individualized in order to address the contextual factors of individual patients and the environments in which they need to move about. The complex nature of functional mobility and obesity will require a coordinated approach utilizing models of shared patient care to address the medical, musculoskeletal and psychosocial factors. Examples of best practice using models of shared patient care can be found in the areas of diabetes management, stroke care and mental health.

Summary

Evidence from studies of obesity that include measures of quality of life and functional mobility consistently shows an association between obesity, impairments of body functions and structures and personal and environmental factors that contribute to mobility disability. However, little is known about the efficacy of interventions that aim to improve functional mobility for use with obese populations. In the absence of existing best practice guidelines to treat mobility disability in obese patients practitioners are encouraged to promote physical exercise with their patients by providing targeted interventions to address the medical, musculoskeletal, neurological and psychosocial factors that contribute to functional mobility and HRQoL. Although weight loss is associated with improvements in functional mobility some patients will require interventions to reduce mobility disability in order to achieve physical exercise at a level required to reduce body weight. It is not known if interventions that target gait parameters, postural control and motor planning are effective for use in patients with obesity. However, chronic disease management and falls prevention programs that include strategies to improve elements of functional mobility such as standing, walking, climbing and bending have been shown to be effective in populations known to have weight related health conditions such as OA, diabetes and cardiovascular disease and therefore are likely to be effective for use in patients with obesity who are at risk for mobility disability. The efficacy of such interventions to reduce mobility disability and its translation to physical exercise is in need of further evaluation.

Practice points

- Patients with obesity are at high risk for mobility disability as a result of a combination of musculoskeletal, neurological, cognitive, personal and environmental factors.
- Obesity experienced in childhood increases the risk of mobility disability later in life.
- The multidimensional nature of mobility disability in obese patients requires the use of shared patient models of care and multidisciplinary approaches to assessment and interventions.
- Patients with obesity are at higher risk of falls and injuries than non-obese patients therefore interventions to improve stability; postural control and motor planning are required.
- Assistive devices such as canes and walkers and the application of energy conservation strategies are recommended to promote musculoskeletal health, to project weight-bearing joints and to reduce pain. There is no evidence to suggest that utilization of such energy conservation strategies promotes weight gain.

Research agenda

- Develop and test a mobility classification system for use with obese populations that can be used in conjunction with emerging obesity classification systems.
- Test efficacy of existing falls prevention programs for use with obese populations.
- Test efficacy of energy conservation strategies to improve functional mobility in terms of duration and pain control.
- Test interventions that address both obesity and mobility disability simultaneously.

Conflict of interest statement

The authors have no conflict of interest to declare.

References

*1. World Health Organization. *International classification of functioning, disability and health*. ICF, Geneva: WHO, 2001.
*2. Stucki A, Borchers M, Stucki G et al. Content comparison of health status measures for obesity based on the international classification of functioning, disability and health. *International Journal of Obesity* 2006; **30:** 1791–1799.
*3. Stucki A, Daansen P, Fuessl M et al. ICF core sets for obesity. *Journal of Rehabilitation Medicine* 2004; (44 Suppl.)**:** 107–113.
4. Graham HK, Harvey A, Rodda J et al. The functional mobility scale (FMS). *Journal of Pediatric Orthopaedics* 2004; **24:** 514–520.
5. Cibulka MT, White DM, Woehrie J et al. Hip pain and mobility deficits-hip osteoarthritis: clinical practice guidelines linked to the international classification of functioning, disability, and health from the orthopaedic section of the American Physical Therapy Association. *Journal of Orthopaedic and Sports Physical Therapy* 2009; **39:** A1–A25.
*6. Shimada H, Sawyer P, Harada K et al. Predictive validity of the classification schema for functional mobility tests in instrumental activities of daily living decline among older adults. *Archives of Physical Medicine and Rehabilitation* 2010; **91:** 241–246.
*7. Sharma AM & Kushner RF. A proposed clinical staging system for obesity. *International Journal of Obesity* 2009**:** 289–295.
8. Gurnluoglu R, Williams SA & Johnson JL. A classification system in the massive weight loss patient based on skin lesions and activity of daily living. *ePlasty* Feburary 6, 2012; **12**. Available on-line from: http://www.eplast.com.
9. Capodaglio P, Cimolin V, Tacchini E et al. Balance control and balance recovery in obesity. *Current Obesity Reports* 2012; **1:** 166–173.

*10. Corbeil P, Simoneau M, Rancourt D et al. Increased risk for falling associated with obesity: mathematical modeling of postural control. *Transactions on Neural Systems and Rehabilitation Engineering* 2001; **9:** 126–136.
11. Wearing SC, Hennig EM, Byrne NM et al. The biomechanics of restricted movement in adult obesity. *Obesity Reviews* 2006; **7:** 13–24.
*12. Gill SV & Narain A. Quantifying the effects of body mass index on safety: reliability of a video coding procedure and utility of a rhythmic walking task. *Archives of Physical Medicine and Rehabilitation* 2012; **93:** 728–730.
13. DeVita P & Hortobágyi T. Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics* 2003; **36:** 1355–1362.
14. Ko S, Stenholm S & Ferrucci L. Characteristic gait patterns in older adults with obesity – results from the Baltimore Longitudinal Study of Aging. *Journal of Biomechanics* 2010; **43:** 1104–1110.
15. Grotle M, Hagen KB, Natvig B et al. Obesity and osteoarthritis in knee, hip and/or hand: an epidemiological study in the general population with 10 years follow-up. *BMC Musculoskeletal Disorders* 2008; **9:** 132.
16. Cicuttini FM, Baker JR & Spector TD. The association of obesity with osteoarthritis of the hand and knee in women – a twin study. *The Journal of Rheumatology* 1996; **23:** 1221–1225.
17. Felson DT, Anderson JJ, Naimark A et al. Obesity and knee osteoarthritis. The Framingham study. *Annals of Internal Medicine* 1988; **109:** 18–24.
18. Villareal DT, Apovian CM, Kushner RF et al. Obesity in older adults: technical review and position statement of the American Society for Nutrition and NAASO, The Obesity Society. *American Society for Clinical Nutrition* 2005; **82:** 923–934.
19. Hart DJ & Spector TD. The relationship of obesity, fat distribution and osteoarthritis in women in the general population: the Chingford Study. *Journal of Rheumatology* 1993; **20:** 331–335.
20. Goulding A, Jones IE, Taylor RW et al. Bone mineral density and body composition in boys with distal forearm fractures: a dual-energy x-ray absorptiometry study. *Journal of Pediatrics* 2001; **139:** 509–515.
21. Pollock NK, Laing EM, Baile CA et al. Is adiposity advantageous for bone strength? A peripheral quantitative computed tomography study in late adolescent females. *American Journal of Clinical Nutrition* 2007; **86:** 1530–1538.
22. Li Y, Dai Q, Jackson JC et al. Overweight is associated with decreased cognitive functioning among school-age children and adolescents. *Obesity* 2008; **8:** 484–488.
23. Boeka AG & Lokken KL. Neuropsychological performance of a clinical sample of extremely obese individuals. *Archives of Clinical Neuropsychology* 2008; **23:** 467–474.
24. Elias MF, Elias PK, Sullivan LM et al. Lower cognitive function in the presence of obesity and hypertension: the Framingham heart study. *International Journal of Obesity and Related Metabolic Disorder* 2003; **27:** 260–268.
25. Wolpert DM & Miall RC. Forward models for physiological motor control. *Neural Networks* 1996; **9:** 1265–1279.
26. Miller JL, Couch J, Schwenk K et al. Early childhood obesity is associated with compromised cerebellar development. *Developmental Neuropsychology* 2009; **34:** 272–283.
27. Dustman RE, Emmerson RY & Shearer DE. Aerobic fitness may contribute to CNS health: electrophysiological, visual and neurocognitive evidence. *Journal of Neurorehabilitation and Neural Repair* 1990; **4:** 241–254.
*28. Marks R. Obesity profiles with knee osteoarthritis: correlation with pain, disability, disease progression. *Obesity* 2007; **15:** 1867–1874.
29. Stovitz SD, Pardee PE, Vazquez G et al. Musculoskeletal pain in obese children and adolescents. *Acta Paediatrica* 2008; **97:** 489–493.
30. Janke AE, Collins A & Kozak AT. Overview of the relationship between pain and obesity: what do we know? Where do we go next? *Journal of Rehabilitation Research & Development* 2007; **44:** 245–262.
31. Marcus DA. Obesity and the impact of chronic pain. *Clinical Journal of Pain* 2004; **20:** 186–191.
32. Barofsky I, Fontaine KR & Cheskin LJ. Pain in the obese: Impact on health-related quality of life. *Annals of Behavioral Medicine* 1997; **19:** 408–410.
33. Lai PP, Leung AK, Li AN et al. Three-dimensional gait analysis of obese adults. *Clinical Biomechanics* 2008; **23**(Suppl. 1)**:** S2–S6.
34. Hills AP & Parker AW. Locomotor characteristics of obese children. *Child Care Health and Development* 1992; **18:** 29–34.
35. McGraw B, McClenaghan BA, Williams HG et al. Gait and postural stability in obese and nonobese prepubertal boys. *Archives of Physical Medicine and Rehabilitation* 2000; **81:** 484–489.
36. Wu X, Yeoh HT, Soangra R et al. Investigation into the functional mobility difference between obese and non-obese elderly. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting September* 2012; **56:** 1814–1816.
37. Hirata RP, Arendt-Nielsen L, Shiozawa S et al. Experimental knee pain impairs postural stability during quiet stance but not after perturbations. *European Journal of Applied Physiology* 2012; **112:** 2511–2521.
38. Adolph KE, Joh AS, Franchak JM et al. Flexibility in the development of action. In: . *The psychology of action* 2008; vol. 2. New York: Oxford University Press, 2008, pp. 399–426.
*39. Bannerman E, Miller MD, Daniels LA et al. Anthropometric indices predict physical function and mobility in older Australians: the Australian Longitudinal Study of Ageing. *Public Health Nutrition* 2002; **5:** 655–662.
40. Lee C, Ory MG & Forjuoh SN. Neighborhood walking among overweight and obese adults: age variations in barriers and motivators. *Journal of Community Health* 2012 Jul 10 [Epub ahead of print].
*41. Kolotkin RL, Crosby RD & Williams GR. Health-related quality of life varies among obese subgroups. *Obesity Research* 2002; **10:** 748–756.
42. Browning RC & Kram R. Pound for pound: working out how obesity influences the energetics of walking. *Journal of Applied Physiology* 2009; **106:** 1755–1756.
*43. Peyrot N, Thivel D, Isacco L et al. Do gait mechanical parameters explain the higher metabolic cost of walking in obese adolescents? *Journal of Applied Physiology* 2009; **106:** 1763–1770.
44. Pressler KA & Ferrar KF. Assistive device use as a dynamic acquisition process in later life. *The Gerontologist* 2010; **50**(3)**:** 371.