The Effects of Obesity on Human Ambulation:

A Lower Joint Analysis

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Abstract

The effects of obesity on the body are complex and numerous especially when combining the effects on an already multi-faceted and multi-systems action such as human ambulation. This study summarizes a wide range of research performed, which investigated the effects of obesity on human ambulation. The effects are broken down into categories including osteoarthritis, replacement surgery, center of mass, stepping cycle, muscular activation, and specifics of the hip, knee and ankle joints as well as foot changes. The overwhelming majority of studies have found obesity to negatively impact ambulation by shifting center of mass (COM), increasing metabolic cost, decreasing cadence speed, widening step width, increasing joint torque and load, changing joint biomechanics, increasing chance of joint replacement surgery, correlating with low back pain (LBP), and correlating with onset of osteoarthritis. Research on the effects of obesity on gait is a new field in which there were many previous unknowns; however, this review is a compilation of what recent studies have now revealed.

The Effects of Obesity on Human Ambulation

Obesity is widely known to be the sweeping health epidemic that is overcoming America, and even becoming a problem in other countries (Anandacoomarasamy, Caterson, Sambrook, Fransen, & March, 2008). Although obesity is frequently a consequence of the lifestyle that people submit themselves to, the American Medical Association is now recognizing obesity as a disease (Cleveland Clinic, 2013). The purpose in officially labeling obesity as a clinical problem is that in doing so, it might encourage people to start taking this condition seriously. In addition, if obesity is labeled as a disease, more programs and intervention facilities might be put into place. The movement towards taking care of obesity is critical since obesity is very closely tied to several other diseases and health problems. Obesity, according to the American College of Sports Medicine, is defined as having a body mass index of greater than 30 (ACSM 2014). Among the few co-morbidities that are linked, obesity increases the risk of type 2 diabetes, cardiovascular disease, dyslipidemia, high blood pressure, and lower back pain (Ehrman, 2009).

In addition, although the correlation is complex, it is common to find those who are obese to have higher instances of depression, lower self-efficacy and lower self-esteem (Rihmer, Purebl, Faludi, & Halmy, 2008). The correlation between obesity and depression could stem from lack of exercise. Studies show that those who exercise on a regular basis have less depression and higher self-efficacy (Salmon, 2001). It is no surprise, therefore, that those who are obese report higher incidences of depression and low self efficacy because they have a greater tendency towards a sedentary lifestyle, which keeps them from experiencing the psychological benefits of exercise (Salmon).

Many researchers who investigated the effects of obesity, selected to analyze children and found that concepts that hold true with children are well equatable to adult scenarios. In research done within the area of gait changes in obese, gait analysis in obese children shows similar differences as obese adults. Since no data has yet proven otherwise, principles discovered only with child subjects can be carried over to adult scenarios (Nantel, Brochu, & Prince, 2006). Obese children, similar to obese adults, are more sedentary than normal weight children and also demonstrate impaired performance in whole body movements (Shultz, Hills, Sitler, & Hillstrom, 2010). Time spent in physical activity has been shown to be inversely related to fat mass (Shultz et al.).

The body is not intended to bear such excess weight, as is seen in one study that only looked at the effect of instantaneous loads on the basic spacing and timing of strides during gait (Blaszczyk et al., 2011). Subjects carried a backpack containing 40% of their body weight while walking, and consequently their strides decreased in length and increased in frequency compared to walking without additional weight (Blaszczyk et al.). Although this study cannot directly correlate with obese subjects, it demonstrates that even during instantaneous loading, the body compromises its walking biomechanics. From this observation, it is important to question what the consequences might be on the body during repeated loads for long periods of time (Blaszczyk et al.). Excess body weight and its affects on locomotion are still poorly understood, but are becoming of more interest to researchers. As the obesity epidemic is sweeping the nation, scientists are now curious as to how much obesity changes the condition of the body (Blaszczyk et al.).

Outside of the unseen side effects of obesity, there are also factors that affect basic quality of life. For those who are obese, even daily activities can be challenging and require extra effort because of the amount of energy it takes to move the weight of their body. In regards to walking or ambulation, implications of obesity on musculoskeletal, locomotion, and daily activities are not well researched and still include many areas that are not understood. However, studies that have been done, have found results of change and impairment in gait phases, biomechanical differences, joint torque, joint pressure, and osteoarthritic tendencies due to lack of physical activity. Other changes have been found as well including kinematic aspects of gait like placement of center of mass, timing of swing phase and stance phase, length of step, and speed of step. These components are also affected by the increased weight that the body experiences when an individual is obese.

Gait

Gait or ambulation is a normal human function that is required for most every day activity. For able bodies, walking is something that is rarely even thought about. When investigating gait from a biomechanical perspective, joints within the lower extremities move in specific sequences in order to accomplish ambulatory tasks. Gait is both universal as well as complex as it is a motor skill that ties together the nervous and muscular systems (Sadeghi, Allard, Prince, & Labelle, 2000). This collaboration allows for the individual to move with coordination, erect posture, and smooth rhythmic motion (Sadeghi et al.). Gait consists of interactions between internal and external forces that require the body to adapt and remain stable during these constant imbalances (de Carvalho, Figueira Martins, & Teixeira, 2012). During this process weight is transferring from one leg to the other and the center of mass within the body is constantly shifting in order to re-gain balance lost during movement (de Carvalho et al.). Individuals may develop different types of compensations within their gait because of functional deficits caused by muscle weakness, muscle spasticity, or joint stiffness (Yu, Ikemoto, Acharya, & Unoue, 2010). The quality of gait is associated with the structural and functional constraints imposed by the locomotor system, the ability to implement an effective motion strategy, and the individual's metabolic efficiency (Hills, Hennig, Byrne, & Steele, 2002). Many individuals who are obese experience these functional constraints such as greater muscle weakness compared to body mass, and increased joint stiffness or mobility because of the excessive amount of adipose tissue around the joints (Hills et al.).

Normal gait phases. When analyzing gait, a gait cycle or stride is defined as the events occurring from one heel strike to the next ipsilateral heel strike (Liu et al., 2014). Therefore, when discussing phases of gait it is assumed that terms are defined for one side of the body. There are two major phases to normal gait: stance and swing (Liu et al.). The stance phase occurs from the moment the heel contacts the ground until the toes push off from the ground. The swing phase of gait is the phase in which the foot is not in contact with the ground (Liu et al.). While observing one leg at a time the stance phase consists of 60% of the time during gait and the swing phase occurs approximately 40% of the time during one stride (Liu et al.). The sub-phases of the stance phase include initial contact, loading response, mid-stance, terminal stance and pre-swing (Liu et al.). The components of the swing are initial swing, mid-swing and terminal swing (Liu et al.). All of these phases have been precisely measured to standardize normal gait so that compensations can be detected (Liu et al.).

The heel strike within the stance phase starts the moment the heel first touches the ground. The next phase is the early flatfoot stage in which the body's center of gravity passes over the top of the foot (Pinney, 2012). The main purpose of this stage is to use the foot as a mode to absorb shock and to cushion the force of the body on the foot. The next stage is the late foot stage in which the foot transitions from a "flexible shock absorber" to a "rigid lever" that can thrust the body forward (Pinney). This stage ends when the heel comes off the ground, which begins the heel rise phase in which the heel leaves the ground. During this phase the ground reaction force going through the foot is 1-1.5X a person's body weight. The last phase of the stance part of gait begins as the toe leaves the ground (Pinney).

Many researchers adopt the concept that locomotion fundamentally is the "translation of the center of gravity through space along a pathway requiring the least expenditure of energy." (Saunders, Inman, & Eberhart, 1953) A study done by Saunders et al, (1953) that laid the foundation for analyzing gait categorized 6 determinants of walking as one theory of gait. These 6 determinates are pelvic rotation, pelvic tilt, knee flexion, hip flexion, knee and ankle interaction, and lateral pelvic displacement (Saunders et al.). Other more recent studies have concluded with similar results, although the order of importance within these six determinates is still debated as research continues (Della Croce, Riley, Lelas, & Kerrigan, 2001)

Within these six categories, compensations can be overcome and the body can still be reasonably effective when there is only one compensation in one characteristic; however, when two or more determinant spots have compensations, the cost of energy for locomotion is increased by threefold. With the increased metabolic cost for locomotion there is an unavoidable increase in drain on body economy (Saunders et al., 1953). The increased drain on the body may help explain why obese individuals have decreased locomotion, because the excess loads on their joints result in multiple abnormal compensations that the body cannot overcome with maintained effectiveness and so it therefore loses efficiency during gait (Saunders et al.). Such compensations will be discussed further on in this analysis.

Osteoarthritis (OA) and Complications

In addition to kinematic compensations, obesity can also have a negative kinetic effect on the joints within the body, especially in the lower extremity joints and their role in walking. Because of the extra weight, lower extremity joints experience more pressure and torque than joints in a normal person’s body. Obesity is consistently labeled within research studies as a risk factor for osteoarthritis (Hills et al., 2002). Osteoarthritis is a chronic disease that consists of the gradual degradation of cartilage and the failure of supporting joint tissues (Anandacoomarasamy et al., 2008). For all major lower extremity joints, obese individuals have a 7 times higher risk of developing osteoarthritis (Ackerman & Osborne, 2012). In a study done by Ackerman and Osborne (2012,) data was collected from 1157 participants that were polled to answer a questionnaire about osteoarthritis. The participants were classified into normal weight, overweight, and obese groups and those with obesity reported to have higher joint pain, more stiffness, less mobility, worse function, and over all greater disease severity (Ackerman & Osborne). Even in the individual with average weight, the forces that are exerted on the joints are 1.5 times greater when walking on a level surface. Other activities produce greater force than just walking, for example, when standing up from a chair, joints experience 2 to 3 times the force of ones body weight. The forces imposed on joints are greater in obese individuals since their weight is greater than the average adult (Savory 2013). Therefore, because obese individuals have excessive forces applied to their joints, they are highly predisposed to developing osteoarthritis. Not only does the excess force and load on the joints make obese individuals at risk for osteoarthritis, but the placement of the excess adipose tissue also increases movement compensations, which can also increase the chance of developing osteoarthritis (Anandacoomarasamy et al.). The risk is not just the weight upon the joints, but also the compensation of movement, which results in the joints operating in ways outside of their intended function. From either source of compensation, obesity puts people on a road towards osteoarthritis and joint pain (Anandacoomarasamy et al.).

Cartilage thickness in the knees of obese subjects respond to loading similarly to that of osteoarthritic patients, and leads researchers to believe that increased weight indicates a pathway of cartilage degeneration before the onset of osteoarthritis (Anandacoomarasamy et al., 2008).

With each increase in kilogram of body weight there is a similar increase in radiographic features of OA at the knee and carpometatarsal joints (Anandacoomarasamy et al.). Obese patients with osteoarthritis have greater joint space narrowing in the compartments of the medial and lateral tibio-femoral joints (Anandacoomarasamy et al.). If someone is already genetically predisposed to osteoarthritis in the knee, obesity compounds the progression of the disease (Anandacoomarasamy et al.).

There is also supportive evidence linking the physical size of the distal femur and proximal tibia with the risk of developing osteoarthritis (Anandacoomarasamy et al., 2008). Although bone size is primarily genetic, because bones respond to the load placed on them, a greater BMI can result in an induced increased subchondral bone size of the knee (Anandacoomarasamy et al.). BMI is classified in this study as 30-35 for class-one obesity and 35-40 for class-two obesity and greater than 40 for class-three obesity. Higher loads expand the joint to larger surface area causing the joint to experience more pressure (Anandacoomarasamy et al.).

Surgical complications. Joint replacements are common for both the average weight person and the obese individual; however, joint replacements have dramatically increased along with the increase in obesity levels (Anandacoomarasamy et al., 2008). One-third of all hip and knee replacements are performed on obese patients (Anandacoomarasamy et al.). Not only do the obese have a higher probability of needing a joint replacement, but the surgery itself is often much more dangerous (Anandacoomarasamy et al.). Obesity significantly increases the duration of surgery, which therefore increases the risk of surgical error, while also increasing cost. When comparing obese to non-obese individuals, the recovery time for obese individuals after a surgical procedure is slower, and in some surgeries excess adipose tissue hinders the ability of the surgeon to perform (Savory, 2013). Obesity is a contraindication for a bilateral total knee replacement, and a BMI of greater than 32 has a predicted failure for minimally invasive surgeries such as knee arthroplasty (Anandacoomarasamy et al.). In addition, the amount of infection for post surgical operations increases from .37% in normal weight individuals to 4.44% in obese cases (Jamsen et al., 2012). The increased time for healing after operation promotes greater sedentary behavior, since obese patients are spending a longer time in a non-movement phase.

Biomechanical Factors of Gait: Center of Mass (COM)

The center of mass is a theoretical point that is considered to be the balance point of the body and represents the motions of the body as a whole because it is the point where mass is equally distributed in all directions (ASU, 2014). Mathematically, the most cost effective form of walking would not include any vertical or lateral displacement; however, because of the form of our body it is impossible to diminish vertical and lateral displacement completely (Orendurff et al., 2004). Therefore, during walking the center of mass travels in the direction of movement but also moves in a sinusoidal pattern thus moving in vertical and lateral directions as well (Orendurff et al.). The specific sinusoidal pattern is described in a prediction called the inverted pendulum, in which the COM in an average healthy adult moves along an arc and the body moves at maximum efficiency (Adamczyk & Kuo, 2009). In many cases healthy subjects during walking deviate from this perfect arc because of mild asymmetries; however, the COM arc of obese are astronomically different. Only when the body is in the phase of single support does the inverted pendulum analogy stand true, the double support phase of walking is not pendular but functions as a transition between single stance phases (Adamczyk & Kuo). For those who are obese, single stance phases are shortened and the non-pendular motion within the double stance phase is not just transitory but prolonged (Adamczyk & Kuo). Metabolic work because of COM increases with the squared product of walking speed and step length (Adamczyk & Kuo).

Lateral displacement of COM is most apparent at slower paces of walking. Those who are obese walk at a slower pace than normal weight subjects; therefore, they have greater lateral COM displacement (Orendurff et al., 2004). The greater the lateral displacement the less efficient the body moves. Increased lateral displacement of COM is costly energetically and metabolically, and displacement is highly correlated with oxygen consumption during walking (Orendurff et al.). In addition to the slower pace of walking, the width of steps affect the lateral displacement of COM. Those with wider step width have increased mechanical and metabolic costs even by 50% (Orendurff et al.).

This research ties in with other studies performed, such as one done on 10 obese subjects and 10 non-obese subjects by Hills and Parker. The subjects' gait was analyzed through fixed cameras at 50 frames per second, in which obese subjects displayed longer cycle duration, lower cadence of walking, lower velocity of walking and a longer stance period than normal subjects (Hills & Parker, 1991). Another study that found similar results was one that investigated the biomechanics of ambulation in obese men. The author's results supported the previous study's conclusion in that obese individuals walked significantly slower. The obese subjects also had shorter strides by almost half a meter. In addition, step width was twice as wide as the non-obese participants (Spyropoulos, Pisciotta, Pavlou, Cairns, & Simon, 1991). The greater width of steps is mainly attributed to excessive adipose tissue between the obese individual's inner thighs, which alters the angular components of the gait (Spyropoulos et al.). The mean velocity of foot swing within the swing stance phase was higher, which is in line with the physics concept that greater mass has higher velocity once moving (Blaszczyk et al., 2011). However, a greater amount of mass also takes more energy to get moving and to slow down. Double support duration was higher as they spent more time within the double support phase than the normal-weight counterparts (Blaszczyk et al.). In addition swing time was significantly shorter and modified in comparison (Blaszczyk et al.). Increased double support increases amount of pressure on both legs, decreases speed of walking, and increases COM displacement (Blaszczyk et al.).

The Hills and Parker study also found that subjects who were obese had more gait asymmetry and differences between legs than normal weight subjects (Hills & Parker, 1991). This study reported that during the slow pace of gait, subjects experienced the most instability (Hills & Parker). This principle coincides with other studies, which concluded that lateral deviation of COM is the greatest at slower speeds, therefore making slow walking a greater risk for instability (Orendurff et al., 2004). This predisposes a greater fall risk in obese individuals

Changes in obese gait can also be explained by the constrained optimization hypothesis, which claims that during walking at the self-selected speed, an individual’s unique gait parameters such as speed, cadence, and stride length is the individual set of basic gait parameters such as speed, cadence, and stride length is in place in order to optimize energy costs (Blaszczyk et al., 2011). The preferred speed that a subject chooses reflects the body’s speed at which it is most efficient based upon its parameters and characteristics (Blaszczyk et al.). Optimal stride characteristics are influenced by the nervous system which can be altered by excess body (Blaszczyk et al.).

The six determinants (pelvic rotation, pelvic tilt, knee flexion, hip flexion, knee and ankle interaction, and lateral pelvic displacement) serve to minimize the vertical and lateral displacement of the center of mass (Della Croce et al., 2001). This theory is the main theory for decreasing COM displacement; however, recently a study done by Gard and Childress (1997) concluded that pelvic obliquity reduces the vertical displacement of COM. Gard and Childress (1997) also concluded that knee flexion reduces the height of the COM by only a few millimeters, which is not as much as predicted prior to the study (Della Croce et al.). Nevertheless, all 6 determinants regardless of which order of importance, are still important to analyze when considering obese individuals and their compensations (Della Croce et al.).

Gait stability is not only affected by COM but also can be affected by the individual's ability to multitask. One study, which investigated walking with and without carrying a box in obese and non-obese children, found that obese children had greater lateral spine movement and more medial/lateral ground reaction force during the dual-task of walking and carrying an object (Hung, Gill, & Meredith, 2013) Such weakness in dual task completion may indicate a tendency for greater instability and maintenance of safety while multitasking during ambulation (Hung et al.). Once again obese individuals are at a greater risk of instability and falling.

Biomechanical Factors of Gait: Muscular Weaknesses

Muscular weakness is one major reason within gait analysis that decreases functionality and impairs correct mechanics (Hills et al., 2002). Even subjects of normal weight have weaknesses that cause impairments and ultimately pain because their muscles are not functioning properly. Such weaknesses increase their risk of fatigue and injury (Hills et al.). Studies of obese children showed a decreased effectiveness in regards to limb power in activities such as standing long jump and vertical jump tests due to the larger mass moving against gravity (Hills et al.). Decreased muscle strength carries over to walking. In order to move a greater amount of mass, more energy must be spent; therefore, compared to average weight individuals the obese get tired faster during ambulation (Hills et al.). When muscles weaken and loads increase, there is an increase in arthritic tendencies (Hills et al.). This concept is very evident in the older population where it is common for them to have a decreased period of eccentric contraction of the quadriceps during heel strike. The muscles are not strong enough to sustain the weight of the body when the heel strikes the ground and therefore the amount of shock absorbed is decreased resulting in increased pressure on joints (Hills et al.). This is seen in the elderly mainly because of their decreased muscular strength; however this principle remains true for those who may not be elderly but certainly have excess weight and weakened muscles.

One specific example of muscle compensation and muscle weakness is seen in a study done on the anterior and posterior muscles of the lower leg (Spyropoulos et al., 1991). Twelve obese men were and twelve non-obese men between the ages of 30-47 years were tested. The obese subjects had significantly greater amounts of dorsiflexion and less plantar flexion than non-obese walking cycles (Spyropoulos et al.). The gastrocnemius is the muscle that facilitates the push off phase of stance, which consists of mostly plantar flexion (Spyropoulos et al.). The decreased plantar flexion may be attributed to the body's compensation in trying to reduce energy expenditure by decreasing the height at which the body is forced up. This compensation decreases range of motion for plantar flexion, which leads to decreased function and weakness of the gastrocnemius (Spyropoulos et al.). Increased amounts of dorsiflexion may stem from the need for toe clearance within the swing phase, since obese individuals have a decreased hip strength which lowers there swing leg to the point where extra effort must be exerted in order for toe-clearance to occur (Orendurff et al., 2004).

In a study investigating the effect of obesity on electromyography (EMG) muscle activity, the researchers examined four muscles during gait: right and left rectus femoris and right and left gastrocnemius (de Carvalho et al., 2012). An EMG is a diagnostic procedure that uses electrodes in order to detect the electrical activity of a muscle to assess the health of the muscles and the neurons that control them (Mayo Clinic). For normal weight participants, the authors found statistically more EMG activity in all 4 muscles when walking at the slowest pace versus a normal pace (de Carvalho et al.). These results are similar to the findings on COM, in which the slower pace is more difficult to maintain balance due to increased COM displacement. Increased muscle activation with the slower paced gait is to be expected since it should be more difficult (de Carvalho et al.). As for the obese subjects, the researchers found no significant difference between the EMG activity when comparing the slow and normal pace walking (de Carvalho et al.). It is interesting that unlike the normal-weight participants, obese subjects showed no change in muscle efficiency with a slower pace. This may be explained by the increase in time that it takes to move their mass, thereby revealing a less efficient self-selected speed (de Carvalho et al.). The decreased efficiency probably reflects their tendency towards altered walking speed, step frequency, and vertical COM displacement (de Carvalho et al.). These principles however, include some speculation since the meaning of this data is not yet fully understood.

Obesity and Low Back Pain (LBP)

Similar to osteoarthritis, obesity is positively correlated with LBP. Many studies show a correlation between obesity and LBP, however researchers are unsure as to whether LBP is from excess weight itself or the biomechanical changes of the lower extremity joints caused by their weight (Leboeuf-Yde, Kyvik, & Bruun, 1999).

For normal healthy subjects the timing between trunk, pelvic rotations, and erector spinae activity changes with the velocity of walking (Lamoth, Daffertshofer, Meijer, & Beek, 2006). In healthy walking, increased velocity changes the phase difference between thoracic and pelvic rotations from synchronized rotations in the same direction (in-phase) to synchronized rotations in the opposite direction (antiphase) (Lamoth et al.). With increased velocity the lumbar erector spinae within healthy individuals show peak EMG activity during the heel phase foot contact of stance phase yet have little movement within the swing phase (Lamoth et al.). A treadmill assessment was performed on subjects with LBP and they showed reduced trunk and pelvic coordination that allows adaption to velocity changes. With increased velocity the pelvic rotations of the LBP individual remain in the in-phase state of coordination (Lamoth et al.). LBP subjects within this study moved their lumbar and pelvic segments as a rigid unit, and their transverse plane coordination within the pelvic and lumbar joints were decreased compared to individuals without LBP (Lamoth et al.). Trunk and pelvis coordination is hypothesized to be linked to gait stability. In accordance with this hypothesis, those with LBP can expect to have ambulation imbalances (Lamoth et al.). Subjects with LBP who ambulated on treadmills which changed speeds unexpectedly had trouble adapting to the differing speeds and had decreased coordination and muscular control (Lamoth et al.). This may explain their attempt to stabilize during such perturbations (Lamoth et al.). Since obese subjects commonly experience LBP, this may also be a contributing factor to their slower paced gait.

In addition, when analyzing obesity in correlation with LBP, the accommodation for the excess weight on the anterior side of the obese body puts pressure on their sacrum, which in turn can shift the pelvic region and cause damage, pain, and biomechanical imbalances in the hip joint that may be present in walking patterns (Bener, Alwash, Gaber, & Lovasz, 2003; Nasreddine, Heyworth, Zurakowski, & Kocher, 2013).

Obesity not only affects the actual body mechanics but also has an effect on the mind, especially in regards to chronic LBP. Obese subjects with LBP had higher scores on the Tampa Scale of Kinesiophobia, an analysis of fear of movement, as well as a heightened sense of disability compared to individuals of normal weight (Vincent et al., 2011).

Joint Biomechanics: Effect on the Hip Joint

Individuals with obesity, especially in adolescence, are at greater risk of developing slipped capital femoral epiphysis (SCFE) (Nasreddine et al., 2013). This is a condition in which the epiphysis, head of the femur, slips off in a posterior direction when articulating with the acetabulum (POSNA 2007). Mechanical insufficiency is said to come from abnormal weakening of the physis, the shaft of the femur. Both endocrine and metabolic factors act on the physis, the shaft of the femur (Witbreuk et al., 2013). When rapid weight is increased with growth as in adolescence with obesity, the hormonal balance in puberty is affected and the risk of SCFE is elevated (Witbreuk et al.). Although SCFE is commonly present in overweight adolescents, this condition can be traced even into adulthood for those with obesity. SCFE essentially represents the first stages of osteoarthritis (Westhoff et al., 2012). Individuals with SCFE sustain functional impairments, which decreases step frequency compared to people without SCFE. Step frequency and single support of the slipped side decreases while step width, double support phase, and the time standing on the sound leg increase (Westhoff et al.). Those with SCEF are shown to have increased sagittal pelvic range of motion and increased external rotation of the ankle bilaterally Westhoff et al.). In addition, sagittal rotation of the hip joint, knee flexion, and sagittal ankle ROM on the affected side decrease (Westhoff et al.).

Many of the negative biomechanical effects of obesity come from decreased joint range of motion. This decrease takes place for two major reasons: the excess adipose tissue itself hinders the ability for the joints to move in their full motion or the excess weight is too much for the muscles to support in full range motion (Hill et al., 2002). In their hip joints, obese individuals experience decreased range of motion in forward flexion (bending forward), which alters their posture during standing work tasks. This postural abnormality increases the hip joint force moments, which can tend to an increase in functional pain during standing (Gilleard & Smith, 2007). In addition, the higher the peak stress on the hip joint, the more likely the incidence of developing hip OA as well as an increase in the progression of hip OA.

When comparing hip biomechanics of obese versus non-obese during walking at a self-selected speed, obese individuals have 14 degrees greater hip abduction during the single limb stance phase (Runhaar, Koes, Clockaerts, & Bierma-Zeinstra, 2011). While walking, obese individuals also have a slower self-selected speed of gait by .3 m/s, which decreases joint movement of the hips. During sit to stand movement obese individuals have decreased hip flexion by 22 degrees and a greater foot displacement by 5 cm (Recknik et al, 2009). For sit to stand, obese individuals also have a 7 degree increase of dorsal flexion (Recknik et al.).

One study, led by Nantel et al (2006), had 10 obese and 10 non-obese children walk 10m across force plates and captured their movement with 3D motion cameras. In their analysis Nantel et al (2006), found the role of the hip to be so great that the study suggests the hip is the only joint that affects compensated gait patterns in obese children (Nantel et al., 2006). This compensation is founded in the transition from the generation of energy at the hip extensor to the absorption of energy at the hip flexor (Nantel et al.). Mechanical energy from the hip extensors is decreased, therefore these muscles are not working as hard and have a tendency to be weak. To compensate, the hip flexors absorb more mechanical energy than is normal (Nantel et al.). Eccentrically extending, or increasing the angle of the hip, should take less metabolic expenditure than flexing or decreasing the angle of the hip concentrically. This increase in angle makes the compensation of the obese individual more efficient; however, although theoretically the mathematical amount of expenditure is lower, this is not how our body is designed to work. Consequently, the authors found that the overall results of efficiency was lower for obese (Nantel et al.). The authors concluded that obese children were less efficient in their ability to transfer energy between eccentric and concentric phases of the hip (Nantel et al.).

In a similar study, 28 obese and non-obese children were assessed with 3D motion analysis in order to analyze lower extremity joint power for two different speeds of walking. The analysis of joint power included hip joint power and hip joint absorption for both flexion and extension (Shultz et al., 2010). The obese subjects experienced a greater generation of force for the H1-S hip extension and H3-S hip flexion, and greater power absorption at the hip compared to the non-obese subjects (Shultz et al.). The increase in power at H1-S is to keep excess weight in the trunk in stability when the heel strikes the ground for the beginning of the stance phase (Shultz et al.).

Hip flexors within the obese children absorbed a greater amount of power than those of normal weight subjects. The increase in power absorption supports Shultz's hypothesis that a larger trunk might cause the center of mass to decelerate faster than normal as the stance phase approaches mid-stance (Shultz et al., 2010). The COM of obese children consistently accelerates and decelerates the hip joints during gait; therefore their muscles have to continuously generate enough power to move and absorb excess power to slow down (Shultz et al.). The cadence and COM pattern of these obese children is compared to the ebb and flow of the ocean waves instead of the steady movement of a running stream in normal weight subjects (Shultz et al.).

Joint Biomechanics: Effect on the Knee Joint

Similar to the hip joint, there is an increased incidence of osteoarthritis development in the knees of the obese. In a study investigating obese ambulation, 21 obese subjects and 18 lean subjects were analyzed with force plates and motion cameras (DeVita & Hortobagyi, 2003). Motion analysis revealed that obese individuals demonstrated 12% less knee flexion during the stance phase of walking and produced 17% higher knee torque (DeVita & Hortobagyi). Although reduced flexion during gait may seem to correlate to less pressure in the knee, less flexion contributes to reduced quadriceps activity. This decreased range of motion and decreased muscles activity also reduces the impulse or signal for the muscles to absorb pressure when the leg contacts the ground, which increases the ground reaction forces. Knee flexion is also important because without knee flexion in the swing phase, the center of mass (COM) height in the opposite leg would need to be higher and would therefore increase the vertical displacement of the COM (Della Croce et al., 2001). Reduced knee flexion contributes to greater COM displacement and therefore increases the metabolic cost of walking as well (Della Croce et al.). Knee joint ROM in obese individuals is also altered in the coronal plane. For example, within the phase between mid-stance to pre-swing in walking, greater maximum adduction angles occur (Della Croce et al.). Excessive knee adduction during the stance phase of gait has been shown to increase OA, since 85% of the work done in the knee is accomplished within the sagittal plane (Ackerman & Osborne, 2012). As the percentage of work done in the coronal plane (adduction) increases, tension within the knee increases (Ackerman & Osborne). According to Sharma et al. (1998), knee adduction moments are one of the most cited factors for increasing articular injury. The knee adduction moments are not necessarily determined by the distribution of the excess fat but more by the sheer weight itself. For example, weight was a predictor for the knee adduction moment in a study performed in 2009, in which 19 normal weight subjects, 20 centrally obese subjects and 20 lower-body obese subjects were tested (Segal, Yack, & Khole, 2009). All subjects reported no knee pain. Between the obese groups weight did not differ, only thigh girth. Weight was a significant predictor of external adduction moment and explained 33% of the knee adduction moments for level walking (Segal et al.).

Although athletes have increased body weight and could be in danger of such knee adduction, athletes differ in comparison to obese individuals. Athletes have higher body weight but also increased muscle tone to handle the increased force. Normal range of motion is also kept within the athletes' movement because of their fitness levels. Therefore, just because weight is a factor that increases knee adduction, athletes are not necessarily apart of the population at risk.

Another study investigated the power generated within the knee and how that affected gait of obese. They discovered greater power phases in sagittal plane joints such as the knee, which they attributed to the increased mass and the need for the joints to maintain upright posture even when moving excess weight (Shultz et al., 2010). The absorption of power done by the knee extensors was increased in order to control limb collapse (Shultz et al.). With a greater amount of power being absorbed this indicates a greater need of knee flexion; however, since decreases of knee flexion is one of the aspects seen in the obese it shows how much of that power being absorbed is being placed directly on the knee joint itself (Shultz et al.). It is therefore understandable that obese individuals, because of their increased knee joint power phases may be predisposed to excess knee trauma and tissue damage (Shultz et al.).

Obese patients also have higher incidences of developing varus malalignment, or bow leggedness; however, due to the complexity of determining causation, researchers have yet show whether varus malalignment of the knee is consequential or casual (Anandacoomarasamy et al., 2008).

The effect of body composition on the longitudinal change of tibial cartilage volume was also looked into with magnetic resonance imaging. A strong positive correlation was found between muscle mass in the lower extremities and medial tibial cartilage volume (Anandacoomarasamy et al., 2008). Over a period of two years subjects were tested and those who increased their muscle mass through exercise showed to have a reduction cartilage volume loss (Anandacoomarasamy et al.).

In regards to avoiding knee surgery, weight reduction is a preventive action towards minimizing chances of surgeries. For individuals who decreased their weight even by 5 kg, it is predicted that they could avoid 24% of knee surgeries (Anandacoomarasamy et al., 2008). In addition for every pound lost there is a 4 pound reduction on the joint load (Anandacoomarasamy et al.).

Joint Biomechanics: Effect on Ankle Joint and Foot

When analyzing the walking patterns of obese individuals, changes can be found in certain sub-phases of gait. Within the heel strike sub-phase of stance, the obese subjects require larger joint powers from the "anti-gravity musculature" (Shultz et al., 2010). The larger joint power must be present in order to keep an upright posture (Shultz et al.). As power increases the amount of energy output increases because it takes metabolic energy to increase muscle force; therefore, it takes a greater amount of energy to keep upright posture for obese subjects while walking (Shultz et al.).

When analyzing children’s gait, obese children have longer mid-stance duration within their gait cycle. Increased mid-stance phase duration is a marker of a safer gait that increases stability and decreases rate of propulsion (Yan, Zhang, Tan, Yang, & Liu, 2013). This indicates a balance adaptation; because the obese children feel less stable when walking they increase their stance phase in order to compensate for their instability (Yan, et al.). These results are comparable to obese adults who have greater duration in a single foot mid-stance, double support duration is higher, meaning they spend more time within the double support phase than the normal-weight counterparts (Blaszczyk et al., 2011).

In addition, the time to achieve peak pressure and the peak pressures in the metatarsal heads were higher Pressure rate or time to pressure is used to estimate risk of injury in the plantar portion of the foot (Yan et al., 2013). Higher pressure indicates greater impact on the foot and higher risk of injury (Yan, et al.). Overall obese children had weaker walking stability and flatter foot pattern (Yan, et al.). Increased plantar loads increase chances of developing foot discomforts and foot pathologies (Yan, et al.). Like both the hip and knee, the ankle joint experiences more torque and more force because of the excess weight obese individuals have on each joint. This increased torque and force slows down movement, increases tension, and increases the amount of energy needed to move.

Foot axis angle has also been shown to be greater in obese individuals, when analyzing the angles of the feet in walking. Foot axis angle is the direction of the rotation of the foot away from the direction of gait (Yan et al., 2013). It is a measure of the amount of internal or external rotation that the subject has during walking (Yan, et al.). Greater amount of external rotation was seen in foot axis angle data indicating a toe position of walking. This position develops due to a need for increased stability and widened base of support (Yan, et al.).

Obese children are also prone to foot abnormalities such as greater pes planus (flat feet) compared to non-obese children (Hills et al., 2002). This abnormality is due to the compression of the longitudinal arch, results in greater mid-foot contact with the ground than in normal foot structure (Hills et al.). This excess contact carries into adulthood and can contribute to increased pressure on the foot and greater foot pronation during (Levinger et al., 2010). As BMI increases, the thickness of the fat pad below the heel, which absorbs shock and the weight of the body, also increases; however, its compressibility does not increase (Hills et al.). Although the excess padding would seem to benefit those with obesity, these individuals report higher incidences of heel pain compared to normal weight individuals (Hills et al.). This reported heel pain may be explained by the findings of greater distribution of polymodal nocioceptors throughout the fat pad. Nocioceptors provide pain reception to the brain and having greater numbers of these receptors may decrease pain threshold (Hills et al.). Peak plantar pressures are also much higher in obese subjects compared to non-obese ((Hills et al.). Therefore, with both the increased pain receptors and increased amount of pressure, it is not surprising that obese individuals have a greater incidence of heel pain during walking, compared to non-obese (Hills et al.).

Swing velocities of the foot during swing phase have been shown to be greater in obese subjects compared to non-obese (Blaszczyk et al., 2011). Greater swing velocity also means however, that more energy is required to move. This concept is associated with increased metabolic cost as discussed in an earlier section. Increased metabolic cost decreases gait efficiency and increases time to exhaustion.

Summary

In summary, obese individuals tend to have more difficult and laborious gait patterns due to the excessive mechanical loads and compensatory biomechanical effects the excess weight creates. Gait is affected by decreased speed, increased base of support, and increased COM displacement. Obesity correlates with lower back pain and muscle weakness, which in turn affect posture and the metabolic efficiency of walking. All major lower extremity joints are affected biomechanically as the excess weight changes amount of torque and force experienced by the joint.

Not only does research support the detrimental effects of obesity, but such effects are also commonly observed in everyday life. Individuals who are obese are less likely to walk up and down stairs or walk long distances because it takes more energy and is more difficult for them to move (Hills et al., 2002). This can turn into a cycle in which as it becomes harder to be active, the greater the individuals desire to be sedentary, especially when OA and joint pain is present with movement. If an obese individual more active however, the healthier they will be.

Although obesity is an American epidemic and has detrimental effects in human ambulation, the body is adaptable and individuals can get back to a state of health by changing their lifestyle habits. Those struggling with excess weight can be encouraged to slowly make changes in their eating habits by increasing high fiber and low glycemic index foods and also decreasing intake of packaged foods high in saturated fats and sugar. They can also increase their activity levels by walking for at least 30 minutes 5 times a week according to ACSM guidelines (ACSM 2014). These habits should be part of everyone's lifestyle in order to increase quality of life and encourage the health movement in America.

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