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Impaired physical function associated with childhood obesity: how should we intervene?

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ABSTRACT

Background: This study examined relationships between adiposity, physical functioning and physical activity.

Methods: Obese (N=107) and healthy-weight (N=132) children aged 10-13 years underwent assessments of percent body fat (%BF, dual energy X-ray absorptiometry), knee extensor strength (KE, isokinetic dynamometry), cardiorespiratory fitness (CRF, peak oxygen uptake by cycle ergometry), physical health-related quality of life (HRQOL), worst pain intensity and walking capacity [six-minute walk (6MWT)]. Structural equation modelling was used to assess relationships between variables.

Results: Moderate relationships were observed between %BF and 6MWT, KE strength corrected for mass and CRF relative to mass (r -.36 to -.69, P≤.007). Weak relationships were found between: %BF and physical HRQOL (r -.27, P=.008); CRF relative to mass and physical HRQOL (r -.24, P=.003); physical activity and 6MWT (r .17, P=.004). Squared multiple correlations showed that 29.6% variance in physical HRQOL was explained by %BF, pain and CRF relative to mass, while 28% variance in 6MWT was explained by %BF and physical activity.

Conclusions*:* It appears that children with a higher body fat percentage have poorer KE strength, CRF and overall physical functioning. Reducing percent fat appears to be the best target to improve functioning. However, a combined approach to intervention, targeting reductions in body fat percentage, pain and improvements in physical activity and CRF may assist physical functioning.

KEYWORDS

Disability, body mass index, weight status, physical activity, pediatrics.

INTRODUCTION

Mounting evidence suggests that childhood obesity may contribute to reduced physical functioning, or 'disability',[1-3] as defined by the World Health Organisation's Framework; the International Classification of Functioning, Disability and Health). Here, an individual's functioning is considered a continuum, whereby any limitations in body functions, activity or participation in broader life contexts may be considered as an 'impairment' or 'disability'. Examples of obesity-related impairments commonly reported in children include reduced cardiorespiratory fitness (CRF), lower limb strength, balance, increased pain, musculoskeletal mal-alignment, altered biomechanics and orthopaedic issues.[1, 4-6] Participation restrictions in daily functioning are also seen with obesity; some children struggle with daily tasks like walking, climbing stairs and rising from a chair.[2, 3, 7] Furthermore, obese children may have poorer physical health-related quality of life (HRQOL)[8] and lower physical activity levels.[9]

The burden of excess fat seems primarily responsible for obesity-related disability in children. However, certain obesity-related impairments (e.g. reduced strength, CRF or pain) may contribute to limitations in daily functioning and could logically serve as targets for interventions to improve functionality. If children move and function better, this may assist them to be more active, facilitating long-term obesity management. Few studies have examined relationships between obesity-related impairments and daily functioning. Some have linked impaired CRF relative to body mass with reduced walk/run capacity.[10-12] Others have found that chronic pain may further compound impairments in physical HRQOL and

difficulties with performing vigorous physical activities in obese children seeking treatment.[13, 14]

Some evidence also suggests that physical activity may influence obesity-related disability. One study[15] reported lower physical HRQOL in overweight children undertaking less than 60 minutes of daily moderate to vigorous physical activity. Similarly, Chen and colleagues[16] found that lower physical activity engagement was associated with a greater risk of reporting poor physical HRQOL (~2-6 times) compared with children who engaged in physical activity 'very often', independent of body mass index (BMI). Hence, physical activity levels should be taken into account when evaluating relationships between weight status and daily functioning, particularly HRQOL.

Gaining a better understanding of the impact of obesity on physical functioning in children is important not only for developing effective strategies to limit obesity-related disability in child- and adulthood, but also to protect against further disability developing throughout adulthood. Hence the aim of this investigation was to further examine the complex relationships between adiposity, physical functioning and physical activity in children who participated in a multicentre observational case-control study,[2] with a view to identifying suitable targets for interventions to improve daily functioning. The hypothesised model of relationships is depicted in Figure 1 (the 'initial' model). Our primary hypotheses of interest are depicted in bold and can be summarised as follows;

1) Adiposity would be directly associated with impairments in physical functioning (walking capacity, physical HRQOL, pain, CRF and KE strength). (Figure 1, pathways 1-5, respectively).

2) Increased pain and impaired CRF, KE strength and reduced physical activity would directly translate into restrictions in daily functioning. (Figure 1, pathways 6-13, respectively).
3) Increased pain, impaired CRF and KE strength and reduced physical activity would be more strongly associated (Figure 1 pathways 6-13) with restrictions in daily physical functioning (physical HRQOL and walking capacity) than adiposity (Figure 1, pathways 1-5). This latter hypothesis was principally concerned with identifying targets (other than weight loss), for interventions to improve daily physical functioning in children. Therefore, we also interrogated the relative contributions of indirect and total effects to assist with identifying optimal targets for intervention.

Although secondary to the hypotheses under study, a number of other justifiable inter-relationships between outcomes of interest were also included as a pre-requisite to achieving a well-fitting model[26] (non-bolded pathways, Figure 1).

MATERIALS AND METHODS

Obese and healthy-weight[17] 10-13 year olds were recruited from three Australian states using media advertisements and flyers as part of a multicentre observational case-control study.[2] Children were excluded if they were underweight,[18] overweight,[17] had ear infections or an acute injury (prior six months), a medical cause for their obesity, a neurological/intellectual impairment, or received obesity treatment in the prior three months. The Human Research Ethics Committees of the University of South Australia, RMIT University, Queensland University of Technology and Flinders Medical Centre provided ethical clearances. Informed consent was sought from parents/legal guardians and children

prior to their participation. Children took part in a single physical assessment appointment; body composition, CRF, KE strength, pain, walking capacity and HRQOL were evaluated. These methods have been described in full elsewhere,[2, 4, 19, 20] however brief descriptions are provided below.

Body composition

BMI (kg/m^2) was calculated and percent body fat (%BF) was assessed by dual energy X-ray absorptiometry (DXA; Lunar Prodigy with standard ENCORE 2003 software version 7.52, General Electric, Madison, USA).

Cardiorespiratory fitness

Oxygen uptake was monitored using indirect calorimetry during an incremental cycle ergometry exercise test to volitional exhaustion as previously described.[20] VO_{2peak} corrected for body mass was considered the most appropriate variable for evaluating associations between CRF and physical functioning. However, to simply express VO_{2peak} as a ratio of body mass incorrectly assumes a linear relationship between CRF and mass and may overestimate deficits in VO_{2peak} relative to body mass. Therefore, allometric modelling[21, 22] was used to normalise VO_{2peak} for body mass. A log linear regression model[21] was employed with an exponent of 0.720 (calculated from this data set).[20]

Knee extensor strength

As previously described,[5] peak isokinetic KE torque was measured on both limbs using an isokinetic dynamometer (Biodex System 4 or Biodex System 3, Biodex Medical Systems Inc., New York, USA). Participants undertook three submaximal and one maximal practice repetitions, followed by 10 consecutive maximal contractions through a 95° range of motion at 60°/s on each limb.[19] Data were exported at 1000Hz (Powerlab 16/30, BioAmp and LabChart version 6 software, AD Instruments Pty Ltd, Colorado Springs, USA) and were

corrected for limb mass. The peak torque for each limb was ascertained and an overall average calculated. As with CRF, peak torques were allometrically normalised for body mass using an exponent of 0.578.

Pain

Worst pain intensity over the prior week was captured using a 100 mm horizontal visual analogue scale, evaluated using the pediatric pain questionnaire™.[4, 23, 24]

Walking capacity

The six-minute walk test (6MWT) was used as an indicator of walking capacity, expressed as the total distance walked up and back along a 10-m track (expressed to the nearest 0.1 m).[2]

Physical HRQOL

The physical functioning subset of the Pediatric Quality of Life Inventory™ (PEDSQL™)[25] was self-reported by children to represent physical HRQOL.[2]

Physical Activity

Participants wore a uniaxial accelerometer (Actigraph®, MTI Health Services, Fort Walton Beach, Florida, USA, version 2.2 model 7164) continuously on their right hip for eight days. Minimum wear criteria were: four weekdays and two weekend days, ≥10 eligible hours (>3000 counts/hr) of daily wear-time. One-minute epochs were used and data were reduced to weekly average counts/hr.[2]

Demographics

Parental socioeconomic status (SES) was evaluated by questionnaire (maternal education and average annual household income). These factors were included in the analysis as they statistically differed between groups and could potentially impact adiposity and physical functioning. Because they are non-modifiable at the individual level, they were not considered suitable intervention targets.

Statistical Analysis

Structural equation modelling was conducted using Analysis of Moment Structures (AMOS) version 17.0 (AMOS development corporation, Crawfordville, USA). Whereas other techniques only test a single relationship at a time (i.e. regression and multiple regression), structural equation modelling examines multiple relationships simultaneously, whereby any variable can act both as a dependent and independent variable.[26, 27] Moreover, this technique enables the inclusion of direct and indirect pathways and provides estimates about *how well* independent variables explain a dependent variable and which variables are most *strongly associated* with the dependent variable.[28] Thus, this statistical approach was ideally suited to the hypotheses investigated here as depicted in Figure 1.

Bootstrap maximum likelihood estimation[27] was selected as the estimation technique as it is not sensitive to skewness/outliers which were detected in this sample. This technique involves the simulation of multiple samples (N=500 used here) from the original sample and computing average parameter estimates derived from all samples.[26] Missing values were imputed using expectation maximisation to reduce bias[26] after checking that data were missing completely at random using Little's test[29] (P=0.61). Age was not entered as a variable in this model due to the homogeneous age range of the sample. It was not an aim of this study to examine differences in daily functioning by gender, particularly given the age and sexual immaturity of the sample; nor was the study powered to conduct such analyses. Modification indices were examined post hoc to ascertain if any potentially relevant pathways were omitted from the model.

RESULTS

Data were included from 107 obese (51 female, 56 male) and 132 healthy-weight (56 female, 76 male) children with a mean age of 11.9±0.1 years. Groups did not differ in age (P=0.38), height (P=0.33) or pubertal development (P=0.13) as previously reported.[2] Descriptive characteristics for the key variables included in the structural equation model are shown in Table 1.

Model evaluation and modification

There was no evidence of multicollinearity (i.e. no correlations >0.8,[26] Table 2), invalid estimates (e.g. implausible standard coefficients, negative measurement error variances or very large standard errors) or prediction errors (standardised residuals were within 2.58 standard deviations of the mean). In the interests of model parsimony, all non-significant pathways (p 0.052 to 0.968) were removed (%BF to pain/physical activity; physical activity to pain/KE strength/physical HRQOL; pain to 6MWT; CRF/KE strength to 6MWT, KE strength to physical HRQOL; maternal education/income to physical HRQOL). Fit of the final model was good and parsimony and model power were improved (Table 3). Modification indices/expected change parameters did not suggest the inclusion of any additional omitted pathways.[26]

Direct effects

Direct effects are shown in Figure 2 in the path diagram and its accompanying table. Higher %BF was moderately inversely associated with lower CRF/KE strength relative to mass and physical HRQOL ($r = -0.36$ to -0.69, $P \leq 0.007$). Higher CRF and physical activity had weak positive associations with physical HRQOL or 6MWT ($r \geq 0.17$, $P \leq 0.004$), whilst more intense pain was associated with lower physical HRQOL. A comparison of all independent variables revealed that %BF had the strongest direct relationship with 6MWT. In contrast,

relationships between %BF/CRF/pain and physical HRQOL were comparable. Furthermore, squared multiple correlations revealed that 28.0% of the variance in 6MWT was explained by %BF and physical activity (95% CI 17.2 to 39.6, P = 0.010). Additionally, 29.6% of the variance in physical HRQOL was explained by %BF, worst pain and CRF relative to mass (95% CI 20.9 to 37.8, P = 0.010). Regarding the 'additional' included pathways, physical activity was significantly related to CRF relative to mass and %BF (weak to moderate positive and negative relationships respectively, Figure 2). Maternal education and income demonstrated a weak inverse relationship with %BF, while the variances of CRF/KE strength relative to mass and maternal education/income were correlated (Figure 2).

Indirect and total effects

Indirect effects on daily functioning (physical HRQOL and 6MWT) were weak (Table 4). %BF had a weak indirect effect on physical HRQOL via CRF, although the total effect was moderate when combined with direct effects. Physical activity also had a weak effect on physical HRQOL, which was *only* attributable to indirect effects (via %BF and CRF relative to mass). Likewise, physical activity had a weak indirect effect on 6MWT via %BF, leading to a meaningful overall total effect when combined with similarly weak *direct* effects.

DISCUSSION

This investigation examined relationships between adiposity, physical functioning and physical activity, thus identifying suitable targets for interventions that improve daily functioning in obese children. Our findings show that body fatness is negatively associated with components of children's functioning and that functional improvements may be best achieved via reductions in body fat. Our data also propose additional intervention targets

for maximising functional gain in existing obesity management programs – specifically, increasing physical activity and CRF whilst reducing pain.

In support of our first hypothesis, higher adiposity was associated with impairments in KE strength and CRF relative to mass and limitations in daily physical functioning (6MWT and physical HRQOL). Thus, obesity *per se* appears to be associated with disability in this population. This is consistent with our recent review of 114 studies,[1] in which obesity-related impairments in lower limb strength, CRF and increased pain, as well as limitations in daily functioning were apparent.

As anticipated in our second hypothesis, our findings also suggest that a child's physical capacity may be directly related to daily physical functioning. Specifically, those with better mass-corrected CRF and less pain may have better physical HRQOL. This novel link between CRF and physical HRQOL indicates that those children with lower CRF relative to mass may also find common everyday tasks more physically demanding. Contrary to previous research,[10, 30] CRF was not related to walking capacity, which could be due to previous studies overcorrecting VO_{2peak} for body mass by using ratio rather than allometric scaling.[10, 30] Alternatively, it may be that the 6MWT is more reflective of functional mobility than cardiorespiratory capacity in this population.

The association between pain and impaired physical HRQOL presents an additional consideration for obesity treatment. There may be a role for clinicians to at least screen children for pain and refer on for treatment/management. The relationship reported here is consistent with previous research showing pain intensity to be associated with increasing

functional disability (r ~ 0.5),[31, 32] although it is unclear if prior studies were representative of children with obesity. Hainsworth et al.[13] reported concurrence of chronic pain and obesity increased the risk of impaired physical HRQOL (by ~7 times) compared with obesity alone. Similarly, Wilson et al.[14] found that pain intensity was a stronger predictor of difficulties with active pursuits (e.g. running) than BMI. However, there may have been a sample bias towards more severely affected individuals as children were recruited from chronic pain clinics.[13, 14] Nevertheless, it appears that children with obesity experience greater pain than healthy-weight children[4] and that greater adiposity is related to poorer physical HRQOL. Therefore, pain should be considered when developing management programs for children with obesity.

Our data suggest that children who are more active may also have better daily functioning. In particular, higher physical activity was moderately linked (total effect) with better walking capacity, which was partly mediated by having less body fat to carry. Similarly, being more active was *indirectly* linked with better physical HRQOL (mediated by %BF and/or CRF). Whereas previous research[15, 16, 33] suggests a *direct* association between physical activity and physical HRQOL, our multivariate path analysis offers a differing perspective. Instead, physical activity may be linked with better CRF and lower body fat, which may in turn be associated with children reporting less difficulty completing everyday physical tasks. It is also worth noting that while the present study used objective measures (accelerometry), previous studies have often relied on self-reported physical activity[16, 33] which could influence their findings.

We expected children's physical capacities to be more strongly associated with daily functioning than adiposity (hypothesis three). Instead, we found that overall (i.e. direct and total effects), %BF had the strongest and most consistent relationships with daily functioning. Furthermore, %BF was also an important mediator of associations between physical activity and daily functioning. Thus reducing %BF seems the best target for improving locomotion and other physical tasks. As %BF is a *relative* measure reflecting both fat mass and lean tissue, such improvements could be achieved via interventions focussing on reducing body fat and/or increasing lean mass (e.g. via physical activity, which is supported in our model). Either way, the burden of excess mass would be reduced, facilitating physical function. In any case, the urgent need for effective obesity interventions is compounded.

Nevertheless, our findings suggest that interventions targeting a *combination* of factors (in addition to reductions in body fat) would have the potential to achieve better functional gains. More specifically, physical HRQOL could be optimised by increasing functional CRF and reducing pain, whilst ambulatory capacity could be improved by increasing overall physical activity.

Therefore, targeted exercise prescription may be particularly relevant to improving daily physical functioning in children. Walking capacity may be improved by higher levels of overall physical activity, working directly but also indirectly, through a lower burden of excess fat in children who are more active. Similarly, higher levels of physical activity may be associated with better physical HRQOL working indirectly via less adiposity and/or higher CRF. Consistent with previous evidence, our data also support a positive relationship

between higher physical activity and weight status.[9, 34-36] Hence, when it comes to prescribing exercise/physical activity as part of obesity treatment programs, both CRF endurance training as well as recommendations to increase overall physical activity may be warranted.

In this study, attempts were made to overcome limitations of previous research by incorporating a validated pain questionnaire, DXA, objective physical activity assessment and rigorous assessments of KE strength/CRF incorporating allometric normalisation methods. Despite this, some limitations are notable. The paediatric pain questionnaire only assessed pain over the prior week, which may not be representative of 'usual' experiences. With regards to KE strength, isokinetic testing was conducted at a single testing velocity, and faster velocities or differing contraction modes (e.g. eccentric rather than concentric) may have differing relationships with functional outcomes.

Structural equation modelling is a strength of this study, enabling the examination of direct and indirect relationships, with certain variables acting as both dependent and independent variables. For this reason, structural equation modelling is said to provide a potentially richer and more realistic view of real-world relationships among variables.[37] Even though this approach explores the directionality of relationships, this analysis does not prove causation and randomised controlled trials and longitudinal studies are needed.[38] Therefore, structural equation modelling was appropriate for this investigation as a means of *identifying* potential targets for intervention to improve functioning. While our data supported the exclusion of a number of relationships between the specified variables, the possibility remains that there may be other competing models that could fit the data just as

well but were beyond the scope of this investigation. For example, impaired daily functioning could potentially feedback into obesity, setting up a debilitating cycle. Similarly, it was not possible for us to include or measure all possible factors that could impact daily functioning (e.g. sedentary activity, motivation levels, social influences). In particular, future investigations should assess relationships with motor skill proficiency, as this could be a factor impacting physical activity levels, CRF and adiposity. Finally, qualitative research should also be undertaken to explore the extent to which the observed impairments in physical functioning are meaningful to children with obesity.

CONCLUSION

Adiposity was associated with impairments in KE strength and CRF, with the latter being positively linked with physical HRQOL. Increasing physical activity levels has the potential to improve daily physical function through direct and indirect pathways. However, reducing %BF remains the best target for interventions to improve physical functioning. Importantly, greater functional gains may be achieved by taking a combined approach to intervention design. In practical terms, this may mean fine-tuning obesity treatment to not only encourage increased physical activity (which may have the added benefit of reducing %BF via fat loss and increased lean tissue), but to also incorporate CRF endurance training. Clinicians should also be mindful of existing pain that could be impacting children's physical HRQOL, and refer on for appropriate assessment and management. Prospective studies are needed to confirm causation and examine changes in daily functioning. The possible impact of motor skill proficiency should also be explored in future studies.

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AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist for any of the authors.

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FIGURE LEGENDS

Fig 1 Initial structural equation model

A straight arrow represents a hypothesised effect. A circle represents the error associated with predicting a dependent relationship with a factor loading of 1. A curved double headed arrow represents a covariance (expected when two factors are related due to another factor not specified in the model). Pathways relating to hypotheses 1-3 are shown in **bold.** Variables include: Physical activity (weekly average accelerometry counts/hour), Mat ed (maternal education), Income (gross annual household income), %BF (percent body fat), CRF (cardiorespiratory fitness operationalised as peak oxygen uptake allometrically normalised to body mass in $mL/min/kg^{-0.720}$), KE strength (knee extensor strength operationalised as average isokinetic peak knee extensor torque allometrically normalised to body mass in $Nm/kg^{-0.547}$), Six minute walk test (m), Worst pain (worst pain intensity over the prior week in mm), Physical HRQOL (physical health-related quality of life scored out of 100).

Fig 2 Final model

A straight arrow represents a hypothesised effect. A circle represents the error associated with predicting a dependent relationship with a factor loading of 1. A curved double headed arrow represents a covariance (expected when two factors are related due to another factor not specified in the model). Standard estimates are presented with bootstrapped bias-corrected 95% confidence intervals in brackets. *P≤0.008. Squared multiple correlations (SMC) are shown for six minute walk and physical HRQOL. Variables include: Physical activity (weekly average accelerometry counts/hour), Mat ed (maternal education), Income (gross annual household income), %BF (percent body fat), CRF (cardiorespiratory fitness operationalised as peak oxygen uptake allometrically normalised to body mass in $mL/min/kg^{-0.720}$), KE strength (knee extensor strength operationalised as average isokinetic peak knee extensor torque allometrically normalised to body mass in $Nm/kg^{-0.547}$), Six minute walk test (m), Worst pain (worst pain intensity over the prior week in mm), Physical HRQOL (physical health-related quality of life scored out of 100).