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Obesity the new childhood disability?

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Summary

This review addresses the impact of obesity on paediatric physical functioning utilizing the World Health Organization International Classification of Functioning, Disability and Health Framework (ICF). The ICF encompasses functioning (as it relates to all body functions and structures), activities (undertaking a particular task) and participation (in a life situation) with disability referring to impairments in body functions/structures, activity restrictions or participation limitations. Electronic databases were searched for peer-reviewed studies published in English prior to May 2009 that examined aspects of physical functioning in children ($\leq$18 years). Eligible studies ($N = 104$) were ranked by design and synthesized descriptively. Childhood obesity was found to be associated with deficits in function, including impaired cardiorespiratory fitness and performance of motor tasks; and there was some limited evidence of increased musculoskeletal pain and decrements in muscle strength, gait and balance. Health-related quality of life and the subset of physical functioning was inversely related to weight status. However, studies investigating impacts of obesity on wider activity and participation were lacking. Further research utilizing the ICF is required to identify and better characterize the effects of paediatric obesity on physical function, activity and participation, thereby improving targets for intervention to reduce disability in this population.

Keywords: Body mass index, function, ICF, impairment.

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Introduction

Since the 1980s there has been a sharp increase in the prevalence of paediatric obesity with recent figures from developed countries suggesting that, based on the International Obesity Task Force (IOTF) Criteria (1), approximately 6–8% of 2–18 year olds are obese (2–5). While the cardiovascular and metabolic consequences of obesity have been studied extensively (6,7), less attention has been paid to investigating the impact of obesity on physical functioning and disability. It is becoming increasingly apparent from the adult literature that obesity is associated with reduced physical functioning and disability (8–10); however, paediatric literature in this area is limited.

Reprints will not be available from the authors.

International classification of disability and functioning

In an attempt to characterize the disability experience linked to a given health condition, the World Health Organization (WHO) developed the International Classification of Functioning, Disability and Health Framework (ICF) (Fig. 1) (11). Within this framework, the term *functioning* is a neutral concept that encompasses all physiological *body functions and structures* (e.g. neuromusculoskeletal functions, pain, etc.), *activities* (i.e. undertaking a particular task) and *participation* (i.e. in a life situation). The term *disability* refers to impairments in body functions/structures, activity restrictions or participation limitations. The functioning of an individual is the result of complex interactions between any given health condition, body

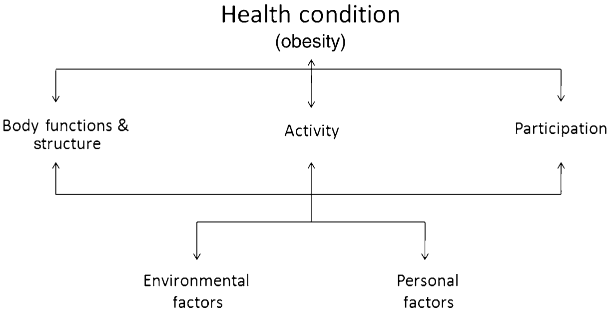

Figure 1 International Classification of Functioning, Disability and Health Framework (11). Adapted with permission from the World Health Organization, Geneva, Switzerland.

structures/functions, activity and participation, and contextual factors (i.e. environmental and personal, Fig. 1). The aim of the current review was to explore the literature examining the impact of obesity on physical functioning/disability in children using the ICF framework, specifically focusing on impairments in body functions predominantly relating to the lower limbs and activity/participation restrictions.

Methods

A systematic search strategy (Table 1) was used to identify literature for this review. Studies identified in the search were classified according to the Australian National Health and Medical Research Council Evidence Hierarchy (12) (Table 2) as providing level I, II, III-1, III-2, III-3 or IV evidence, whereby level I represents the highest level of evidence (e.g. systematic reviews of level II studies such as randomized controlled trials or prospective cohort studies) and level IV the lowest level of evidence (e.g. case series or cross-sectional studies). To synthesize eligible literature, a descriptive critical analysis of studies was completed, with key features summarized into tables (Tables 3–7).

Body functions

Lower limb muscle function

In relation to lower limb muscle function, in general the literature indicated that obese children had similar (13–15) or higher *absolute* muscle strength/power compared with non-obese children (16,17) (Table 3), but lower relative values (i.e. per unit body mass) (13–15,17). Almuzaini *et al.* (18) found a moderate positive relationship between absolute muscle strength and body mass index (BMI) ($r = 0.58$–0.69) and a weaker but significant inverse relationship between knee extensor (KE) endurance and BMI ($r = -0.34$). Similarly, a longitudinal study by Armstrong and colleagues (19) found a weak inverse relationship between skin-folds and cycling peak power. In contrast, Grund *et al.* (20) found no relationship between knee flexor (KF)/KE strength and weight status.

The findings of higher *absolute* muscle strength/power in obese compared with non-obese children in some studies (16,17) could be explained by the constant loading of the musculature due to a larger body mass that may impose a 'training effect'. This premise has support from research indicating that obese children have higher absolute fat-free mass (FFM) (17,20). However, relative strength/power is more important for activities which require people to move their own body mass and while the majority of studies indicate that relative strength/power is lower in obese compared with non-obese children, controversy exists regarding the most appropriate scaling method to enable comparisons between individuals of differing body size (21). Most authors have used ratio standards (see Table 3), whereby strength/power is divided by some measure of body size (e.g. mass, FFM), although this method assumes a linear relationship between variables which is not always the case (21,22). Consequently, some studies have used allometric scaling (21–23), whereby strength is divided by a measure of body size to the power of a specific scaling exponent, although agreement around the most appropriate exponent for children is lacking (17,22). Alternatively, some studies have used a measure of body size as a covariate in analyses to control statistically for any differences (17).

When correcting muscle strength/power for FFM or muscle cross-sectional area using ratio, allometric or covariate methods, most studies have reported no differences between obese and non-obese children (13,14,17,24) (Table 3), although one study (20) reported that the weakest children had the highest absolute body mass, fat mass (FM) and FFM. This latter finding might be explained by reduced motivation to provide a maximal effort during strength testing in obese children compared with controls rather than to any difference in the quality of muscle tissue. This is supported by Blimkie *et al.* (13,14) who found that obese boys exhibited reduced motor unit activation during maximal strength testing compared with non-obese boys (14), despite no differences in electrically evoked KE torques (13). Indeed, the findings of Blimkie *et al.* (13,14) and studies reporting no differences in muscle strength after normalizing for FFM (17,24) suggest that limitations in relative strength are more likely due to reduced motivation to express maximal strength or alternatively, to a mismatch between muscle strength and body mass resulting from excessive body fat (24), rather than to any difference in the quality of muscle tissue.

However, data on the effect of weight status on lower limb muscle function are somewhat limited by the fact that of the eight studies identified all were classified as providing lower quality evidence (i.e. level III-3 case–control or level

Table 1 Search methods

	Key concepts	Search terms (combined using 'OR', wildcards used where available)
1	Obesity	obese, obesity, overweight, adipose, adiposity, BMI, 'body mass index', fat, fatness, 'weight status'
2	Child	child, children, adolescent, youth, pediatric, paediatric, adolescence, girls, boys
3	Strength	'muscle strength', torque, isometric, isokinetic, Kincom, Cybex, dynamometer, dynamometry, 'muscle weakness', muscle, quadriceps, 'knee flexion', 'knee flexors', 'knee extension', 'knee extensors', Biodex, concentric, eccentric
4	Field-based tests	'physical performance', 'motor performance', 'motor skill', coordination, 'motor proficiency', 'movement abc', BOTMP, 'Bruinicks Oseretsky Test of Motor Proficiency', 'Gross motor', Eurofit, 'standing broad jump', 'vertical jump', fitness, 'gross motor skills', 'sit and reach', 'bent arm hang', 'field based fitness test'
5	CRF	'cardiorespiratory fitness', CRF, fitness, VO2 max, 'maximal oxygen uptake', 'peak oxygen uptake', '6 minute walk test', 'six minute walk test', 6MWT, '12 minute walk test', 12MWT, 'submaximal fitness test', 'shuttle run', 'incremental exercise', 'cycle ergometry', cycle ergometer, oxygen uptake, 'exercise testing', 'exercise test', 'ventilatory threshold', 'ventilator threshold', 'submaximal fitness', 'incremental exercise'
6	Gait & balance	'postural control', 'postural stability', Vicon, 'single leg stance', SLS, 'postural sway', 'postural capacities', walking, 'plantar pressure', balance, Bruinicks Oseretsky Test of Motor Proficiency, BOTMP, Movement abc, 'Movement assessment battery'
7	Pain	pain, painful, discomfort, noxious, 'musculoskeletal pain', 'low back pain'
8	Health-related quality of life	Repeated search strategy cited in reference (129) for newly published literature
9	Disability, activity & participation	disability, 'physical function', capacity, 'ICF', 'International classification of functioning, disability and health', ADL, 'activities of daily living', 'participation restriction', 'participation limitation', 'activity restriction', 'activity limitation', 'physical capacity', 'physical performance'

Search	Databases	*Limits set	General inclusion criteria	General exclusion criteria
All searches	PubMed, Medline	English, human, all children 0–18, †type of article, published after 1986.	Examined children (0–18 years), looked at relationship/differences in the ‡key concept(s) by weight status.	Did not assess weight status OR look at relationship/differences in the ‡key concept(s) by weight status, §included adults (≥19 years), focused on other health conditions, ¶type of article, **exercise interventions.
1 and 2 and 3, 1 and 3	+Sport Discuss, OVID, CINAHL, Google Scholar	–	–	+Only examined grip strength.
1 and 2 and 4, 4	+OVID, CINAHL, Google scholar, AMED, Embase	–	–	–
6, 6 and 1	+Embase, AMED, Google Scholar	–	–	–
1 and 2 and 5, 5	+Sport Discuss, OVID, CINAL, Google Scholar, Embase	–	+Included lab-based tests of physiological exercise response (e.g. oxygen uptake).	+Only included field-based tests of CRF.
7, 7 and 2, 7 and 1 and 2	+CINAL, Psych info, psych articles, Google Scholar, Embase	–		+Only examined migraine or upper limb pain.
9 and 1 and 2, 9 and 1	+Web of science, CINAHL	–	–	+Exclusively examined physical activity.

Reference lists were hand searched and database auto-alerts set-up where available.

*Where database allows.

†Included clinical trial, meta-analysis, systematic review, randomized controlled trial, evaluation study, comparative study, controlled clinical trial.

‡Key concepts were: obesity, child, strength, field-based tests, CRF, gait & balance, pain, HRQOL, disability activity & participation limitation.

§At enrolment.

¶Excluded abstracts, dissertations, non-English, expert opinions, narrative reviews, editorials, case studies.

**Physical activity/exercise intervention studies were excluded as it would not be possible to differentiate if functional gains were due to the exercise, or improvements in weight status, with the exception of studies statistically investigating these relationships.

CRF, cardiorespiratory fitness; HRQOL, health-related quality of life; SLS, Single leg stance.

Table 2 National Health and Medical Research Council of Australia Evidence Hierarchy (12)

Level	Intervention	Diagnostic accuracy	Prognosis	Aetiology	Screening intervention
I	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies
II	A randomized controlled trial	A study of test accuracy with: an independent, blinded comparison with a valid reference standard, among consecutive persons with a defined clinical presentation	A prospective cohort study	A prospective cohort study	A randomized controlled trial
III-1	A pseudorandomized controlled trial (i.e. alternate allocation or some other method)	A study of test accuracy with: an independent, blinded comparison with a valid reference standard among non-consecutive persons with a defined clinical presentation	All or none	All or none	A pseudorandomized controlled trial (i.e. alternate allocation or some other method)
III-2	A comparative study with concurrent controls: a non-randomized experimental trial, cohort study, case–control study, interrupted time series with a control group	A comparison with reference standard that does not meet the criteria require for Level II and III-1 evidence	Analysis of prognostic factors amongst persons in a single arm of a randomized controlled trial	A retrospective cohort study	A comparative study with concurrent controls: non-randomized experimental trial, cohort study, case–control study
III-3	A comparative study without concurrent controls: historical control study, two or more single arm study, interrupted rime series without a parallel control group	Diagnostic case–control study	A retrospective cohort study	A case–control study	A comparative study without concurrent controls: historical controls, two or more single arm study
IV	Case series with either post-test or pre-test/post-test outcomes	Study of diagnostics yield (no reference standard)	Case series, or cohort study of persons at different stages of disease	A cross-sectional study or case series	Case series

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Table 3 Lower limb strength and weight status in children

Reference	Author, year, design, evidence level	Subjects*	Obesity definition, reference data	Outcomes	Absolute strength higher in OB?	Strength lower in OB?		Strength & weight status related?	Body size correction
						per kg mass	per kg FFM		
(24)	Maffiuletti 2008, CC, III-3	10 SOB, 10 non-OB males, 13–17 years	SOB BMI > 97%	BMI, Tanner, FFM (BI), Peak IK KE T, KE fatigue (Cybex)	Yes (IK KE T)	–	No difference	–	?Ratio
(18)	Almuzaini 2007, CS, IV	44 boys, 11–19 years	–	BMI, SF, Peak IK KE & KF T, IK KE endurance (Cybex)	–			Yes – BMI & strength ($r = 0.58$–0.69)	–
(17)	Duche 2002, CC, III-3	44 OB, 50 non-OB, ~14 years	OB BMI > 97%, French	DXA (OB), SF (non-OB), BMI, CPP	Yes	Yes	No difference	Yes – CPP dependent on BF in OB	Ratio & allometric
(19)	Armstrong 2001, long., II	747, 10–11 years	–	SF, BMI, CPP, Tanner	–	–	–	Yes – mass explains CPP (0.88), SF & CPP (r –0.16)	–
(20)	Grund 2000, CC, III-3	88, 4–11 years	OB > 97%, German	BMI, BI, KE + KF strength (CT)	Weakest group had higher BMI/FM	–	–	No	–
(15)	Ward 1997, CC, III-3	†54 OB, 96 non-OB, 5th grade girls	–	PA recall, BMI, SF, PWC170	Similar for W	Yes – W	Yes – W	–	Ratio
(14)	Blimkie 1990, CC, III-3	10 non-OB, 11 OB boys, 15–18 years	OB > 30% BF	SF, Tanner, IM & IK KE T (Cybex), EET, MUA, KE CSA	No difference	Yes	‡No difference	–	Ratio
(13)	Blimkie 1989, CC, III-3	11 non-OB, 13 OB boys, 9–13 years	OB > 30% BF	SF, BMI, Tanner, R KE T (Cybex). EET, muscle CSA	No difference (KE)	Yes – KE	‡No difference	–	Ratio

Tanner, the Tanner scale has been widely used to assess pubertal development (134), as body composition is known to vary with puberty. The Tanner scale depicts five stages of sexual maturation, represented by drawings of pubic hair, scrotum and testes and breasts and has been validated as a self-assessment measure (135).

*Unless otherwise stated subjects were of mixed gender.

†Only included African–American girls.

‡Normalized using muscle cross-sectional area.

BF, body fat; BI, bioelectrical impedance; BMI, body mass index; CC, case–control observational; CPP, cycling peak power; CS, cross-sectional; CSA, cross-sectional area; CT, computer tensiometry; DXA, dual energy X-ray absorptiometry; EET, electrically evoked torque; F, flexor; FFM, fat-free mass; HGS, handgrip strength; IK, isokinetic; IM, isometric; KE, knee extensor; KF, knee flexion; long., longitudinal study; MUA, motor unit activation; non-OB, non-obese; OB, obese; PA, physical activity; PWC 170, physical work capacity cycle ergometry 170 test; SF, skin-folds; SOB, severely obese; T, torque; V, voluntary; W, power.

Table 4 Field-based fitness tests

Reference	First author, year, design, evidence level	Subjects* *N*, age range	Obesity definition & reference data	Outcomes	Performance lower in OB?	Performance & weight status related?
(35)	D'Hondt 2009, CS, IV	61 NW, 22 OW, 34 OB, 5–10 years	IOTF	BMI, Movement ABC, accelerometry	Yes	Yes – BMI z-score explained 3.9–20% variance in balance, total score & ball skills
(18)	Almuzaini 2007, CS, IV	44 boys, 11–19 years	–	BMI, SF, vertical jump, sit & reach	–	Yes – vertical jump & % body fat ($r = -0.39$)
(53)	Bovet 2007, CS, IV	4599, 12–15 years	IOTF	BMI, shuttle runs, lateral & vertical jumps, 40 m sprint, ball throw, sit-ups, push-ups	Yes	Yes – inverse J shape for most tests
(54)	Brunet 2007, CS, IV	1140, 6–10 years	IOTF	BMI, WC, standing long jump, shuttle-run, sit-ups	–	Yes – all items ($r = -0.16$ to -0.45)
(45)	Casajus 2007, CS, IV	1068, 7–12 years	IOTF	BMI, Eurofit, extra-curricular PA	†Yes	–
(55)	Korsten-Reck 2007, CS IV	49 OB, 8–12 years	BMI > 97% German	GSMT, aerobic capacity, SF, maturational status	‡Yes	–
(34)	Maurer 2007, CS, IV	95, 7–9 years	–	BMI, parent-proxy PA Q, heel rises	–	Yes – heel rises & BMI ($r = -0.12$)
(51)	Mond 2007, CS, IV	9415, 4–8 years	IOTF	BMI, Modified Bavarian GM skills test	Yes	Yes – OB OR 1.65 for impaired GM skills
(36)	Fogelhome 2007, CS, IV	2266, 15–16 years	IOTF	BMI, PA Q, endurance shuttle, sit-ups, sit & reach, back-forth jumping, 5 jump, ball skills	§Yes	†Yes – $r = -0.12$ to -0.26
(136)	Sartorio 2006, CS, IV	306 OB, 10–17 years	Italian	Magaria stair test, BMI, bioimpedance, Tanner	–	Yes – W/kg negatively affected by BMI (F ratio 3.294)
(46)	Chen 2006, long., II	13935, 6–18 years	IOTF	Sit-ups, sit & reach, step-test, BMI	§Yes	–
(126)	Riddiford-Harland 2006, CC, III-3	43 OB, 43 non-OB, 8.4 years	IOTF	Basketball throw, standing long jump, arm push & pull, vertical jump, BMI	Yes	–
(47)	Tokmakidis 2006, CS, IV	709, age ~9 years	IOTF	BMI, Eurofit	§Yes	–
(37)	Kim 2005, CS & long., II	2927, 5–14 years	CDC BMI > 95%	BMI, endurance shuttle run, curl-ups, sit & reach, pull-ups, flexed arm hang,	§Yes	Yes – inverse relationship. 62% who failed fitness tests were OW
(32)	Okely 2004, CS, IV	4363, grades 4,6,8,10	IOTF	Run, vertical jump, throw, catch, kick, strike, BMI, waist	Yes	Yes – with BMI ($r = -0.103$ to -0.326)
(38)	Graf 2004, CS, IV	668, 1st grade	OB > 97% German	Boyd gross motor development test, BMI	Yes	Yes – with BMI ($r = -0.16$)
(137)	Graf 2004, CS, IV	344, mean age 6.8 years	OB > 97% German	Dordel & Koch fitness test, BMI, PA Q	Yes	–
(31)	Olds 2004, CS, IV	1430, aged 10–12 years	–	BMI, 1.6 km walk/run	–	Yes – SF & running ($r = -0.44$ to 0.52).
(52)	Deforche 2003, CC, III-3	3214 OB & non-OB, 12–18 years	OB > 90%	SF, BMI, Eurofit, Baeke PA Q	Yes	–
(39)	Westerstahl 2003, CS, IV	855, ~16 years	OW BMI > 25 kg m^{-2}	BMI, run-walk, vertical jump, 2-hand lift, sit-ups, bench press, back extensions	–	BMI explained 43% decrease in run-walk
(138)	Chen 2002, CS, IV	444 652 boys, 433 555 girls, 7–18 years	OB > 95%	BMI, 800 m/1.6 km walk/run, standing long jump, sit-ups, sit & reach	Yes	–
(139)	Butterfield 2002, CS, IV	65, 5–8 years	–	TGMD, Kaesch step-test, sit & reach test, sit-ups, BMI	–	No – TGMD, Yes – sit-ups (beta –0.26)
(44)	McKenzie 2002, long., II	207, 4–12 years	–	SF, SLS, lateral jumping, ball catch, PA interview	–	Yes – SF & balance/jump ($r = -0.29/-0.15$)
(30)	Fj(toft 2000, CS, IV	75, 5–7 years	–	Eurofit, weight	–	Yes – bent arm hang/shuttle run & weight ($r = -0.26/0.46$)
(40)	Minck 2000, long., II	181, 13 years f/u to 27 years	–	SF, MOPER fitness test battery, PA interview	–	§Yes – % fat & most items ($r = -0.15$ to -0.29)
(29)	Reeves 1999, CS, IV	51, 5–6 years		BOTMP short, ½ mile walk/run, PFGT, SF, BMI	–	Yes – half-mile time & % fat/BMI (r ~–0.5)
(56)	Marshall 1997, CC, III-3	100 OB, 100 lean, grades 1–4	Marshall adiposity VRS	TGMD, SF, 20 m shuttle run	Yes (TGMD)	–
(41)	Raudsepp 1997, CS, IV	215 girls, 7–10 years	–	SF, Eurofit, BMI, 7 d PA recall	–	Yes – SF & shuttle run, long jump, bent arm hang, ($r = -0.28$ to -0.58)
(28)	Malina 1995, CS, IV	6700 girls, 7–17 years	–	BMI, SF, test battery similar to Eurofit	§Yes	Yes – SF & most items ($r = -0.13$ to -0.37)
(48)	Pongprapai 1994, CS, IV	259, 6–12 years	OB > 120% mass, Bangkok	50 m run, weight, height, sit & reach, sit-ups	§Yes	–
(42)	Chatterjee 1993, CS, IV	629 boys, 9–18 years	–	Weight, sit & reach, vertical jump, step-test, Magaria stair test, 50 yard dash, shuttle run	–	Yes – weight & most items ($r = 0.61$ to 0.9)
(27)	Sallis 1993, CS, IV	528	–	PA Q, 24 h recall, accelerometry, FITNESSGRAM	–	Yes – SF & pull ups/sit-ups ($r = -0.41/-0.22$)
(43)	Pate 1989, CS, IV	4782, 6–16 years	–	SF, SCFT, 1 min sit-ups, sit & reach, distance run	–	†Yes – SF & distance run ($r = -0.11$ to -0.27, sit-ups ($r = -0.001$ to -0.14)

*Unless otherwise stated subjects were of mixed gender.

†Plate tapping was not significant, and sit & reach and leg lift were only significant in girls after controlling for mass and height.

‡Compared with German normative reference data, there was no difference in single leg stance and ball toss.

§Not significant for sit and reach test, and/or coordination tests.

BF, body fat; BMI, body mass index; BOTMP, Bruininks-Oseretsky Test of Motor Proficiency; CDC, Centre for Disease Control Prevention; CPP, cycling peak power; CS, cross-sectional study design; CSA, cross-sectional area; CT, computerized tomography; DXA, dual energy X-ray absorptiometry; F, flexor; FFM, fat-free mass; GM, gross motor; GSMT, General Sports Motor Test; HGS, handgrip strength; IK, isokinetic; IM, isometric; IOTF, International Obesity Task Force Criteria; KE, knee extensor; L, left; long., longitudinal study design; Movement ABC, Movement Assessment Battery for Children; MUA, motor unit activation; non-OB, non-obese; NW, normal weight; OB, obese; OR, odds ratio; OW, overweight; PA, physical activity; PFGT, Prudenctial Fitnessgram Test; Q, questionnaire; R, right; SCFT, South Carolina Fitness Test; SF, skin-folds; SLS, Single leg stance; TGMD, Test of Gross Motor Development; V, voluntary; VRS, visual rating scale; WC, waist circumference.

Table 5 Cardiorespiratory fitness and weight status in children

Reference no	Author, year, design, evidence level	Subjects*	Obesity definition & reference data	Outcomes	Absolute CRF higher in OB?	Fitness lower in OB?			Fitness & weight status related?	Body size correction
		N, age range				Per kg mass	Per kg FFM	Per kg FM		
(57)	Drinkard 2007, CC, III-3	117 SOB, 43 non-OB, 12–17 years	OB > 95%, ?CDC	†CE (VO_{2max}), BMI, ADP	No difference	–	VO_{2max} 25% less in SOB	–	–	Ratio
(73)	Berndtsson 2007, CS IV	219 OB, 11–16 years	IOTF	‡CE (VO_{2max}), BMI, PA interview	§Yes	§Yes			Yes – BMI explained 45% of relative VO_{2max}	Ratio
(140)	Klasson-Heggebo 2006, CS, IV	4072, 9–15 years	–	†CE (W_{max}/kg), SF, WC, BP, Tanner	–	–	–	–	¶Yes – W_{max}/kg & WC/SF (*r* = 0.5 to 0.7)	Ratio
(74)	Reybrouck 2005, CC, III-3	22 OB 22 non-OB, ~11 years	>20% OW, Tanner curves	‡TT (O_2 deficit, VE), Tanner, BMI	Similar O_2 deficit, VE	–	–	–	No – O_2 deficit & BMI	Ratio & % change
(58)	Norman 2005, CC, III-3	129 SOB, 34 non-OB, ~14 years	CDC OB ≥ 95%	†CE (VO_{2max}, $ULVO_2$), BMI, ADP, Tanner, 12 min walk/run	Only for $ULVO_2$	–	Yes – VO_{2max}	Yes – VO_{2max}	Yes – BMI & $ULVO_2$, $ULVO_2$ & FM (*r* ~0.8)	Cov. & indep
(141)	Gutin 2005, CS, IV	421, 16.2 years	–	‡TT (VO_2170, VO_{2max}), BMI, DXA (% fat), acc.	–	–	–	–	Yes – %fat & VO_2170 (*r* = –0.69)	Ratio
(60)	Lazzer 2005, CC, III-3	27 OB, 50 non-OB, 12–16 years	OB 97% French	†TT (VO_{2max}), BI, BMI, DXA, Tanner, PA (HR, acc., PA diary)	Yes	–	No difference	–	–	Ratio
(66)	Ayub 2003, CC, III-3	9 OB, 9 lean, 11–18 years	–	†TT (VO_{2max}), BMI, DXA, Tanner	No difference	Yes	–	–	–	
(72)	Marinov 2002, CC, III-3	30 OB, 30 non-OB, 6–17 years	IOTF	†TT (VO_{2max}) VE, SF, BSA	Yes – VO_{2max}, & VE	Yes	No difference	–	Yes – VE & mass (*r* = –0.375)	Ratio
(69)	Rump 2002, CS, IV	120, 6.8–8.2 years	–	†TT (ET, W, VO_{2max}), SF, BMI	–	–	–	–	Yes – Vo_{2max}/kg & % fat (*r* = –0.76)	Ratio
(65)	Loftin 2001, CC, III-3	46 OB, 47 lean girls, 7–18 years	NCHS	†TT (VO_{2max}), BMI, mass, SF	No difference	Yes	–	–	**Yes – Vo_{2max}/kg & mass (*r* = –0.48 in OB)	Ratio & allometric
(77)	Torok 2001, CC, III-3	22 OB (MS), 17 OB, 29 non-OB	>20% OW, BF > 25–30%	‡TT (PWC-170, VO_{2peak}), bloods, BP, SF, BMI	No	Yes	–	–	–	Ratio
(82)	Drinkard 2001, CS, IV	18 OB, 12–17 years	?	†CE (VO_{2max}), 9 & 12 min walk/run, ADP, BMI	–	–	–	–	Yes – walk/run & BMI/fat (*r* ~–0.5 to –0.8)	–
(20)	Grund 2000, CS, IV	88, 5–11 years	OB > 97% German	‡CE (RER, O_2 pulse, VO_2), BI, SF, BMI, Tanner	Yes	Yes ($V0_2$)	No difference	–	Yes – VO_2/kg & BMI/FM (*r* = –0.49/–0.57)	Ratio
(61)	Goran 2000, CS, IV	129, 9.6 years	OB > 30%fat	†TT (VO_{2max}, O_2 pulse, VE) DXA, Tanner	Yes	Yes	No difference	–	††Yes – VO_{2max} & FM/BMI (*r* = 0.66/0.61)	Ratio & FFM cov.
(40)	Minck 2000, long., II	181, f/u 3–27 years	–	†TT, (VO_{2max}/kg $^{2/3}$), SF, PA interview	–		–	–	††Yes – fat & VO_{2max}/kg $^{2/3}$ (*r* = –0.4)	Mass cov. allometric
(75)	Trueth 1998, CC, III-3	12 OB, 12 non-OB, 7–10 years	NCHS	†TT (VO_{2peak}), DXA, BMI, DLW	Yes	No	No (cov.)	–	–	Mass & FFM cov.
(78)	Reybrouck 1997, CC, III-3	29 OB, 16 non-OB, 5–15 years	Tanner tables, OB > 50% OW	‡TT (slope of VO_2 vs. VCO_2 above VT), SF, BMI	Yes, steeper slopes	–	–	–	–	–
(28)	Malina 1995, CS, IV	6700 girls, 7–17 years	–	‡CE (PWC_{170}), SF, BMI	–	–	–	–	Yes – §§SF & PWC_{170} (*r* = –0.26 & –0.4)	–
(142)	Stewart 1995, CS, IV	53, 9–10 years	–	‡TT (W170), BMI, SF, PA interview	–	–	–	–	Yes – SF & W170 (*r* = 0.5)	–

Table 5 *Continued*

Reference no	Author, year, design, evidence level	Subjects*	Obesity definition & reference data	Outcomes	Absolute CRF higher in OB?	Fitness lower in OB?			Fitness & weight status related?	Body size correction
		N, age range				Per kg mass	Per kg FFM	Per kg FM		
(62)	Watanabe 1994, CC, III-3	13 OB, 24 non-OB, 12–15 years	OB > 20–20% %fat	TT (VO_{2max}), underwater weighing	Yes – boys	Yes	No difference	–	Yes – VO_{2max}/kg & % fat ($r = -0.74$ to -0.84)	Ratio
(48)	Pongprapai 1994, CS, IV	259, 6–12 years	OB>120% OW Bangkok	[‡]CE (VO_{2max}), BMI	–	Yes	–	–	–	Ratio
(63)	Maffeis 1994, CC, III-3	14 OB, 8 non-OB, 9.5 years	Tanner tables, OB > 20%	[†]CE & TT (VO_{2max}, VE_{max}, VE/Vo_2), Tanner, SF, BMI	Yes – VO_{2max}/VE_{max}	Yes	No difference	–	Yes – VO_{2max} & FFM ($r = 0.72$), VE_{max}	Ratio
(123)	Maffeis 1993, CC, III-3	23 OB, 17 non-OB, 9.3 years	OB > 20% OW Tanner tables	TT (VE), BMI, Tanner, SF	Larger VE response	–	–	–	–	–
(68)	Rowland 1991, CC, III-3	13 OB, 14 non-OB girls, 15–18 years	OB SF > 90%	[†,‡]TT, (VO_{2max}, VE, O_2 pulse), SF, BMI	Yes – VE, VO_{2max}	Yes – VE & VO_{2max}/kg	–	–	Yes – SF & VO_2 ($r = 0.72$), SF & VO_2/kg ($r = -0.49$)	Ratio
(143)	Taylor 1991, CC, III-3	93 high fat, 93 low fat, 8–13 years	Low fat (SF ≤ 42.9)	[‡]CE (PWC_{170}), SF, BMI, observed PA	–	–	–	–	Yes – PWC_{170} & BMI/SF (beta = –0.38/–0.17)	–
(80)	Cooper 1990, CS, IV	18 OB, 9–17 years	>120% OW ?reference data	[†]CE (UVO_2, VT, Δ VO_{2max}, VE-VCO_2 slope), weight	–	–	–	–	Yes – UVO_2 & mass ($r = 0.71$)	Mass indep
(70)	Zanconato 1989, CC, III-3	23 OB, 37 non-OB 9–14 years	OB ≥ 20% OW Tanner tables	[†]TT, (VAT, VO_{2max}) BMI, weight	No difference	Yes	–	–	No VO_{2max} & % OW not sig ($r = -0.33$)	Ratio
(64)	Elliot 1989, CC, III-3	16 OB, 17 non-OB, 9–18 years	OW/OB SF > 85%	[†]CE (VO_{2max}), SF	No difference	Yes	No difference	–	–	Ratio
(71)	Reybrouck 1987, CC, III-3	15 OB, 257 non-OB, 4–16 years	?Tanner tables	[‡]TT (VT), Tanner, SF, mass, PA Q	Yes – VO_2/VT lower in OB	Yes – girls	–	–	No – VE & SF not sig ($r = 0.14$)	Ratio
(76)	Huttunen 1986, CC & UCT, III-3	31 OB, 31 non-OB, 5.7–16.1 years	OB + 2SD, Finnish	[†]CE (HR, RER, VO_{2max}), BMI, SF, parent-proxy PA Q	No difference	Yes	Yes	–	Yes – % fat & VO_{2max}/kg FFM ($r = -0.53$)	Ratio

Tanner curves/tables, The Tanner scale has been widely used to assess pubertal development (134), as body composition is known to vary with puberty. The Tanner scale depicts five stages of sexual maturation represented by drawings of pubic hair, scrotum and testes and breasts and has been validated as a self-assessment measure (135).

*Unless otherwise stated subjects were of mixed gender.

[†] Maximal exercise testing.

[‡] Submaximal exercise testing.

[§] Compared with reference data.

[¶] Curvilinear relationship.

**Not significant when allometric scaling used.

[††] Not significant when controlling for FFM.

[‡‡] Corrected for PA, height and weight.

[§§] In 12- and 13-year-old girls.

Acc., accelerometry; ADP, air displacement plethysmography; AT, anaerobic threshold; BI, bioelectrical impedence; BIA, bioimpedance; BMI, body mass index; BP, back pain; BSA, body surface area; CC, comparative control study (observational); CDC, Centre for Disease Control Prevention; CE, cycle ergometry; cov., covariate(s); CS, cross-sectional study; DLW, doubly labelled water; FFM, fat-free mass; FM, fat mass; HR, heart rate; IOTF, International Obesity Task Force Criteria; long., longitudinal study; $LTVO_2$, lactate threshold; NCHS, National Centre for Health Statistics (USA); non-OB, non-obese; O_2, oxygen pulse; OB, obese; OW, overweight; PA, physical activity; PA Q, physical activity questionnaire; PWC_{170}, physical working capacity at HR of 170 bpm; RER, respiratory exchange ratio; SOB, severely obese; SF, skin-folds; TT, treadmill test; $ULVO_2$, oxygen uptake during unloaded cycling; VE, ventilator efficiency; VO_{2max}, maximal oxygen uptake; WC, waist circumference; VAT, visceral adipose tissue; VT, ventilatory threshold; UCT, uncontrolled clinical trial study.

Table 6 Musculoskeletal pain and weight status in children

Reference	Author, year, design, evidence level	Subjects* *N*, age range	Obesity definition & reference data	Outcomes	Pain recall period	Greater MS pain in OB?	Pain & weight status related?
(98)	Bell 2007, CS, IV	104 OW/OB, 73 non-OB, 6–13 years	IOTF & CDC	†BMI, BMI z-score, MSE, puberty	Current	–	Yes – OR pain increases 2.54 per unit BMI z-score
(86)	Masiero 2007, CS, IV	7542, 13–15 years	–	†,‡BMI, LBP Q, VAS, activity Q	1 year	–	No (BMI)
(87)	Mohseni-Bandpei 2007, CS, IV	4813, 11–14 years	–	†LBP Q, BMI	Current, 1 month, 6 months, 1 year	–	No
(88)	Chiang 2006, CS, IV	55, 11–14 years	–	†BMI, LBP Q, PA Q	2 weeks	No – LBP had lower BMI	–
(99)	De sa Pinto 2006, CS, IV	49 OB, 47 non-OB, 7–14 years	NHNES I OB > 95%	†,§BMI, MSE, pain Q	1 month	Yes – LBP & LL	–
(100)	Podeszwa 2006, CS, IV	50 SOB, 2–17 years	CDC OB > 95%	†BMI, PODC	?	Yes cf reference data	–
(101)	Taylor 2006, CS, IV	227 OB, 128, ¶non-OB, 12.8 years	NHNES I, OB > 95%	†BMI, IWQOL, DXA, Tanner, MSE, medical chart review	?	Yes – OR 4.04 in OB	–
(96)	**Poussa 2005, long., II	430, 10 years (3 years f/u & at 22 years)	–	†LBP Q, BMI	Current, 1 d, 1 month, 1 year, lifetime	–	No
(89)	Sjolie 2004, CS, IV	88, 14.7 years	–	†,§BMI, mod. Nordic LBP Q	1 year	Yes – higher BMI in LBP girls	Yes (box plot)
(90)	Sheir-Neiss 2003, CS, IV	1126, 12–16 years,	–	‡,§CHQ, BP Q, intensity rating, pain diagram, BMI	1 month	Yes – BP had higher BMIs	–
(91)	Kovacs 2003, CS, IV	7361, 13–15 years	–	†,††Validated LBP Q, BMI, activity Q	Lifetime, 1 d & current	–	No
(92)	Watson 2003, CS, IV	1446, 11–14 years	–	†2 LBP questions, BMI, activity Q	1 month	No	No
(93)	Szpalski 2002, long., II	287, 9–12 years	–	†LBP Q, lifestyle Q, mass, MSE	?	–	No
(102)	Wake 2002, CS, IV	2863, 5–13 years	UK	§CHQ, BMI	?	Yes – OR 1.8 in OB boys	–
(97)	Lake 2000, long., II	11407, f/u 7–33 years	OB > 85%	†,††BMI, LBP Q	Lifetime, onset	–	No – BMI at 7 years unrelated to LBP
(85)	Salimen 1995, long., II	62, 15 years, 3 years f/u	–	†,§LBP Q, BMI, MRI, activity Q	Lifetime, 1 year	LBP were heavier	No – BMI does not predict LBP
(94)	Salimen 1992, CS, IV	38 no LBP & 38 LBP, 15 years	–	†LBP pain questions, BMI	Past week	No difference in BMI between groups	–
(95)	Harreby 1999, CS, IV	1389, 13–16 years	–	‡,§LBP Q, BMI	Current, 1 d, 1 week, 1 year, lifetime	Yes – severe LBP more common if BMI > 25	–
(103)	Vahasarja 1995, CS, IV	856, 9–15 years	–	†,§Postal knee pain Q, MSE, X-rays	?	No	–
(112)	Nissinen 1994, long., II	859, 10.1 years, 3 years f/u	–	†LBP Q, BMI	Current, 1 d, 1 month, 1 year, lifetime		No – BMI not related LBP at 1 year

Tanner, The Tanner scale has been widely used to assess pubertal development (134), as body composition is known to vary with puberty. The Tanner scale depicts five stages of sexual maturation, represented by drawings of pubic hair, scrotum and testes and breasts and has been validated as a self-assessment measure (135).

*Unless otherwise stated subjects were of mixed gender.

†Assessed pain prevalence.

‡Assessed pain intensity.

§Assessed pain frequency.

¶Included overweight participants in their non-OB group.

**Extension of Nissinen 1994.

††Assessed pain recurrence.

BMI, body mass index; BP, back pain; CDC, Centre for Disease Control Prevention; CHQ, Child Health Questionnaire; CS, cross-sectional; DXA, dual energy X-ray absorptiometry; f/u, follow-up; IOTF, International Obesity Task Force Criteria; IWQOL, Impact of Weight on Quality of Life questionnaire; LBP, low back pain; LL, lower limb; long., longitudinal study; MRI, magnetic resonance imaging; MS, musculoskeletal; MSE, musculoskeletal examination; NHNES, National Centre for Health Statistics (USA); non-OB, non-obese; NW, normal weight; OB, obese; OR, odds ratio; OW, overweight; PA, physical activity; PODC, Paediatric Outcomes Data Collection Instrument; Q, questionnaire or questions;
ROM, range of motion; SOB, severely obese; VAS, visual analogue scale.

Table 7 Balance, gait and weight status

Reference	Author, year, design, evidence level	Subjects* *N*, age range	Obesity definition & reference data	Outcomes	Deviated gait in OB?	Impaired balance in OB? Or balance & weight status related?
(113)	Colne 2008, CC, III-3	16 OB, 10 NW, ~16 years	?	Force plate (CP), BMI	Yes – ↑DS & swing phase, ↓progression velocities & anticipatory phase with ↑velocity	Yes. Static: ↑CP sway, dynamic: ↓AP LOS
(116)	Nantel 2006, CC, III-3	10 OB, 10 non-OB, 8–13 years	OB > 95% ?CDC	3D gait, FP, BMI	Yes – ↓SLS time, altered hip kinetics	–
(111)	Gushue 2005, CC, III-3	10 OB, 13 NW, ~12 years	CDC OB > 95%	3D gait, FP, BMI	Yes – ↑knee abd moment & ↓peak KF, ↑variability knee kinetics	–
(66)	Volpe 2003, CC, III-3	9 OB, 9 non-OB boys, 11–18 years	–	DXA, BMI, PA Q, treadmill max test	Yes – ↑% VO_{2max} when walking, mass explained 62–89% variance in energy cost	
(121)	Goulding 2003, CC, III-3	25 OW/OB, 47 NW, boys 14.9 years	USA OW/OB > 85%	DXA, BOTMP, SOT, LOS, PA Q	–	Yes – ↓ balance & %fat (*r* = –0.3)
(117)	McGraw 2000, CC, III-3	10 OB, 10 non-OB, 8–10 years boys	CDC OB > 95%	†3D gait, standing & tandem stance, FP	Yes – ↑DS & stance time, ↓swing time, ↓speed	Yes – ↑ sway & med/lat variability, especially with ↓ vision
(115)	Habib 1998, CS, IV	180, 5–13 years	–	BOTMP, FRT, TUG, mass	–	Yes – mass & balance (beta~ –0.3)
(123)	Maffeis 1993, CC, III-3	23 OB, 17 non-OB, ~9 years,	–	Treadmill walk/run	Yes – EE 12% higher in OB with faster walking	–
(122)	Hills 1993, CC, III-3	10 OB, 4 NW, 8–10 years	‡OB > 95%	†Gait EMG	No differences in EMG activity	–
(118)	Hills 1991a, CC, III-3	10 OB, 10 NW, 8–10 years	‡OB > 95%	†2D gait	Yes – ↑stance, ↓speed, asymmetry, ↑stride width	–
(119)	Hills 1991b, CC, III-3	10 OB, 4 NW, 8–10 years	‡OB > 95%	†2D gait	Yes – ↑stance, ↓cadence & speed, asymmetry	–
(124)	Katch 1988, CS, IV	20 OB, ~13 years	NCHS II, OB > 178%	BMI, UW, treadmill walking	Yes – ↓efficiency with ↑walking speed	–

↓ – Decreased/slower/reduced; ↑ – increased/greater/longer.

*Unless otherwise stated subjects were of mixed gender.

†Walking at slow, fast and self-selected speeds.

‡NHMRC Australian reference data.

2D, two dimensional; 3D, three dimensional; abd, abduction; AP, antero-posterior; BMI, body mass index; BOTMP, Bruininks-Oseretsky test of motor proficiency balance subset; CC, case–control observational study; CDC, Centre for Disease Control Prevention; CG, centre of gravity; CP, centre of foot pressure trajectory; CS, cross-sectional study; DS, double-limb support; DXA, dual energy X-ray absorptiometry; E, extension; EE, energy expenditure; EMG, electromyography; F, flexion; FP, force plate; FRT, functional reach test; KF, knee flexion; LOS, balance master limits of stability test; LOS, limits of stability; med/lat, medial/lateral; NCHS, National Centre for Health Statistics (USA); NHMRC, National Health and Medical Research Council of Australia; NW, normal weight; OB, obese; OW, overweight; PA, physical activity; PA Q, physical activity questionnaire; RSA, running speed agility; SLS, single leg stance; SOT, Equitest sensory organization test; TUG, timed up and go test; UW, underwater weighing; VO_2, oxygen uptake; VO_{2max}, maximal oxygen uptake.

IV cross-sectional) (13–15,17,18,20,24) except for one prospective study which was classified as level II (19) (see Table 3). Additionally, definitions of weight status varied between studies with some assessing body fat or skin-fold thicknesses (13–15,17,19) while others used BMI (18,20,24); none applied the IOTF criteria (1). Only four papers (13,14,19,24) considered the potential confounding impact of puberty on muscle function (25) and comparisons between studies were complicated by differing assessments/components of muscle function, including isokinetic and isometric peak KE torque, peak isokinetic KF torque, cycling peak power, KE endurance and electrically evoked muscle contractile properties (Table 3). Even where studies assessed common outcomes using the same dynamometer (14,18,24), test protocols varied due to a lack of any consensus around standardized dynamometry testing in children (26). Nevertheless, in general the data suggest that obese children have similar or higher absolute, but lower relative, muscle strength compared with non-obese children.

Field-based tests

Numerous studies have examined the impact of weight status on health-related physical fitness and motor skill competency, utilizing field-based tests (Table 4). Studies which compared obese children (or combined overweight/obese samples) with non-obese children all found that the former performed significantly worse in tasks requiring them to support or move their body mass (Table 4), which agrees with the findings of a number of studies which have reported weak to moderate inverse relationships between measures of weight status and performance in weight-bearing tasks (18,27–44) (Table 4). Similarly, flexibility (i.e. sit and reach test) and coordination (i.e. plate tapping, stick balance, etc.) were impaired in overweight/obese children compared with controls (28,36,37,42,45–48) (Table 4). Three studies (36,40,41) examined whether performance in field-based tests was impacted by physical activity levels and found that while increased physical activity levels may be associated with improved physical performance, this did not completely negate the detrimental effect of increased weight status. Minck *et al.* (40) (level II evidence) and Raudsepp *et al.* (41) (level IV evidence) used similar test batteries, and found persistent weak to moderate inverse relationships between physical performance and skin-folds after controlling for moderate/vigorous activity in multivariate analyses. Similarly, Fogelholm and colleagues (36) (level IV evidence) found that overweight participants performed more poorly than their lean counterparts irrespective of their physical activity levels, although interestingly they found stronger relationships between physical activity and performance ($\beta = 0.31–0.49$) than between overweight and physical performance ($\beta = –0.24–0.27$), suggesting that a lack of physical activity may be more important than the extent of overweight in predicting performance.

A limitation of the studies which have examined the impact of weight status on health-related physical fitness is that they have utilized self-report or parent-proxy methods to assess physical activity which can be subject to bias and reduced accuracy of recall (49,50). Additionally, most of these studies constitute lower level evidence (levels III-3 or IV), although some utilized very large sample sizes (28,31,32,36,37,43,45,51–54), therefore improving the generalizability of their findings. Importantly, four prospective studies (level II evidence) were located (37,40,44,46), two of which had relatively large samples ($>N = 2900$) (37,46). Almost all studies utilized BMI (see Table 4); some reported skin-fold thicknesses (18,28,40,41,43,44,52,55,56), whilst others only reported weight (30,42), without normalizing for height. This is an important limitation because height has a positive influence on physical performance (18). Notably, most studies did not consider the impact of puberty, which positively impacts physical performance in both boys ($r = 0.56–0.73$) and girls ($r = 0.24–0.46$) (25), although the relationship is weaker in girls. Despite these various limitations, the study findings are relatively consistent, but further research utilizing objective methods appears warranted.

Cardiorespiratory fitness

Studies which have examined cardiorespiratory fitness (CRF) and weight status in children suggest that it is unlikely that obese children have impaired absolute CRF, although some decrements may be present in severely obese adolescents (57,58). However, CRF relative to body mass is impaired and this is related to activity restrictions in walk/run performance, but the link between relative CRF and real-life participation restrictions remains unexplored.

Studies examining CRF and weight status in children were classified as either level III-3 or IV evidence, with the exception of one prospective study (40) (level II evidence) (Table 5). Maximal (VO_{2max}) or peak (VO_{2peak}) oxygen uptake were most commonly investigated (Table 5). However, many studies utilized submaximal testing protocols to predict VO_{2max}, which is less precise than direct measurement (59). Even where studies undertook maximal fitness testing, no consistent testing protocols or criteria for defining what constituted a valid maximal test were used (57,58,60–66). Furthermore, some studies used proxy measures of CRF such as endurance time, work performed, oxygen deficit and heart rate during submaximal exercise (Table 5), making it difficult to draw direct comparisons between findings. As with muscle function, controversy exists regarding correction for body size when evaluating impairments in CRF. For the most part, studies have used ratio standards, although allometric modelling (40,65) and statistically controlling for FFM/height (58,61,67) or other body size-independent outcomes have also been used (Table 5). Other limitations have included the use of varying definitions of weight status, proxy measures of fatness and failure to assess pubertal development.

Despite the aforementioned limitations, moderate to strong inverse relationships between relative VO_{2max} (per kilogram of body mass) and weight status were consistently reported indicating that fitness relative to body mass declines with increasing weight/BMI/fat ($r = -0.49$ to -0.843) (20,40,62,65,68,69) (Table 5). In contrast, when examining absolute VO_{2max} (in litres per minute), most studies reported a positive relationship with weight status, indicating that absolute VO_{2max} increased with weight status ($r = 0.55$–0.72) (61,68,69). Conversely, one prospective study (40) reported that absolute VO_{2max} decreased with increasing skin-fold thickness ($r = -0.4$), although two of the four measurement points in this study occurred during adulthood. Similarly, Zanconato *et al.* (70) provided some evidence of a relationship between absolute VO_{2max} and per cent overweight ($r = -0.3$), but this was not statistically significant, suggesting they were underpowered due to a small sample size ($N = 60$).

Many studies seeking to determine the effects of paediatric obesity on CRF have compared differences between obese and non-obese children. This research suggests that obese children have at least similar, and more often, higher absolute VO_{2max} compared with their lean counterparts (20,57,58,60–66,70–76) (Table 5). However, despite a greater absolute VO_{2max}, it has been consistently found that relative VO_{2max} (per kilogram of body mass) is lower in obese compared with non-obese children (20,48,61–66,68,70–73,76,77) (Table 5). Studies have also normalized VO_{2max} per kilogram of FFM, and in most cases have found no difference between obese and non-obese participants (20,60–64,72,75) (Table 5), suggesting that the higher absolute VO_{2max} in obesity is most likely a function of the greater FFM. However, Drinkard *et al.* (57) found that VO_{2peak} per kilogram of FFM was impaired by 25% in severely obese compared with non-obese adolescents, and Norman *et al.* (58) found that VO_{2max} remained lower in severely obese adolescents compared with controls despite controlling for differences in FFM. It is unclear why there are discrepancies in the literature, but the majority of studies in this area support the proposition that the quality of FFM in terms of its ability to utilize oxygen does not differ between obese and non-obese children and the differences in both absolute and relative VO_{2max} or VO_{2peak} are due to differences in the quantities of FFM and body fat present.

As a result of the ongoing debate around normalization of CRF for body size, a number of authors have attempted to utilize measures of CRF that are independent of body size. For example, Reybrouck *et al.* (78) concluded that obese participants had reduced exercise capacity based on measurements of ventilatory threshold, which is proposed to represent the maximal aerobic exercise intensity that can be sustained for a prolonged period (79). In addition, Norman and colleagues (58) examined oxygen consumption during unloaded cycling ($ULVO_2$), expressed as a percentage of VO_{2max} and found that obese participants utilized a higher proportion of their cardiorespiratory reserve during unloaded cycling compared with non-obese participants. A similar study (80), which investigated the effect of obesity on VO_2 reserve ($VO_{2max} - ULVO_2$), found that in lean children, VO_{2max} increased whilst $ULVO_2$ remained unchanged with increasing weight, resulting in an increase in VO_2 reserve, whilst in obese children VO_2 reserve remained unchanged with increasing weight, due to parallel increases in VO_{2max} and $ULVO_2$. The findings of these studies (58,80) appear to reflect the inefficiencies associated with additional lower limb fat tissue mass impacting on the energy cost of unloaded cycle exercise and indicate a progressive reduction in efficiency with increasing FM. Despite this, there are no widely accepted size-independent measures of CRF, so relative VO_{2max} remains the most commonly reported indicator of CRF in both obese and non-obese populations.

There is evidence that engaging in moderate/vigorous physical activity increases CRF (81). Whilst a number of studies investigating weight status and CRF have also assessed physical activity levels, only one study (40) statistically corrected for physical activity levels, finding an inverse relationship between relative VO_{2max} and adiposity ($r = -0.2$), suggesting that physical activity does not completely moderate the relationship between adiposity and CRF.

A small number of studies have examined the relationship between CRF and the ability, or inability, to undertake specific activities (i.e. activity restriction). Norman and colleagues (58) found that $ULVO_2$ (expressed as a percentage VO_{2max}) was inversely related to walk/run distance ($r = -0.98$) in severely obese adolescents. Similarly, VO_{2peak} was related to walk/run capacity ($r = 0.19$–0.72) (58,82). However, no studies controlled for height which is positively related to physical performance ($r = 0.45$) (83).

Musculoskeletal pain

It has been proposed that obese children experience more musculoskeletal (MS) pain than healthy-weight children as a result of the increased loading and/or biomechanical deviations due to excessive FM. Such loading may be particularly detrimental during the periods of rapid growth and development that occur in childhood (84). While there is some evidence to suggest that obese children experience a higher prevalence of pain compared with non-obese children, the evidence is limited, and has not examined whether the higher pain prevalence in obese children is associated with activity and participation restrictions.

Cross-sectional (level IV evidence) and longitudinal studies (level II evidence) have investigated the relationship between MS pain and weight status in children and adolescents (Table 6). Most cross-sectional studies used large sample sizes (~1000 to ~7500), which strengthens the generalizability of their findings, and the vast majority of studies investigated low back pain (85–97), with few examining overall MS pain (90,98–102). Thus, there is a paucity of evidence on which to base conclusions about weight status and any impact on lower limb or other forms of MS pain, other than low back pain.

Most pain research in children and adolescents has utilized self-report questionnaires, often containing only one or two specific questions about pain (Table 6). All of the literature has examined the presence of pain (prevalence or incidence), with few studies examining other aspects of pain such as intensity (86,90,95), frequency (85,90,95,99,102,103), or recurrence of episodes (91,97) and none have investigated the qualitative affective/emotional pain experience. Pain intensity assessments are particularly relevant in children and adolescents as higher intensity pain has been linked to functional limitations in the general paediatric literature (104–106). The pain recall periods used by authors to assess pain intensity have ranged from point assessments to lifetime prevalence/incidence despite evidence that the pain recall period used can influence the outcome. Whilst 72–83% of 3–17 year olds can accurately recall painful events after 1 and 6 weeks (107,108), accuracy declines to only 65% after 12 months (109). Accuracy of recall also appears to differ between pain modalities, with recall being better for acute than chronic pain (110). Thus, interpretation of pain outcomes in children should take account of the modality of the pain (acute or chronic) and the pain recall period.

Only five studies (Level III-3 and IV evidence) have specifically examined MS pain in obese children (98–102), reporting higher pain prevalence compared with non-obese children. Authors have found that obese children are approximately two to four times more likely to experience MS pain compared with healthy-weight children (98,101,102) (Table 6), although Wake *et al.* (102) only found this to be the case in obese boys. In contrast, Podeszwa *et al.* (100) only found a higher pain prevalence in obese girls and older children (≥11 years) when compared with normative reference data. De Sa Pinto *et al.* (99) found that obese children had double the prevalence of lower extremity pain compared to non-obese children. Notably, all studies were methodologically limited, with Taylor *et al.* (101) assessing pain retrospectively from medical charts and, like others, relying on poorly defined ‘physical examinations’ (98,99,101). Two studies used validated questionnaires (100,102), although one of these (100) only included children presenting to their orthopaedic clinic which is a likely source of bias. The other study (102) used the Child Health Questionnaire which only included one question evaluating pain frequency, hence offering limited insight into the pain experienced by children. Interestingly, some studies (95,96) reported biomechanical deviations in obese participants including knee recurvatum and valgus (100,101) which supports the hypothesis that obesity may induce biomechanical deviations which predispose to pain. Similarly, Gushue *et al.* (111) found that obese children had increased knee abduction moments during locomotion when compared with their lean counterparts, which could lead to overloading of the medial joint compartment, potentially causing progressive damage which would predispose the child to future pain development.

The majority of studies in this area examined back pain in general paediatric populations and found no relationship between weight status and low back pain (85–88,91–93,96,103,112). In particular, four prospective studies found that child/adolescent BMI did not predict low back pain incidence (85,96,97,112), although one of these studies (85) did find that adolescents with back pain were heavier, but they were also taller, hence the lack of relationship with BMI. Only one of these four studies (97) defined the weight status of participants as either overweight, obese or healthy and found no relationship between back pain and weight status, but the defined BMI cut-offs were lower than current IOTF definitions, meaning healthy-weight children would have been classified as overweight and overweight children would have been classified as obese. In contrast, some studies have reported that BMI is higher in participants with back pain (89,90,95), but their cross-sectional designs do not make it possible to establish whether the back pain was caused by a higher BMI, or whether having pain limited activity resulted in a higher BMI. In the remaining literature, it is unclear if obese children were included. Furthermore, even though some studies attempted to categorize weight status using BMI, without more accurate assessments of adiposity it will not be possible to determine whether a certain level of excess FM is associated with increased MS pain.

In summary, more research is needed to specifically examine the relationship between obesity and overall MS pain and in particular, lower limb pain, utilizing valid, multidimensional pain assessment tools that incorporate assessments of pain intensity and its relationship to functional limitations. There is an urgent need for research examining whether MS pain is associated with activity and participation restrictions in obese children.

Balance and gait

It has been postulated that obesity may be associated with instability, deviations and inefficiencies in gait and balance

(113,114), and in general this is supported by the literature. Twelve eligible studies examined the impact of weight status/obesity on gait and postural control, consisting of level III-3 and IV evidence, involving very small samples of obese and lean children ($N \leq 26$) in all but one study ($N = 128$) (115) (Table 7). Postural stability has been assessed both statically (e.g. bipedal stance) and dynamically (e.g. unstable weight-bearing surface). While motion analysis and force platforms have been used by some authors to assess balance and gait (66,111,113,116–119) (Table 7), most research has used field-based balance assessments such as the Flamingo Balance Test from the Eurofit Test Battery (120). Although studies using field-based assessments have typically involved large samples which increases generalizability (Table 4), they do not provide insight into medio-lateral vs. antero-posterior restrictions in postural control that are afforded by studies using force platforms.

The majority of evidence suggests that postural stability, in particular dynamic stability, may be impacted negatively by obesity and/or increasing weight status in children (Tables 4 and 7). Colne *et al.* (113) reported that under static conditions postural sway was greater in obese compared with lean children. In contrast, Goulding *et al.* (121) reported no decrement in static balance in obese children, although their comparative non-obese sample included overweight children which may have attenuated any differences between obese and lean participants. However, in terms of dynamic stability, most research agrees that obesity and/or increasing weight status has a negative impact, particularly under novel/unfamiliar conditions (30,52,113,115,117,121) (Tables 4 and 7), with the exception of one study (41) utilizing the Flamingo Balance Test. Force-plate studies have reported impaired antero-posterior and medio-lateral balance (113,117), particularly when visual feedback has been compromised, suggesting that obese children may be very dependent on visual feedback to maintain balance (117). Whether the impaired balance in obese children is mediated in any way by physical activity levels is not clear. Intuitively, one may expect that increased muscle strength associated with physical activity might assist in maintaining balance. However, even though Goulding *et al.* (121) found impaired dynamic stability in obese children, there were no differences in their self-reported physical activity compared with controls.

Dynamic balance is important in terms of its contribution to gait and impairments in gait have been reported in children with obesity (level III-3 and IV evidence, Table 7). Multiple studies have reported kinematic (i.e. spatiotemporal) deviations in gait in obese children (113,116–119), with some authors interpreting this as a ‘slowing effect’ while others have attributed it to poor dynamic stability (i.e. poor dynamic balance) (113). The deviations in gait observed include: slower self-selected walking speeds, shorter swing phase, longer stance phase, reduced single limb support time, greater stride width and reduced step length and frequency (113,117–119,122). There is also evidence of overall gait asymmetry and variability in knee kinetics (111,118,119) which would reduce efficiency, despite altered hip kinetics which might attenuate some of this efficiency loss (116). However, the alteration in hip kinetics does not appear to completely balance the loss of efficiency due to overall gait asymmetry and variability in knee kinetics, as obese children have been shown to expend more energy than lean children when walking at faster speeds (66,123,124).

In summary, there is evidence to support the presence of balance and gait deviations in obese children; however, studies are few and draw findings from very small samples. Furthermore, the potential confounding impact of physical activity levels has not been addressed in any of these studies. Whilst gait analysis is informative, it must be remembered that the conditions under which it is performed are not necessarily reflective of everyday life, and clinical gait analysis may not reflect true functional mobility. These questions would be addressed by studies examining whether decrements in balance or gait translate into real-life functional limitations, but these studies are lacking in the current literature.

Obesity and activity/participation limitations

While obesity is associated with multiple impairments in body functions, it is important to examine the effect of these impairments on activity (ability to undertake a specific task) and participation (engagement in a real-life situation), as these may impact on quality of life. Activity and participation may be further qualified in terms of *capacity* (i.e. ability to execute a task in a uniform or controlled environment) and *performance* (i.e. what the person actually does in real-life situations), with the gap between capacity and performance potentially reflecting the impact of, or interaction with, environmental factors (125).

Activity restriction

Much of the research using field-based fitness tests (see Table 4) has examined the *capacity* to perform specific *activities*. However, many tasks within field-based test batteries are highly specific (e.g. plate tapping, standing long jump, etc.) and are not representative of common daily activities undertaken by children. Nevertheless, in assessments of walk/run activities, which are representative of daily tasks, obese children exhibit capacity restrictions (see Table 4 and reference (58)), which is not surprising, given the additional mass they are required to move. For example, Norman *et al.* (58) found that severely obese adolescents covered 42% less distance than non-obese children during a 12-min walk/run test. Riddiford-Harland *et al.* (126) also found that obese children had restrictions when moving from sit to stand, with 69% of children needing external assistance to complete the task. However, the seat height was very low (25% of participant stature) and it is not clear whether obese children have difficulty getting up from a more conventional height chair. While these studies provide evidence of difficulty in performing some basic daily activities, evidence relating to the effects of child obesity on the performance of other common functional daily tasks is lacking.

Participation limitations

There is a distinct lack of available research specifically examining participation limitations in obese children (i.e. within meaningful life situations). Whilst a large body of literature has examined physical activity behaviours in obese children, physical activity only represents a very small proportion of what a child does during their day and therefore such studies are not reflective of overall participation restrictions. In contrast, studies investigating health-related quality of life (HRQOL) (defined as physical, mental and social well-being related to a health condition (127)) have examined multiple components of activity and participation (128) and, to a much lesser extent, body functions. A review investigating the impact of weight status on HRQOL in children has already been published by the authors (129) and indicated that, in general, greater weight is associated with lower HRQOL. More specifically, there were strong inverse relationships between overall HRQOL and BMI and between physical functioning and BMI, with the physical function domain of HRQOL including assessments of engagement in activities of daily living. Other studies have also confirmed that obese individuals have impaired HRQOL and physical functioning compared with their lean counterparts (130,131), and that overall HRQOL and physical functioning are likely to improve with weight loss (132,133). It is worth noting that the physical functioning subset of the PedsQL^{TM}, which is the most commonly used paediatric HRQOL instrument, assesses a limited range of life areas and activities, therefore providing minimal insight into activity and participation restrictions in children with obesity.

Conclusion

It is apparent from the literature that, even in childhood, obesity is accompanied by functional impairments such as decrements in CRF relative to body mass and deficits in performance of body mass-dependent motor tasks (i.e. components of field-based fitness tests). A small number of studies reported a higher prevalence of MS pain in obese children although there was no evidence of low back pain associated with paediatric obesity. Impairments in knee strength relative to body mass and gait deviations have also been reported in obese children, but such findings are based on a limited number of studies with small sample sizes.

Obesity is also associated with activity restrictions and the literature indicates a negative impact on walk/run capacity, although impacts on other common daily activities are unclear. HRQOL studies suggest that increasing weight status is associated with poorer real-life physical functioning. However, HRQOL tools only provide limited insight; hence broader impacts on participation and functioning are not known.

Perhaps most importantly, those studies which have examined the effect of obesity on impairment have failed to investigate whether impairments in body functions translate into activity/participation restrictions; a flaw most likely related to a lack of consideration of the ICF framework. Future research should utilize international classifications of BMI to facilitate comparisons between studies, and endeavour to assess activity and participation restrictions, particularly within the context of the ICF framework, rather than just examining engagement in physical activity. This will provide a more meaningful evaluation of the effects of obesity on activity/participation. In particular, it is important to consider the impact of obesity on specific impairments in activity and participation as this may provide targets for clinical intervention to improve functioning in the short term whilst the more difficult and longer-term task of weight management is undertaken. Furthermore, by intervening in childhood, there may be an opportunity to improve functioning and disability before the onset of obesity-related degenerative MS changes that are prevalent in obese adults.

Conflict of interest statement

No conflict of interest was declared.

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References

1. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000; **320**: 1240–1243.
2. Rennie KL, Jebb SA. Prevalence of obesity in Great Britain. *Obes Rev* 2005; **6**: 11–12.
3. Booth ML, Dobbins T, Okely AD, Denney-Wilson E, Hardy LL. Trends in the prevalence of overweight and obesity among young Australians, 1985, 1997, and 2004. *Obesity* 2007; **15**: 1089–1095.

4. Jackson-Leach R, Lobstein T. Estimated burden of paediatric obesity and co-morbidities in Europe. Part 1. The increase in the prevalence of child obesity in Europe is itself increasing. *Int J Pediatr Obes* 2006; **1**: 26–32.

5. Australian Bureau of Statistics. *National Health Survey: Summary of Results 2007–2008*. Australian Bureau of Statistics: Canberra, 2008.

6. Goran MI, Ball F, Cruz M. Obesity and risk of Type 2 diabetes and cardiovascular disease in children and adolescents. *J Clin Epidemiol Metab* 2003; **88**: 1417–1427.

7. Grundy S. Obesity, metabolic syndrome, and coronary atherosclerosis. *Circulation* 2002; **105**: 2696–2698.

8. Rolland Y, Lauwers-Cances V, Cristini C, Grandjean H, Banks WA, Morley JE, Vellas B. Disability in obese elderly women: lower limb strength and recreational physical activity. *Obes Res Clin Pract* 2007; **1**: 39–51.

9. Rolland Y, Lauwers-Cances V, Cristini C, Abellan van Kan G, Janssen I, Morley J, Vellas B. Difficulties with physical function associated with obesity, sarcopenia, and sarcopenic-obesity in community-dwelling elderly women: the EPIDOS (EPIDemiologie de l'OSteoporose) Study. *Am J Clin Nutr* 2009; **89**: 1895–1900.

10. Zoico E, Di Francesco V, Guralnik JM, Mazzali G, Bortolani A, Guariento S, Sergi G, Bosello O, Zamboni M. Physical disability and muscular strength in relation to obesity and different body composition indexes in a sample of healthy elderly women. *Int J Obes Relat Metab Disord* 2004; **28**: 234–241.

11. World Health Organization. *Towards A Common Language for Functioning, Disability and Health: International Classification for Functioning, Disability and Health*. World Health Orgnasation: Geneva, 2002.

12. Coleman K, Norris S, Weston A, Grimmer-Somers K, Hillier S, Merlin T, Middleton P, Tooher R, Salisbury J. *NHMRC Additional Levels of Evidence and Grades for Recommendations for Developers of Guidelines*. National Health and Medical Research Council of Australia: Canberra, 2009.

13. Blimkie CJ, Ebbesen B, MacDougall D, Bar-Or O, Sale D. Voluntary and electrically evoked strength characteristics of obese and nonobese preadolescent boys. *Hum Biol* 1989; **61**: 515–532.

14. Blimkie CJ, Sale DG, Bar-Or O. Voluntary strength, evoked twitch contractile properties and motor unit activation of knee extensors in obese and non-obese adolescent males. *Eur J Appl Physiol Occup Physiol* 1990; **61**: 313–318.

15. Ward DS, Trost SG, Felton G, Saunders R, Parsons MA, Dowda M, Pate RR. Physical activity and physical fitness in African–American girls with and without obesity. *Obes Res* 1997; **5**: 572–577.

16. Maffiuletti NA. Caution is required when comparing the effectiveness of voluntary versus stimulated versus combined strength training modalities. *Sports Med* 2008; **38**: 437–438.

17. Duche P, Ducher G, Lazzer S, Dore E, Tailhardat M, Bedu M. Peak power in obese and nonobese adolescents: effects of gender and braking force. *Med Sci Sports Exerc* 2002; **34**: 2072–2078.

18. Almuzaini KS. Muscle function in Saudi children and adolescents: relationship to anthropometric characteristics during growth. *Pediatr Exerc Sci* 2007; **19**: 319–333.

19. Armstrong N, Welsman JR, Chia MYH. Short term power output in relation to growth and maturation. *Br J Sports Med* 2001; **35**: 118–124.

20. Grund A, Dilba B, Forberger K, Krause H, Siewers M, Rieckert H, Muller MJ. Relationships between physical activity, physical fitness, muscle strength and nutritional state in 5- to 11-year-old children. *Eur J Appl Physiol* 2000; **82**: 425–438.

21. Nevill AM, Holder RL. Scaling, normalizing, and per ratio standards: an allometric modeling approach. *J Appl Physiol* 1995; **79**: 1027–1031.

22. Wren TA, Engsberg JR. Normalizing lower-extremity strength data for children without disability using allometric scaling. *Arch Phys Med Rehabil* 2007; **88**: 1446–1451.

23. Jaric S. Muscle strength testing: use of normalisation for body size. *Sports Med* 2002; **32**: 615–631.

24. Maffiuletti NA, Jubeau M, Agosti F, De Col A, Sartorio A. Quadriceps muscle function characteristics in severely obese and nonobese adolescents. *Eur J Appl Physiol* 2008; **103**: 481–484.

25. Jones MA, Hitchen PJ, Stratton G. The importance of considering biological maturity when assessing physical fitness measures in girls and boys aged 10 to 16 years. *Ann Hum Biol* 2000; **27**: 57–65.

26. Jones MA, Stratton G. Muscle function assessment in children. *Acta Paediatr* 2000; **89**: 753–761.

27. Sallis JF, McKenzie TL, Alcaraz JE. Habitual physical activity and health-related physical fitness in fourth-grade children. *Am J Dis Child* 1993; **147**: 890–896.

28. Malina RM, Beunen GP, Classens AL, Lefevre J, Vanden Eynde BV, Renson R, Vanreusel B, Simons J. Fatness and physical fitness of girls 7 to 17 years. *Obes Res* 1995; **3**: 221–231.

29. Reeves L, Broeder CE, Kennedy-Honeycutt L, East C, Matney L. Relationship of fitness and gross motor skills for five- to six-yr.-old children. *Percept Mot Skills* 1999; **89**: 739–747.

30. Fjotoft I. Motor fitness in pre-primary school children: the Eurofit motor fitness test explored on 5–7 year-old children. *Pediatr Exerc Sci* 2000; **12**: 424–436.

31. Olds T, Dollman J. Are changes in distance-run performance of Australian children between 1985 and 1997 explained by changes in fatness? *Pediatr Exerc Sci* 2004; **16**: 201–209.

32. Okely AD, Booth ML, Chey T. Relationships between body composition and fundamental movement skills among children and adolescents. *Res Q Exerc Sport* 2004; **75**: 238–247.

33. Sartorio A, Proietti M, Marinone PG, Agosti F, Adorni F, Lafortuna CL. Influence of gender, age and BMI on lower limb muscular power output in a large population of obese men and women. *Int J Obes Relat Metab Disord* 2004; **28**: 91–98.

34. Maurer C, Finley A, Martel J, Ulewicz C, Larson CA. Ankle plantarflexor strength and endurance in 7–9 year old children as measured by the standing single leg heel-rise test. *Phys Occup Ther Pediatr* 2007; **27**: 37–54.

35. D'Hondt E, Deforche B, De Bourdeaudhuij I, Lenoir M. Relationship between motor skill and body mass index in 5- to 10-year-old children. *Adapt Phys Activ Q* 2009; **26**: 21–37.

36. Fogelholm M, Stigman S, Huisman T, Metsamuuronen J. Physical fitness in adolescents with normal weight and overweight. *Scand J Med Sci Sports* 2007; **18**: 162–170.

37. Kim J, Must A, Fitzmaurice GM, Gillman MW, Chomitz V, Kramer E, McGowan R, Peterson KE. Relationship of physical fitness to prevalence and incidence of overweight among schoolchildren. *Obes Res* 2005; **13**: 1246–1254.

38. Graf C, Koch B, Kretschmann-Kandel E, Falkowski G, Christ H, Coburger S, Lehmacher W, Bjarnason-Wehrens B, Platen P, Tokarski W, Predel HG, Dordel S. Correlation between BMI, leisure habits and motor abilities in childhood (CHILT-project). *Int J Obes Relat Metab Disord* 2004; **28**: 22–26.

39. Westerstahl M, Barnekow-Bergkvist M, Hedberg G, Jansson E. Secular trends in body dimensions and physical fitness among adolescents in Sweden from 1974 to 1995. *Scand J Med Sci Sports* 2003; **13**: 128–137.

40. Minck MR, Ruiter LM, Van Mechelen W, Kemper HC, Twisk JW. Physical fitness, body fatness, and physical activity: the

Amsterdam Growth and Health Study. *Am J Hum Biol* 2000; **12**: 593–599.

41. Raudsepp L, Jurimae T. Relationships of physical activity and somatic characteristics with physical fitness and motor skill in prepubertal girls. *Am J Hum Biol* 1997; **9**: 513–521.

42. Chatterjee S, Mandal A, Das N. Physical and motor fitness level of Indian school-going boys. *J Sports Med Phys Fitness* 1993; **33**: 268–277.

43. Pate RR, Slentz CA, Katz DP. Relationships between skinfold thickness and performance of health related fitness test items. *Res Q Exerc Sport* 1989; **60**: 183–189.

44. McKenzie TL, Sallis JF, Broyles SL, Zive MM, Nader PR, Berry CC, Brennan JJ. Childhood movement skills: predictors of physical activity in Anglo American and Mexican American adolescents? *Res Q Exerc Sport* 2002; **73**: 238–244.

45. Casajus JA, Leiva MT, Villarroya A, Legaz A, Moreno LA. Physical performance and school physical education in overweight Spanish children. *Ann Nutr Metab* 2007; **51**: 288–296.

46. Chen LJ, Fox KR, Haase A, Wang JM. Obesity, fitness and health in Taiwanese children and adolescents. *Eur J Clin Nutr* 2006; **60**: 1367–1375.

47. Tokmakidis SP, Kasambalis A, Christodoulos AD. Fitness levels of Greek primary schoolchildren in relationship to overweight and obesity. *Eur J Pediatr* 2006; **165**: 867–874.

48. Pongprapai S, Mo-suwan L, Leelasamran W. Physical fitness of obese school children in Hat Yai, southern Thailand. *Southeast Asian J Trop Med Public Health* 1994; **25**: 354–360.

49. Baranowski T. Validity and reliability of self-report measures of physical activity: an information procesing perspective. *Res Q Exerc Sport* 1988; **59**: 314–317.

50. Treuth MS, Sherwood NE, Baranowski T, Butte NF, Jacobs DR, McClanahan B, Gao S, Rochon J, Zhou A, Robinson TN, Pruitt L, Haskell W, Obarzanek E. Physical activity self-report and accelerometry measures from the Girls health Enrichment Multi-site Studies. *Prev Med* 2004; **38**: 43–49.

51. Mond JM, Stich H, Hay PJ, Kraemer A, Baune BT. Associations between obesity and developmental functioning in pre-school children: a population-based study. *Int J Obes (Lond)* 2007; **31**: 1068–1073.

52. Deforche B, Lefevre J, De Bourdeaudhuij I, Hills AP, Duquet W, Bouckaert J. Physical fitness and physical activity in obese and nonobese Flemish youth. *Obes Res* 2003; **11**: 434–441.

53. Bovet P, Auguste R, Burdette H. Strong inverse association between physical fitness and overweight in adolescents: a large school-based survey. *Int J Behav Nutr Phys Act* 2007; **4**: 24.

54. Brunet M, Chaput JP, Tremblay A. The association between low physical fitness and high body mass index or waist circumference is increasing with age in children: the 'Quebec en Forme' Project. *Int J Obes (Lond)* 2007; **31**: 637–643.

55. Korsten-Reck U, Kaspar T, Korsten K, Kromeyer-Hauschild K, Bos K, Berg A, Dickhuth HH. Motor abilities and aerobic fitness of obese children. *Int J Sports Med* 2007; **9**: 762–767.

56. Marshall JD, Bouffard M. The effects of quality of daily physical education on movement competency in obese versus non-obese children. *Adapt Phys Activ Q* 1997; **14**: 227–237.

57. Drinkard B, Roberts MD, Ranzenhofer LM, Han JC, Yanoff LB, Merke DP, Savastano DM, Brady S, Yanovski JA. Oxygen-uptake efficiency slope as a determinant of fitness in overweight adolescents. *Med Sci Sports Exerc* 2007; **39**: 1811–1816.

58. Norman A-C, Drinkard B, McDuffie JR, Ghorbani S, Yanoff LB, Yanovski JA. Influence of excess adiposity on exercise fitness and performance in overweight children and adolescents. *Pediatrics* 2005; **115**: e690–e696.

59. Balady GJ, Berra KA, Golding LA, Gordon NF, Maheler DA, Myers JN, Sheldahl LM. *Acsm's Guidelines for Exercise Testing and Prescription – American College of Sport Medicine*, 6th edn. Lippincott Williams & Wilkins: Philadelphia, PA, 2000.

60. Lazzer S, Boirie Y, Bitar A, Petit I, Meyer M, Vermorel M. Relationship between percentage of VO2max and type of physical activity in obese and non-obese adolescents. *J Sports Med Phys Fitness* 2005; **45**: 13–19.

61. Goran M, Fields DA, Hunter GR, Herd SL, Weinsier RL. Total body fat does not influence maximal aerobic capacity. *Int J Obes Relat Metab Disord* 2000; **24**: 841–848.

62. Watanabe K, Nakadomo F, Maeda K. Relationship between body composition and cardiorespiratory fitness in Japanese junior high school boys and girls. *Ann Physiol Anthropol* 1994; **13**: 167–174.

63. Maffeis C, Schena F, Zaffanello M, Zoccante L, Schutz Y, Pinelli L. Maximal aerobic power during running and cycling in obese and non-obese children. *Acta Paediatr* 1994; **83**: 113–116.

64. Elliot DL, Goldberg L, Kuehl KS, Hanna C. Metabolic evaluation of obese and nonobese siblings. *J Pediatr* 1989; **114**: 957–962.

65. Loftin M, Sothern M, Trosclair L, O'Hanlon A, Miller J, Udall J. Scaling VO(2) peak in obese and non-obese girls. *Obes Res* 2001; **9**: 290–296.

66. Ayub B, Bar-Or O. Energy cost of walking in boys who differ in adiposity but are matched for body mass. *Med Sci Sports Exerc* 2003; **35**: 669–674.

67. Treuth MS, Hunter GR, Pichon C, Figueroa-Colon R, Goran MI. Fitness and energy expenditure after strength training in obese prepubertal girls. *Med Sci Sports Exerc* 1998; **30**: 1130–1136.

68. Rowland TW. Effects of obesity on aerobic fitness in adolescent females. *Am J Dis Child* 1991; **145**: 764–768.

69. Rump P, Verstappen F, Gerver WJM, Hornstra G. Body composition and cardiorespiratory fitness indicators in prepubescent boys and girls. *Int J Sports Med* 2002; **23**: 50–54.

70. Zanconato S, Baraldi E, Santuz P, Rigon F, Vido L, Da Dalt L, Zacchello F. Gas exchange during exercise in obese children. *Eur J Pediatr* 1989; **148**: 614–617.

71. Reybrouck T, Weymans M, Vinckx J, Stijns H, Vanderschueren-Lodeweyckx M. Cardiorespiratory function during exercise in obese children. *Acta Paediatr Scand* 1987; **76**: 342–348.

72. Marinov B, Kostianev S, Turnovska T. Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. *Clin Physiol Funct Imaging* 2002; **22**: 254–260.

73. Berndtsson G, Mattsson E, Marcus C, Larsson UE. Age and gender differences in VO2max in Swedish obese children and adolescents. *Acta Paediatr* 2007; **96**: 567–571.

74. Reybrouk T, Vinckx J, Gewillig M. Assessment of oxygen deficit during exercise in obese children and adolescents. *Pediatr Exerc Sci* 2005; **17**: 291–300.

75. Treuth MS, Figueroa-Colon R, Hunter GR, Weinsier RL, Butte NF, Goran MI. Energy expenditure and physical fitness in overweight vs non-overweight prepubertal girls. *Int J Obes Relat Metab Disord* 1998; **22**: 440–447.

76. Huttunen NP, Knip M, Paavilainen T. Physical activity and fitness in obese children. *Int J Obes (Formerly Int J Obes Relat Metab Disord)* 1986; **10**: 519–525.

77. Török K, Szelényi Z, Pórszász J, Molnár D. Low physical performance in obese adolescent boys with metabolic syndrome. *Int J Obes (Formerly Int J Obes Relat Metab Disord)* 2001; **25**: 966–970.

78. Reybrouck T, Mertens L, Schepers D, Vinckx J, Gewillig M. Assessment of cardiorespiratory exercise function in obese children

and adolescents by body mass-independent parameters. *Eur J Appl Physiol Occup Physiol* 1997; **75**: 478–483.
79. Hollmann W. 42 years ago – development of the concepts of ventilatory and lactate threshold. *Sports Med* 2001; **31**: 315–320.
80. Cooper DM, Poage J, Barstow TJ, Springer C. Are obese children truly unfit? Minimizing the confounding effect of body size on the exercise response. *J Pediatr* 1990; **116**: 223–230.
81. Ruiz JR, Rizzo NS, Hurtig-Wennlof A, Ortega FB, Warnberg J, Sjostrom M. Relations of total physical activity and intensity to fitness and fatness in children: the European Youth Heart Study. *Am J Clin Nutr* 2006; **84**: 299–303.
82. Drinkard B, McDuffie J, McCann S, Uwaifo GI, Nicholson J, Yanovski JA. Relationships between walk/run performance and cardiorespiratory fitness in adolescents who are overweight. *Phys Ther* 2001; **81**: 1889–1896.
83. Li AM, Yin J, Yu CCW, Tsang T, So HK, Wong E, Chan D, Hon EKL, Sung R. The six-minute walk test in healthy children: reliability and validity. *Eur Respir J* 2005; **25**: 1057–1060.
84. Hestbaek L, Leboeuf-Yde C, Kyvik KO. Are lifestyle-factors in adolescence predictors for adult low back pain? A cross-sectional and prospective study of young twins. *BMC Musculoskelet Disord* 2006; **7**: 27.
85. Salminen JJ, Erkintalo M, Laine M, Pentti J. Low back pain in the young. A prospective three-year follow-up study of subjects with and without low back pain. *Spine* 1995; **20**: 2101–2107.
86. Masiero S, Carraro E, Celia A, Sarto D, Ermani M. Prevalence of nonspecific low back pain in schoolchildren aged between 13 and 15 years. *Acta Paediatr* 2007; **97**: 212–216.
87. Mohseni-Bandpei MA, Bagheri-Nesami M, Shayesteh-Azar M. Nonspecific low back pain in 5000 Iranian school-age children. *J Pediatr Orthop* 2007; **27**: 126–129.
88. Chiang HY, Jacobs K, Orsmond G. Gender-age environmental associates of middle school students' low back pain. *Work* 2006; **26**: 197–206.
89. Sjolie AN. Low-back pain in adolescents is associated with poor hip mobility and high body mass index. *Scand J Med Sci Sports* 2004; **14**: 168–175.
90. Sheir-Neiss GI, Kruse RW, Rahman T, Jacobson LP, Pelli JA. The association of backpack use and back pain in adolescents. *Spine* 2003; **28**: 922–930.
91. Kovacs FM, Gestoso M, Gil del Real MT, Lopez J, Mufraggi N, Mendez JI. Risk factors for non-specific low back pain in schoolchildren and their parents: a population based study. *Pain* 2003; **103**: 259–268.
92. Watson KD, Papageorgiou AC, Jones GT, Taylor S, Symmons DP, Silman AJ, Macfarlane GJ. Low back pain in schoolchildren: the role of mechanical and psychosocial factors. *Arch Dis Child* 2003; **88**: 12–17.
93. Szpalski M, Gunzburg R, Balague F, Nordin M, Melot C. A 2-year prospective longitudinal study on low back pain in primary school children. *Eur Spine J* 2002; **11**: 459–464.
94. Salminen JJ, Maki P, Oksanen A, Pentti J. Spinal mobility and trunk muscle strength in 15-year-old schoolchildren with and without low-back pain. *Spine* 1992; **17**: 405–411.
95. Harreby M, Nygaard B, Jessen T, Larsen E, Storr-Paulsen A, Lindahl A, Fisker I, Laegaard E. Risk factors for low back pain in a cohort of 1389 Danish school children: an epidemiologic study. *Eur Spine J* 1999; **8**: 444–450.
96. Poussa MS, Heliovaara MM, Seitsamo JT, Kononen MH, Hurmerinta KA, Nissinen MJ. Anthropometric measurements and growth as predictors of low-back pain: a cohort study of children followed up from the age of 11 to 22 years. *Eur Spine J* 2005; **14**: 595–598.
97. Lake JK, Power C, Cole TJ. Back pain and obesity in the 1958 British birth cohort. cause or effect? *J Clin Epidemiol* 2000; **53**: 245–250.
98. Bell LM, Byrne S, Thompson A, Ratnam N, Blair E, Bulsara M, Jones TW, Davis EA. Increasing body mass index z-score is continuously associated with complications of overweight in children, even in the healthy weight range. *J Clin Endocrinol Metab* 2007; **92**: 517–522.
99. de Sa Pinto AL, de Barros Holanda PM, Radu AS, Villares SM, Lima FR. Musculoskeletal findings in obese children. *J Paediatr Child Health* 2006; **42**: 341–344.
100. Podeszwa DA, Stanko KJ, Mooney JF, Cramer KE, Mendelow MJ. An analysis of the functional health of obese children and adolescents utilizing the PODC instrument. *J Pediatr Orthop* 2006; **26**: 140–143.
101. Taylor ED, Theim KR, Mirch MC, Ghorbani S, Tanofsky-Kraff M, Adler-Wailes DC, Brady S, Reynolds JC, Calis KA, Yanovski JA. Orthopedic complications of overweight in children and adolescents. *Pediatrics* 2006; **117**: 2167–2174.
102. Wake M, Salmon L, Waters E, Wright M, Hesketh K. Parent-reported health status of overweight and obese Australian primary school children: a cross-sectional population survey. *Int J Obes (Formerly Int J Obes Relat Metab Disord)* 2002; **26**: 717–724.
103. Vahasarja V. Prevalence of chronic knee pain in children and adolescents in northern Finland. *Acta Paediatr* 1995; **84**: 803–805.
104. Kashikar-Zuck S, Goldschneider KR, Powers SW, Vaught MH, Hershey AD. Depression and functional disability in chronic pediatric pain. *Clin J Pain* 2001; **17**: 341–349.
105. Roth-Isigkeit A, Thyen U, Stoven H, Schwarzenberger J, Schmucker P. Pain among children and adolescents: restrictions in daily living and triggering factors. *Pediatrics* 2005; **115**: e152–e162.
106. Gauntlett-Gilbert J, Eccleston C. Disability in adolescents with chronic pain: patterns and predictors across different domains of functioning. *Pain* 2007; **I131**: 132–141.
107. Merritt KA, Ornstein PA, Spicker B. Children's memory for a salient medical procedure: implications for testimony. *Pediatrics* 1994; **94**: 17–23.
108. Zonneveld LNL, McGrath PJ, Reid GJ, Sorbi MJ. Accuracy of children's pain memories. *Pain* 1997; **71**: 297–302.
109. Badali MA, Pillai RR, Craig KD, Giesbrecht K, Chamber CT. Accuracy of children's and parent's memory for a novel painful experience. *Pain Res Manag* 2000; **4**: 161–168.
110. Erskine A, Morley S, Pearce S. Memory for pain: a review. *Pain* 1990; **41**: 255–265.
111. Gushue DL, Houck J, Lerner AL. Effects of childhood obesity on three-dimensional knee joint biomechanics during walking. *J Pediatr Orthop* 2005; **25**: 763–768.
112. Nissinen M, Heliovaara M, Seitsamo J, Alaranta H, Poussa M. Anthropometric measurements and the incidence of low back pain in a cohort of pubertal children. *Spine* 1994; **19**: 1367–1370.
113. Colne P, Frelut ML, Peres G, Thoumie P. Postural control in obese adolescents assessed by limits of stability and gait initiation. *Gait Posture* 2008; **28**: 164–169.
114. Wearing SC, Hennig EM, Byrne NM, Steele JR, Hills AP. The impact of childhood obesity on musculoskeletal form. *Obes Rev* 2006; **7**: 209–218.
115. Habib Z, Westcott S. Assessment of anthropometric factors on balance tests in children. *Pediatr Phys Ther* 1998; **10**: 101–109.
116. Nantel J, Brochu M, Prince F. Locomotor strategies in obese and non-obese children. *Obesity* 2006; **14**: 1789–1794.
117. McGraw B, McClenaghan BA, Williams HG, Dickerson J, Ward DS. Gait and postural stability in obese and nonobese prepubertal boys. *Arch Phys Med Rehabil* 2000; **81**: 484–489.

118. Hills AP, Parker AW. Gait characteristics of obese children. *Arch Phys Med Rehabil* 1991; **72**: 403–407.

119. Hills AP, Parker AW. Gait asymmetry in obese children. *Neuro-orthopedics* 1991; **12**: 29–33.

120. Adam C, Klissouras V, Ravazzolo M, Renson R, Tuxworth W. *Eurofit: European Test of Physical Fitness*. Council of Europe. Committee for the Development of Sport: Rome, 1988.

121. Goulding A, Jones IE, Taylor RW, Piggot JM, Taylor D. Dynamic and static tests of balance and postural sway in boys: effects of previous wrist bone fractures and high adiposity. *Gait Posture* 2003; **17**: 136–141.

122. Hills AP, Parker AW. Electromyography of walking in obese children. *Electromyogr Clin Neurophysiol* 1993; **33**: 225–233.

123. Maffeis C, Schutz Y, Schena F, Zaffanello M, Pinelli L. Energy expenditure during walking and running in obese and nonobese prepubertal children. *J Pediatr* 1993; **123**: 193–199.

124. Katch V, Becque MD, Marks C, Moorehead C, Rocchini A. Oxygen uptake and energy output during walking of obese male and female adolescents. *Am J Clin Nutr* 1988; **47**: 26–32.

125. WHO. *International Classification of Functioning, Disability and Health: Short Version*. World Health Organization: Geneva, 2001.

126. Riddiford-Harland DL, Steele JR, Baur LA. Upper and lower limb functionality: are these compromised in obese children? *Int J Pediatr Obes* 2006; **1**: 42–49.

127. Williams J, Wake M, Hesketh K, Maher E, Waters E. Health-related quality of life of overweight and obese children. *JAMA* 2005; **293**: 70–76.

128. Cieza A, Stucki G. Content comparison of health-related quality of life (HRQOL) instruments based on the international classification of functioning, disability and health (ICF). *Qual Life Res* 2005; **14**: 1225–1237.

129. Tsiros MD, Olds T, Buckley JD, Grimshaw P, Brennan L, Walkley J, Hills AP, Howe PR, Coates AM. Health-related quality of life in obese children and adolescents. *Int J Obes (Formerly Int J Obes Relat Metab Disord)* 2009; **33**: 387–400.

130. Zhang L, Fos PJ, Johnson WD, Kamali V, Cox RG, Zuniga MA, Kittle T. Body mass index and health related quality of life in elementary school children: a pilot study. *Health Qual Life Outcomes* 2008; **6**: 77.

131. Wake M, Hardy P, Sawyer MG, Carlin JB. Comorbidities of overweight/obesity in Australian preschoolers: a cross-sectional population study. *Arch Dis Child* 2008; **93**: 502–507.

132. Yackobovitch-Gavan M, Nagelberg N, Demol S, Phillip M, Shalitin S. Influence of weight-loss diets with different macronutrient compositions on health-related quality of life in obese youth. *Appetite* 2008; **51**: 697–703.

133. Loux TJ, Haricharan RN, Clements RH, Kolotkin RL, Bledsoe SE, Haynes B, Leath T, Harmon CM. Health-related quality of life before and after bariatric surgery in adolescents. *J Pediatr Surg* 2008; **43**: 1275–1279.

134. Tanner JM. *Growth at Adolescence*, 2nd edn. Blackwell Scientific: London, 1962.

135. Brooks-Gunn J, Warren MP, Rosso J, Gargiulo J. Validity of self-report measures of girls' pubertal status. *Child Dev* 1987; **58**: 829–841.

136. Sartorio A, Agosti F, De Col A, Lafortuna CL. Age- and gender-related variations of leg power output and body composition in severely obese children and adolescents. *J Endocrinol Invest* 2006; **29**: 48–54.

137. Graf C, Koch B, Dordel S, Schindler-Marlow S, Icks A, Schuller A, Bjarnason-Wehrens B, Tokarski W, Predel HG. Physical activity, leisure habits and obesity in first-grade children. *Eur J Cardiovasc Prev Rehabil* 2004; **11**: 284–290.

138. Chen W, Lin CC, Peng CT, Li CI, Wu HC, Chiang J, Wu JY, Huang PC. Approaching healthy body mass index norms for children and adolescents from health-related physical fitness. *Obes Rev* 2002; **3**: 225–232.

139. Butterfield SA, Lehnhard RA, Coladarci T. Age, sex, and body mass index in performance of selected locomotor and fitness tasks by children in grades K-2. *Percept Mot Skills* 2002; **94**: 80–86.

140. Klasson-Heggebo L, Andersen LB, Wennlof AH, Sardinha LB, Harro M, Froberg K, Anderssen SA, Mota J. Graded associations between cardiorespiratory fitness, fatness, and blood pressure in children and adolescents. *Br J Sports Med* 2006; **40**: 25–29.

141. Gutin B, Yin Z, Humphries M, Barbeau P. Relations of moderate and vigorous physical activity to fitness and fatness in adolescents. *Am J Clin Nutr* 2005; **81**: 746–750.

142. Stewart KJ, Brown CS, Hickey CM, McFarland LD, Weinhofer JJ, Gottlieb SH. Physical fitness, physical activity, and fatness in relation to blood pressure and lipids in preadolescent children. Results from the FRESH Study. *J Cardiopulm Rehabil* 1995; **15**: 122–129.

143. Taylor W, Baranowski T. Physical activity, cardiovascular fitness, and adiposity in children. *Res Q Exerc Sport* 1991; **62**: 157–163.