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Current Understanding of the Impact of Childhood Obesity on the Foot and Lower Limb

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ABSTRACT

Childhood obesity has emerged in recent years as a major public health problem. As this continues to concern across local, national and international populations, and as our understanding of obesity advances, access to multi-disciplinary care and understanding of the complications is warranted. Recent findings have suggested that the musculoskeletal system is one of the multiple body systems compromised by obesity and that aberrant biomechanical function may be a precursor to the onset of musculoskeletal symptoms. This review will consider childhood obesity and its impact on the paediatric foot and lower limb through examination of literature on foot structure and biomechanics of gait. An overview of evidence-based management is out with the context of this review, however some recommendations for clinical practice will
be proposed.

Introduction

Childhood obesity is a major public health concern with recent figures from the National Child Measurement Programme (2010/11) reporting the proportion of overweight and obese in reception year to be 22.6%, rising to 33.4% in year 6 (The NHS Information Centre, 2011). There is evidence emerging of the association between socio-economic status and obesity with variable rates of obesity being linked to the socio-demographic mix of local populations (Dinsdale and Ridler, 2010). The escalation of childhood obesity over the previous decade is even more of a concern when it is considered that obesity in childhood tends to persist into adulthood and is associated with an increase in adult mortality and morbidity (Reilly et al, 2003). Associated with obesity in children are comorbidities affecting multiple body systems including cardiovascular disease, liver disease, diabetes mellitus, respiratory disease and various musculoskeletal disorders, particularly affecting the feet and lower limbs (Hills et al, 2001). This review will consider the impact of obesity on the musculoskeletal system in children, with a particular focus on the foot and biomechanics of gait.

Persistent and abnormal loading of the musculoskeletal system has been implicated in the predisposition to aberrant gait patterns in children, loss of mobility (Messier et al, 1994) and to a range of long-term orthopaedic conditions including Blount's Disease (Dietz, 1998) and Slipped Capital Femoral Epiphysis (Murray and Wilson, 2008). Nevertheless, the implications of childhood obesity on the lower limb musculoskeletal and locomotor systems, particularly during weight-bearing tasks, are poorly understood (Wearing et al, 2006). Past research in children with obesity has revealed changes in foot structure (Riddiford-Harland et al, 2000), aberrant mechanics of foot loading (Messier et al, 1994), altered gait characteristics (Hills and Parker, 1991; McGraw et al, 2000; Morrison et al, 2008) and reduced muscle strength and power (RiddifordHarland et al, 2006) when compared with non-obese individuals. Futher problems commonly reported among obese children include general discomfort in simple activities of daily living such as walking and stair climbing and pains in the joints of the lower extremities (Hills et al, 2001). Hills et al, (2001) reported that these pains might be due to the increased stresses placed upon the feet and the greater absolute loads experienced at joints by the need to bear excessive mass.

To date, the consequences of childhood obesity on the development and function of the musculoskeletal system and the musculoskeletal injuries that result from altered lower limb/foot mechanics has received little attention. A greater understanding of these areas will have implications for the prevention, treatment and management of pathological gait patterns, loss of mobility and other mal-adaptations in the lower extremities of obese children. Thus, the aim of this review is to consider current literature pertaining to the influence of obesity on the structure and function of the foot and lower limb.

Discussion

Foot Structure in the Obese Child

The foot is a complex biomechanical structure, which acts as a shock absorber, force transducer and stabiliser through progression of gait (Perry, 1992). Throughout stages of growth and development, the posture of the foot adapts in response to the demands placed upon it and, as a consequence of aberrant mechanics, the foot is susceptible to deformity due to its distal location, flexibility and late ossification (LeVeau and Bernhardt, 1984).

A common musculoskeletal co-morbidity associated with childhood obesity is pes planus (flat feet) (Bordin et al, 2001; Chen et al, 2011; Pfeiffer et al, 2006; Riddiford-Harland et al, 2011; Villarroya et al, 2009). The link between the development of pes planus and obesity is yet to be elucidated, but is thought to be a result of excessive mass disrupting the immature musculoskeletal structure of the child's foot and consequently, altering foot function (Dowling et al, 2001; Dowling et al, 2004; Morrison et al, 2007; Morrison et al, 2008; Nantel et al, 2006; Riddiford-Harland, et al 2000; Villaroya et al, 2008). The suggestion that structural foot differences are associated with obesity emerged from early studies utilising static footprint assessment to characterise the weight bearing foot and also to identify contact area of the midfoot; the view being that the greater the mid-foot contact the more planus (flatter) the foot type. Riddiford-Harland et al, (2000) explored the association between obesity and foot structure. This research utilised the Footprint Angle and the Chippaux-Smirak Index (CSI) as ratio measures of the narrowest and widest part of the foot, purported to indicate flattening of medial longitudinal arch. Static footprints were collected from 62 obese and 62 non-obese children (mean age: 8.5 ± 0.5 years) and the results reported a lower mean arch height, suggestive of the pes planus foot type. Following this study Dowling et al, (2004) utilised both static and dynamic measures to evaluate foot structure in obese children. A smaller sample size was recruited (n=13 obese children and n=13 non-obese children) and similar findings emerged with the obese subjects demonstrating a flatter foot type. Changes in foot structure identified by static footprint analysis have also been reported in more recent studies (Mickle et al, 2006; Villarroya et al, 2008), but the validity of the conclusions from this body of work are limited. It can be asserted that the static footprint may offer an indirect measure of arch height but provides little or no information with regards to three-dimensional structure or foot function. Further to this, a recent study looking at arch structure in adults with obesity suggested that footprint based measures should be interpreted with caution as they were not reflective of the actual osseous changes of the foot (Wearing et al, 2012).

The evaluation of discrete changes in anthropometric characteristics of the foot in childhood obesity may offer further understanding of the structural changes underpinning the development of pathology, and on the wider demands placed upon the foot structure. Mauch et al, (2004) evaluated the influence of age, gender and body mass index (BMI) on the 3-dimensional foot shape in 1,996 children, aged 3–10 years and concluded that BMI influenced all foot measures. Emerging from this study was the suggestion that footwear modifications may be needed for obese children and thus, clinical assessment by appropriate Allied Health Professionals was warranted. A later study by Mauch et al, (2008) evaluated the static morphology of the feet in normal, underweight and overweight children. In keeping with the previous study, this work concluded that increased body mass resulted in larger foot dimensions (indicated by higher than normal foot volume and length), but associations between BMI and flat feet were weak. Findings from this work identified 5 foot types - *flat feet, slender feet, robust feet, short feet and long feet* - where children with a higher BMI had robust feet (normal arch, higher volume and length) and children with lower BMI had slender feet (higher arch, lower volume and length). Changes in anthropometric foot characteristics are further echoed in recent work by Morrison et al, (2007) where obese children were reported to have larger and wider feet. Reasons underpinning these changes are not clear but, could be related to a number of factors such as biomechanical deformity, excess of adipose tissue and/or increased bone formation and sub-periosteal expansion resulting from increased plantar forces experienced during gait.

Whether obesity leads to the clinical presentation of flat feet is yet to be elucidated and it has been proposed that the flat feet in obese children may be due to the existence of a thicker plantar fat pad underneath the midfoot, giving the appearance of a flatter foot due to greater ground contact. This was investigated by Riddiford-Harland et al, (2011) who compared 75 obese children to 75 age and sexmatched non-obese children and reported that the obese group had both a significantly greater medial midfoot fat pad thickness (4.7 and 4.3mm respectively, $p<0.001$) and a lower medial longitudinal arch (23.5 and 24.5mm respectively, $p< 0.006$) when compared to their leaner counterparts.

With the increasing evidence of changes to the foot structure in children with obesity there is an additional need to understand the impact of the structural changes observed and to further understand the functional impact, particularly in relation to biomechanical function and the development of musculoskeletal pathology. It is important that approaches to evaluating foot structure are both valid and reliable in order to further inform the evidence base. It must be recognised that measures of static foot structure offer little information about dynamic function and thus the links between obesity, foot pathology and foot structure are yet to be determined. In light of this, further studies looking at the dynamic function of the foot are required.

Characteristics of Foot Loading in Obese Children

The clinical evaluation of the dynamic foot is challenging, particularly when attempting to classify foot structure and establish relationships to pathology. In clinical practice and in research, plantar pressure assessment can be employed to determine the dynamic loading of the foot, as well as providing specific loading information at each region of the foot to determine loading characteristics (Stebbins et al, 2005; Mickle et al, 2006). Several authors have commented upon the clinical relevance of plantar pressure assessment in not only describing the overall loading effects on structures of the foot but also having the potential to express the damage that may occur in the tissues of the foot as a result of these loads, making them meaningful and effective in the management of patients with a wide variety of foot and lowerextremity disorders (Cavanagh and Ulbrecht, 1994; Hennig, 2002). When compared with other assessment devices typically used in clinical gait analysis, plantar pressure assessment is easier to implement, less time consuming and cumbersome for the patient and less expensive than complex gait analysis equipment (Giacommozzi, 2011).

In a study utilising a pressure platform (Mini E-med system, Novel, Munich) Dowling et al, (2001) investigated the effects of obesity on plantar pressures generated by 13 obese and 13 non-obese peripubescent children, matched by gender, age and height. The obese children generated significantly higher pressures under the forefoot during walking (39.3 ± 15.7 N.cm-2) when compared to the nonobese children (32.3 ± 9.2 N.cm-2). These results were re-iterated in 2004 by Dowling et al, who identified that during standing, obese children generated significantly higher forces over a larger foot area and experienced significantly higher plantar pressures compared to their non-obese counterparts. During walking, the obese children generated significantly greater forces over all areas of their feet, except the toes. In addition the obese children experienced significantly higher plantar pressures in the midfoot, heel and metatarsal heads compared to non-obese children. An increased loading at the midfoot may be indicative of a pes planus foot type with increased loading at the metatarsal heads predisposing to soft-tissue and osseous pathology.

Other studies investigating the effects of childhood obesity on plantar pressure distributions during standing and walking have also reported significantly higher pressures and forces across different regions of the foot (Gravante et al, 2003; Kellis, 2001; Mickle et al, 2006). Mickle et al, (2006) compared the dynamic plantar pressures generated in 17 overweight/obese children (4.4 ± 0.8 years) and 17 age, gender and height matched non-obese peers (4.4 ± 0.7 years). The authors reported that when walking, the overweight/obese children displayed significantly larger contact areas and generated significantly larger forces on the plantar surface of their total foot, heel, midfoot and forefoot compared to the non-obese children.

A study investigating the effects of obesity on plantar pressure distributions in young adults reported an increase in contact area of the midfoot and significantly higher peak and mean pressures ($P< 0.0001$) in the foot (Gravante et al, 2003). Gravante et al, (2003) compared the plantar contact area and peak plantar pressures in 38 obese young adults and 34 health controls (mean age 23 years) during standing on a pressure platform. The authors reported that obesity was associated with significantly larger plantar contact areas (+ 10.6%) and peak pressures (+ 43.0 %) in both the rearfoot and forefoot. These increased pressures exerted on the foot contribute to the view that assessment of biomechanics and gait in the clinical evaluation of the obese patient is warranted.

The findings from the literature are consistent with the view that obese children are at an increased risk of developing foot discomfort and/or foot pathologies, including stress fractures as a result of the increased pressure acting upon the immature musculoskeletal structure of the foot. Furthermore, foot discomfort associated with these increased plantar pressures in obese children may hinder their participation in physical activity; weight-bearing activities can become difficult if not appropriately designed to account for these structural characteristics. Recently, Mickle et al, (2011) explored the relationships between obesity, physical activity and sedentary behaviour in a sample of 95 children aged 3–5 years. Findings from the study confirmed that increased peak pressures negatively correlated with physical activity and sedentary behaviour. Emerging from this research was the suggestion that raised foot pressures may influence engagement with activity and thus, interventions to reduce pressures under the foot are required. In light of these findings further research is required to understand the impact of obesity on the foot to ensure that foot pathologies in obese children are identified and managed appropriately.

The findings reported in the aforementioned studies must be interpreted with some caution as methodological differences with regards to the classification of childhood obesity, different methodological protocols, sample sizes and lack of control for ethnicity all affect the external validity of the work. As the long-term consequences of the increased planter pressure distributions are unknown, it is recommended that the effects of obesity on the potential alterations of foot function characteristics between obese and non-obese children be further investigated. Furthermore, this body of literature has tended to view the foot in isolation and it must be appreciated that the foot forms part of the lower limb kinetic chain and therefore, the foot should be assessed as part of this. Further work on the impact of obesity on the gait patterns of children with obesity will be discussed.

Gait Analysis in Childhood Obesity

Clinical gait analysis allows the measurement and assessment of walking biomechanics but is limited in that the clinician cannot capture movement in three planes or appreciate the kinetics of the movements taking place. Clinical analysis facilitates the identification of abnormal characteristics and can guide clinical management strategies but detailed analysis is required to characterise the impact of disease processes. Changes to gait patterns can be identified in many pathological conditions and recent findings have suggested changes to the gait pattern in children with obesity.

Changes in the gait pattern of children with obesity were first documented by Hills and Parker (1991a,b,c,d). Conclusions from this body of work were that obese children displayed greater asymmetry with their gait, along with increased double-limb and shorter single-limb support period when compared with non-obese children (Hills and Parker, 1991b). Other temporal differences included a longer cycle duration, lower cadence, lower relative velocity and greater stride width (Hills and Parker, 1991c); all pointing to a slower, safer and more tentative walking gait in obese children relative to normal weight children. Additionally, the findings from this work indicated that obese children displayed a more flat-footed weight acceptance pattern in early stance and a greater external rotation of the foot at all phases of the gait cycle (Hills and Parker, 1991a).

A later study by McGraw et al, (2000) also reported that instability during gait in children was linked to excessive body mass. In this study 20 male participants were recruited (10 obese, 10 non-obese, aged between 8 and 10 years) and gait and postural stability was evaluated with two-dimensional video and a force platform. The authors concluded that the obese subjects displayed increased doublestance duration ($p<0.02$), and significantly greater sway areas ($p<0.01$) in the medial-lateral direction. Changes in spatio-temporal gait parameters have been echoed by recent studies where the temporal gait parameters of decreased preferred walking speed, reduction in step length and lower step frequency have been reported in obese compared to normal weight children (DeVita and Hortobágyi, 2003; Morrison et al, 2008; Nantel et al, 2006).

Differences in preferred walking speed between obese and non-obese individuals might account for the reported alterations in spatiotemporal measures. DeVita and Hortobágyi (2003) reported that spatiotemporal stride characteristics were comparable when 21 obese and 18 non-obese adults walked at a standard speed (1.50m·s-1) compared to self selected speed (1.29m·s-1). DeVita and Hortobágyi (2003), observed, however, that joint kinematics varied with body weight in the obese group irrespective of walking speed; obese adults demonstrated approximately 5° greater hip extension, approximately 4° less of knee flexion and approximately 6° greater ankle plantar flexion compared to the non-obese adults. Results from this work also presented kinetic differences revealing that when walking at a standardised speed only ankle joint torque and powers were higher (both p<0.000) in obese adults by 88% and 61%, respectively.

Frontal plane kinematics of the lower limbs during gait in male children (aged 10 to 12 years) has been examined (McMillan et al, 2009). The overweight subjects (BMI 40.5 ± 10.0 kg/m2) produced a significantly greater rearfoot eversion range of motion and later timing of peak eversion motion relative to the healthy weight subjects (BMI 17.0 ± 3.3 kg/m2). Peak knee adduction motion in early and late stance was of greater amplitude and the timing of peak hip adduction motion was significantly later in the healthy weight group. These findings suggest that overweight males may redistribute forces in the medial-lateral direction during gait. Shultz et al, (2009) reported no significant differences for joint kinematics between 10 overweight (BMI 30.47 ± 5.54 kg/m2) and normal weight (BMI 16.85 ± 1.31 kg/m2) children during swing and stance phase. The study did reveal that overweight children had significantly greater sagittal, frontal and transverse plane absolute peak joint moments at the hip, knee and ankle regardless of walking cadence. The authors surmise that because body mass is not proportional to joint articulating surfaces, higher absolute peak joint moments will increase the risk of malalignment and injury in overweight children. In particular, the ankle dorsiflexor moments were significantly greater in the overweight compared to normal weight group. This suggests a greater muscular force is needed when carrying excess mass to implement a braking mechanism during stance phase.

Gushue et al, (2005) investigated the effects of excessive body mass on 3-D knee joint biomechanics during walking. Ten overweight children (BMI 29.9kg/m2) were compared to 13 normal weight subjects (BMI 18 kg/m2) using an ethnically diverse sample of children. It was reported that overweight participants demonstrated significantly lower peak knee flexion angle (14.5° ± 5.5°) compared to normal weight subjects (21.1° ± 5.0°), but no significant differences in peak internal knee extension moment were found (22.5° ± 10.5° and 10.8° ± 5.5°). The overweight group, however, showed a significantly higher peak internal knee abduction moment (22.5° ± 10.5° and 10.8° ± 5.5°) suggesting that overweight children may not be able to compensate for increased force through the knee in the frontal plane. In a study by Nantel et al, (2006) looking at the locomotor lower limb strategies of obese and nonobese children, it was reported that only the hip joint kinetics were modified in the obese compared to non-obese children during walking. The obese subjects demonstrated decreased energy generation from the hip extensors and increased energy absorption from the hip flexors. In addition, obese children were less efficient at transferring energy between the eccentric and concentric phases at the hip. The work suggests that obese children develop a gait adaptation to maintain a similar knee extensor load and take advantage of a passive hip strategy to achieve forward progression during gait.

Recently Shultz et al, (2009) reported that obese children (n=10) demonstrated greater absolute peak joint moments of flexion and extension at the hip, knee and the ankle joints in the sagittal plane of motion in comparison to normal weight children (n=10). It was thought that this increased joint loading might result in cumulative stress, which has been associated with the development of varus angular deformities of the knee joint (i.e. Blounts Disease). Increased joint moments (particularly at the knee), may compromise the structures that control joint stability and this could explain the slower more tentative walking pattern displayed in obese children (Hills and Parker, 1991a; McGraw et al, 2000). These findings, however, require further investigation to determine the impact of excessive body weight on joint forces and the influence this has on the biomechanics of the lower limb and foot of young children.

Conclusion

Biomechanical changes impacting upon the foot and lower limb in children with obesity have been documented in the literature. Changes to foot structure and foot loading characteristics can predispose to the development of musculoskeletal pathology, however the links between these changes and the manifestation of pathology are lacking. Changes in the gait pattern and joint loading have also been proposed which may also be linked to the development of musculoskeletal problems. Further exploration of the impact of the biomechanics of adiposity is required, utilising robust and rigorous protocols, along with a uniform approach to defining obesity. The long-term implications of obesity in childhood are yet to be determined. In light of the trends identified in the literature further work is required to inform the multidisciplinary care of children with obesity.

Recommendations for Clinical Practice

1. Clinicians involved in the management of children with obesity should consider the biomechanics of the lower limb and consider the impact upon the foot.

2. Access to specialist foot care and footwearservices is needed for children with obesity reporting foot and/or lower limb musculoskeletal pathology.

3. The application of appropriate technology canenhance the assessment of children with obesity and inform the clinical management.
4. Clinical management of childhood obesity should utilise weight management services as a fundamental part of multi-disciplinary care

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