NCCOR WORKSHOP

Revisiting Rapid Infant Growth: Assessing Growth in Children Under Age 2

Panel: Researchers in Rapid Infant Growth and Early-life Obesity Risk – Biological Perspective

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Panel: Researchers in Rapid Infant Growth and Early-life Obesity Risk – Biological Perspective

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Cambridge University

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Revisiting Rapid Infant Growth: Assessing Growth in Children Under Age 2

Rapid Infant Weight Gain

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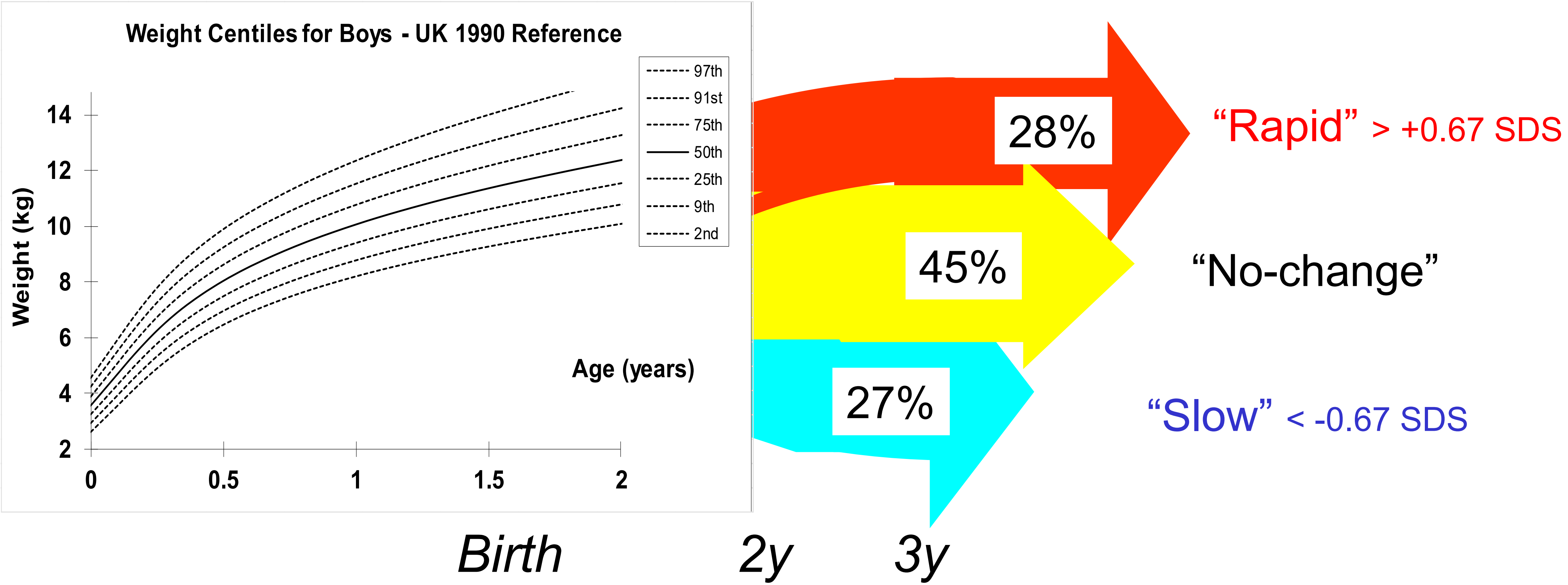
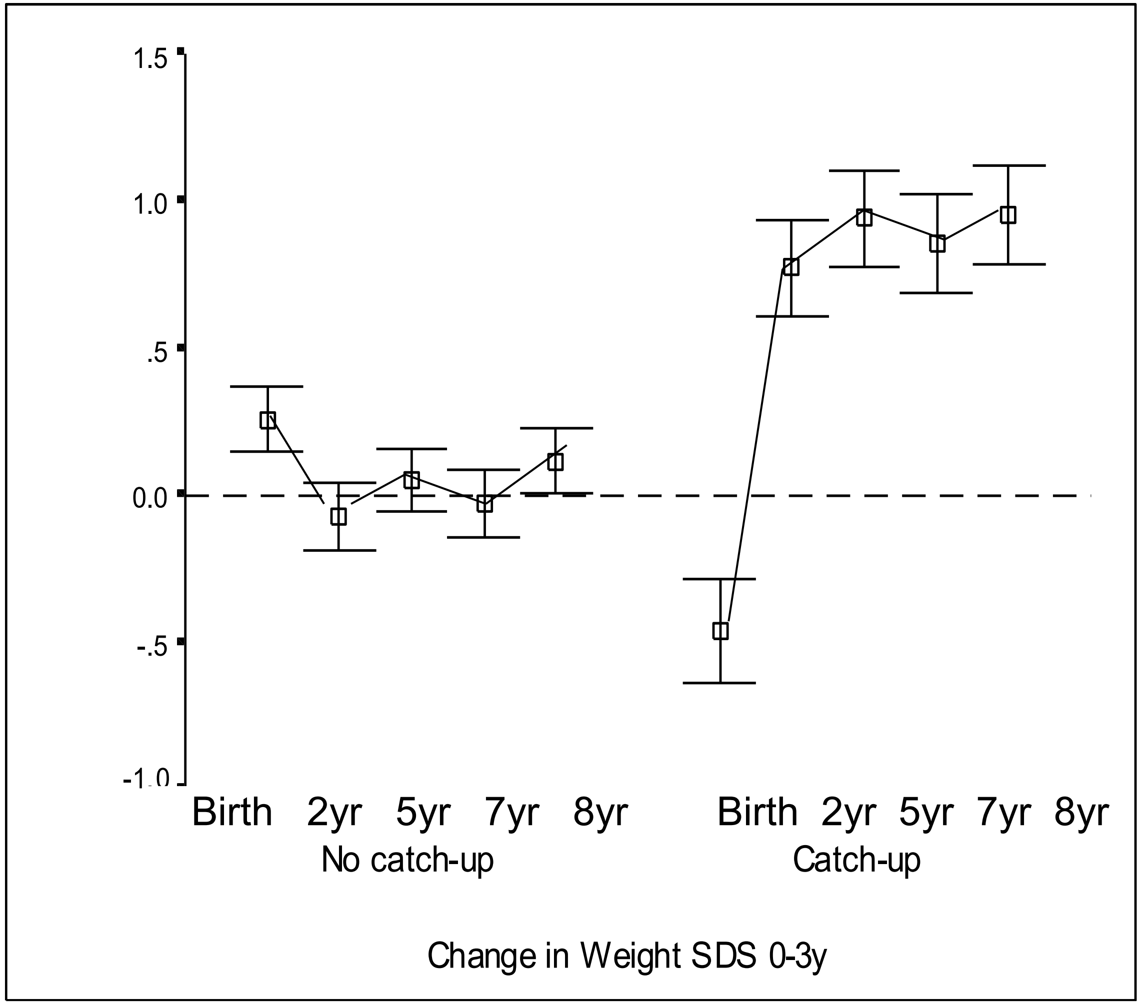
Wide variation in infancy growth



Ong et al., *BMJ* 2000

Persisting effects of rapid infancy weight gain



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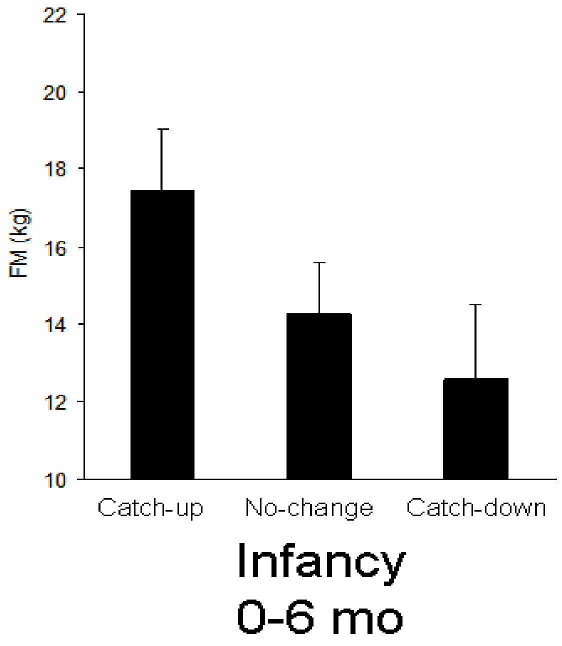
Ong KK et al. *BMJ* 2000
plus updated ALSPAC data at age 8y

Persisting, consistent and sizeable effects of RIWG

Fat mass
at 17 years



SWEDES cohort.
Ekelund et al, *AJCN* 2006

Systematic Reviews:

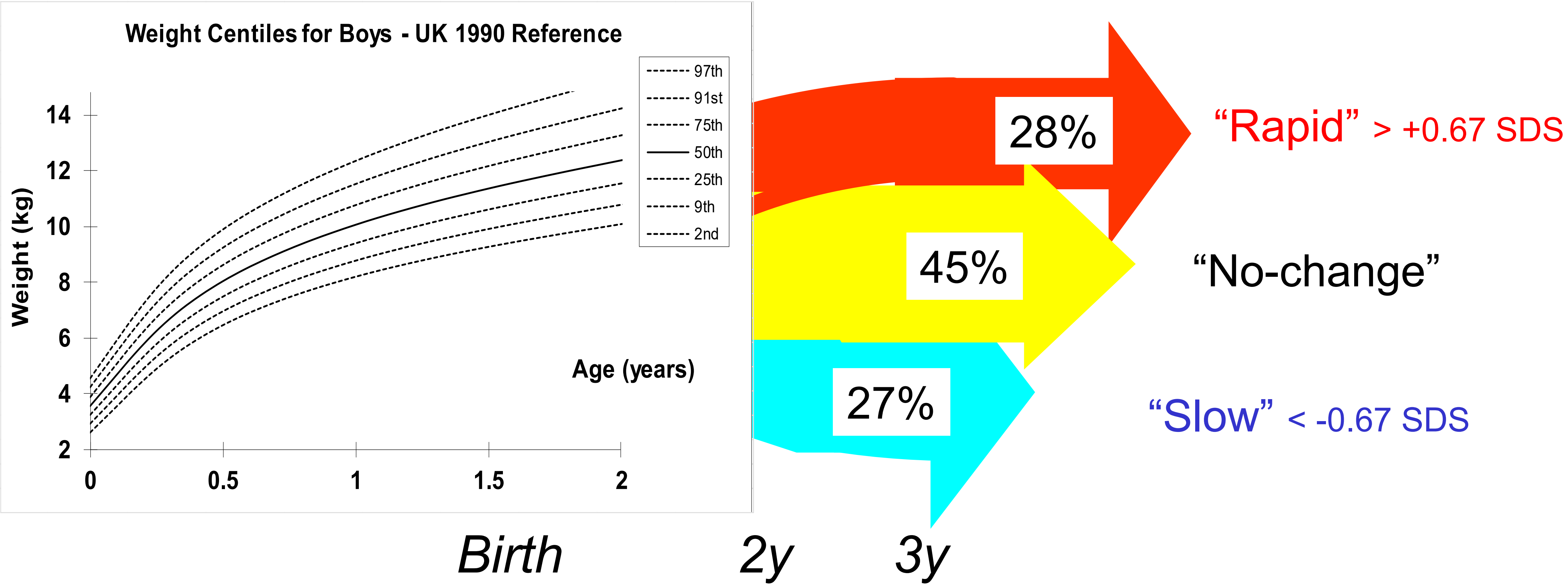
Woo-Baidal et al. *Am J Prev Med* 2016 — ***+ve association with OW/OB in 45/46 studies***

Zheng et al. *Obes Rev* 2018 — MA **Odds ratio for OW/OB = 3.66** (2.59-5.17) per +0.67 SDS

Questions

1. Initial definitions of rapid infant weight gain?
2. Rapid infant weight gain vs. catch-up growth in small term infants
3. Influence of early weight gain on later obesity and diabetes

Wide variation in infancy growth



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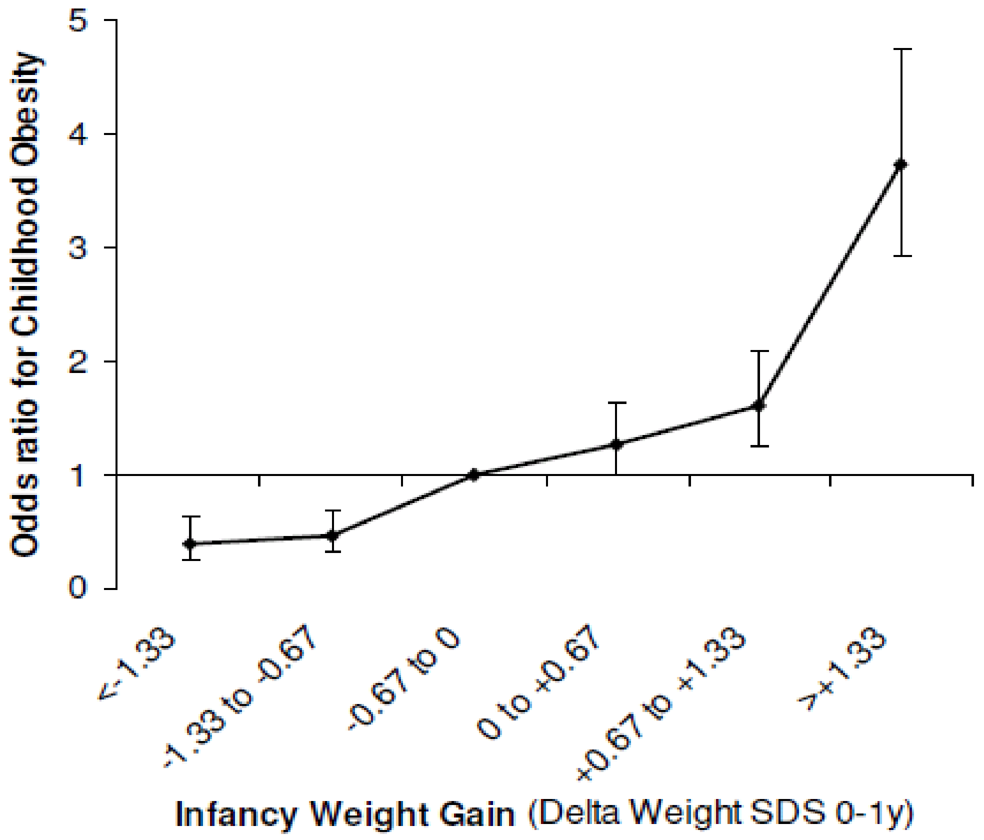
Ong et al., *BMJ* 2000

Odds ratio for childhood obesity by infant weight gain 0-1 year



IPD meta-analysis of 10 cohorts

N=44,829

IOTF Childhood obesity in 0.8% to 4.2%

Druet et al, *Paediatric & Perinatal Epidemiology* 2012

Questions

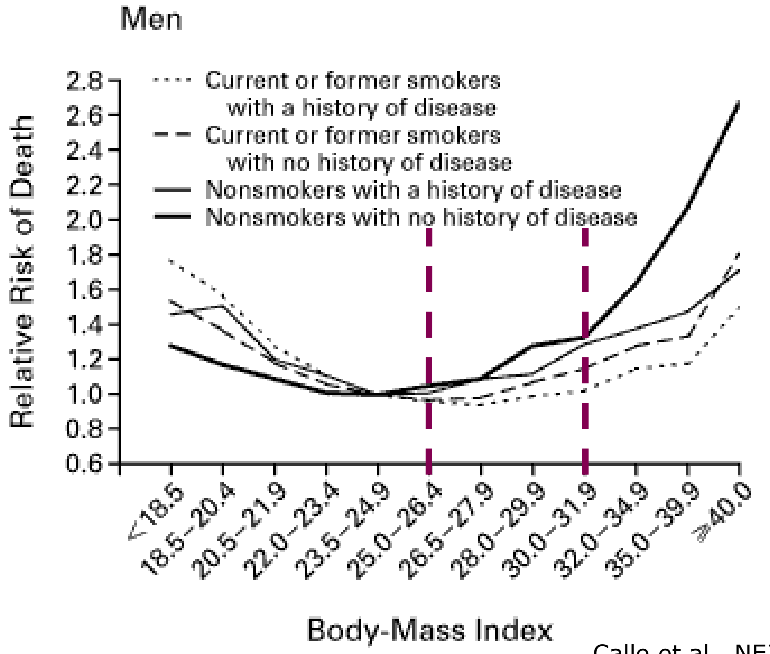
1. Initial definitions of rapid infant weight gain?
   - +0.67 SDS is ***indicative*** of rapid weight gain—**not *definitive*** (it depends on the outcome)

Definition of Obesity

- Obesity is a condition of ***excess body fat*** that has an ***adverse effect on health***

Adult obesity is defined by the shape of association between BMI and mortality

BMI and Mortality in a Prospective Cohort of U.S. Adults



MRC Epidemiol

Calle et al., NEJM 1999

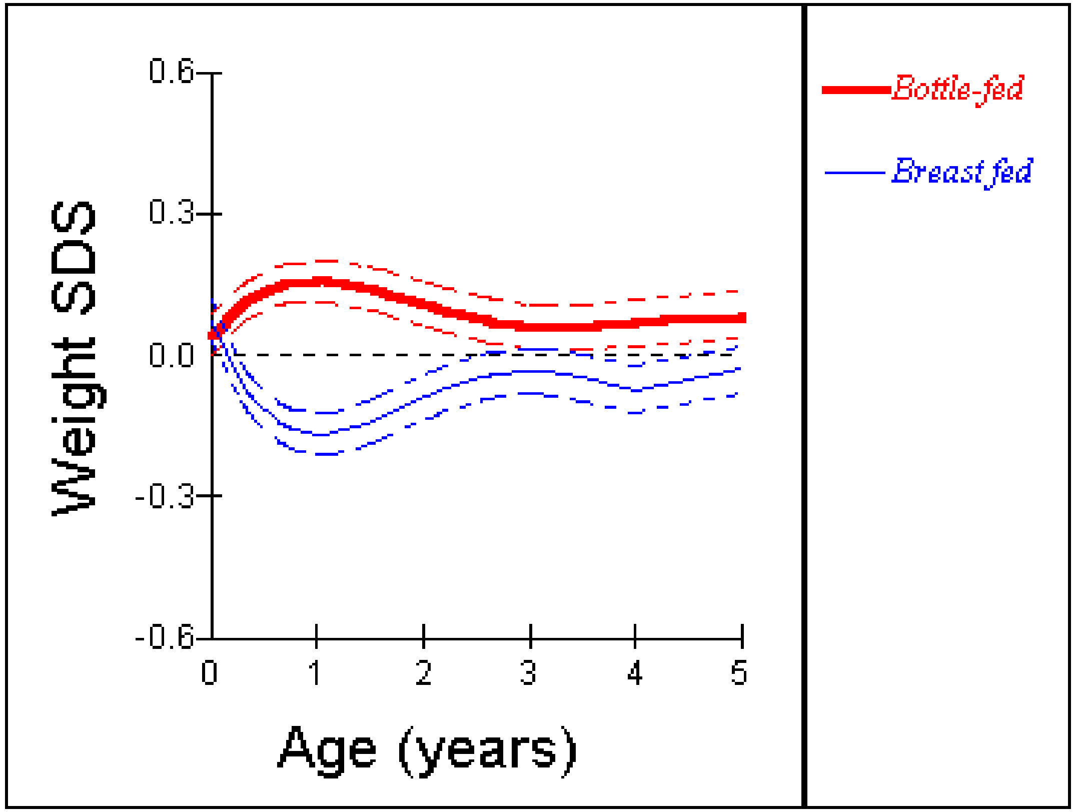
Cancer Prevention Study II

N=1.1M participants - age 57 years at baseline

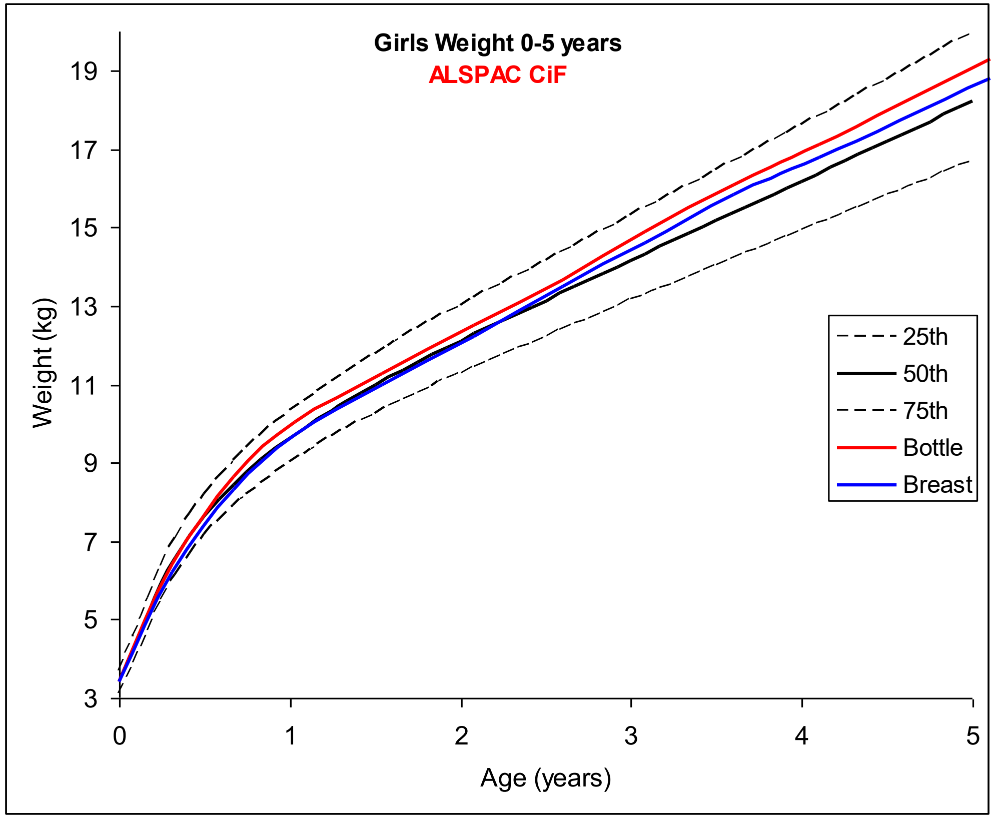
Questions

1. Initial definitions of rapid infant weight gain?
    - +0.67 SDS is *indicative* of rapid weight gain—not *definitive* (it depends on the outcome)
    - **Which measure of weight? SDS or Kg**

Weight gain in formula vs. breastfed infants



Weight in SDS



Weight in Kg

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Ong et al. *Ped Res* 2003

Questions

1. Initial definitions of rapid infant weight gain?
   - +0.67 SDS is *indicative* of rapid weight gain – not *definitive* (it depends on the outcome)
   - Which measure of weight? SDS or Kg
   - **What about other infant growth parameters – *length, BMI, adiposity*?**

Cambridge Baby Growth Study: born 2001-09

- Growth, body composition and fat distribution 0–2 years

Higher metabolic disease risk?

Central fat

Fat mass

Peripheral fat

Rapid weight

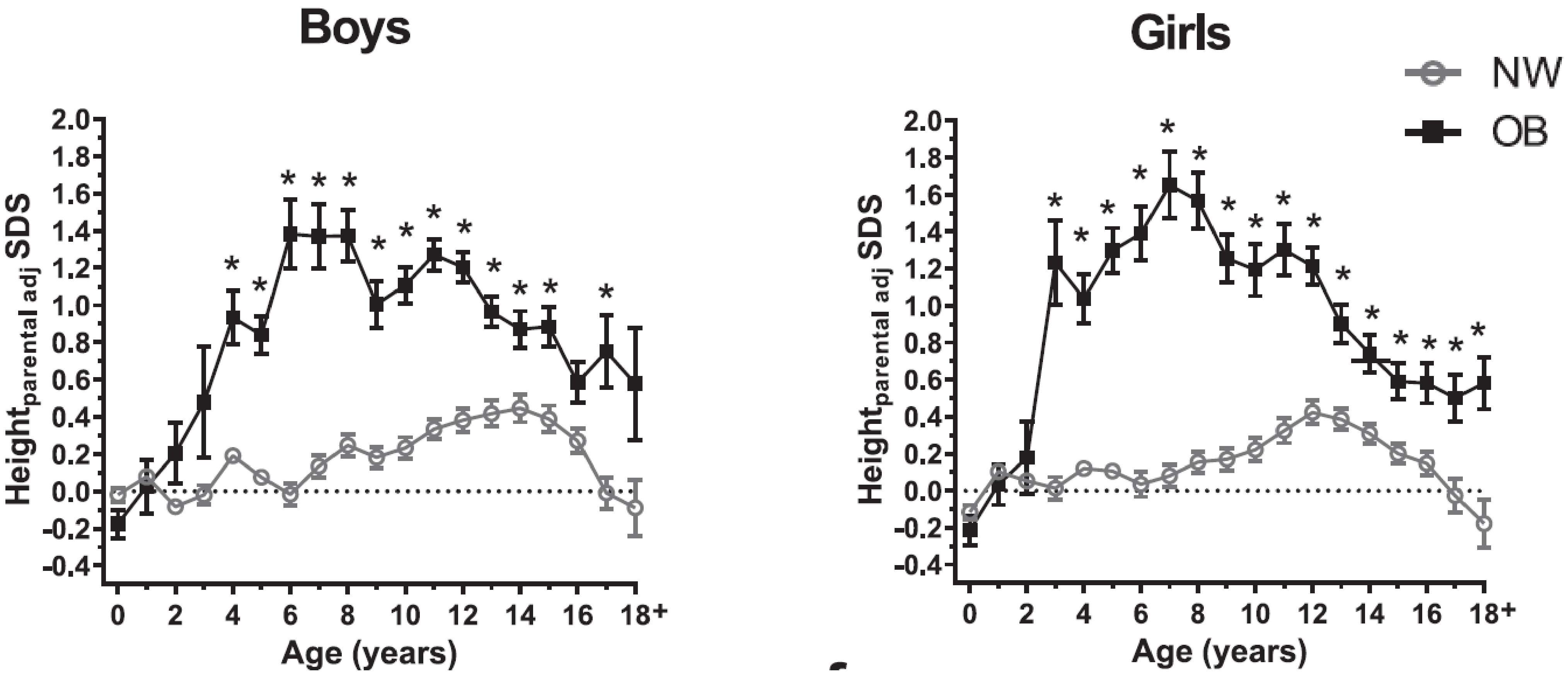
Lean mass + height

Slow weight

Lower metabolic disease risk?

Cohort Profile: Prentice et al. *Int J Epid* 2016

‘Rapid tempo’ of linear growth in children with obesity



Leipzig Obesity Childhood cohorts
8,629 children, 37,493 measurements

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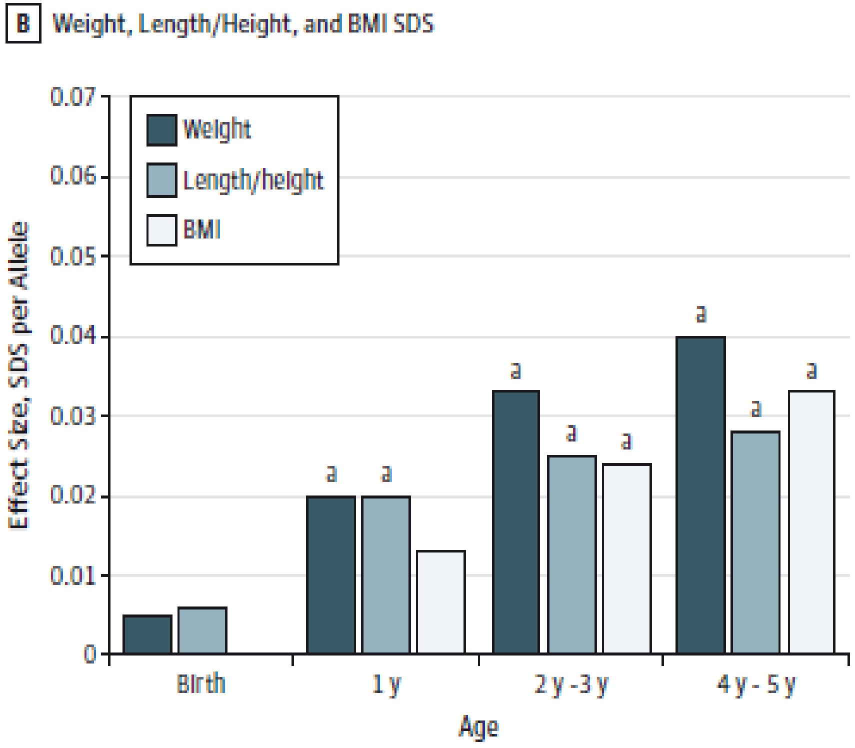
E. Kempf et al. *EClinicalMedicine* 2021

'Rapid tempo' of linear growth in children with higher genetic susceptibility to obesity

Figure 1. Cross-sectional Associations Between the Obesity Risk-Allele Score and Early Childhood Body Size and Composition

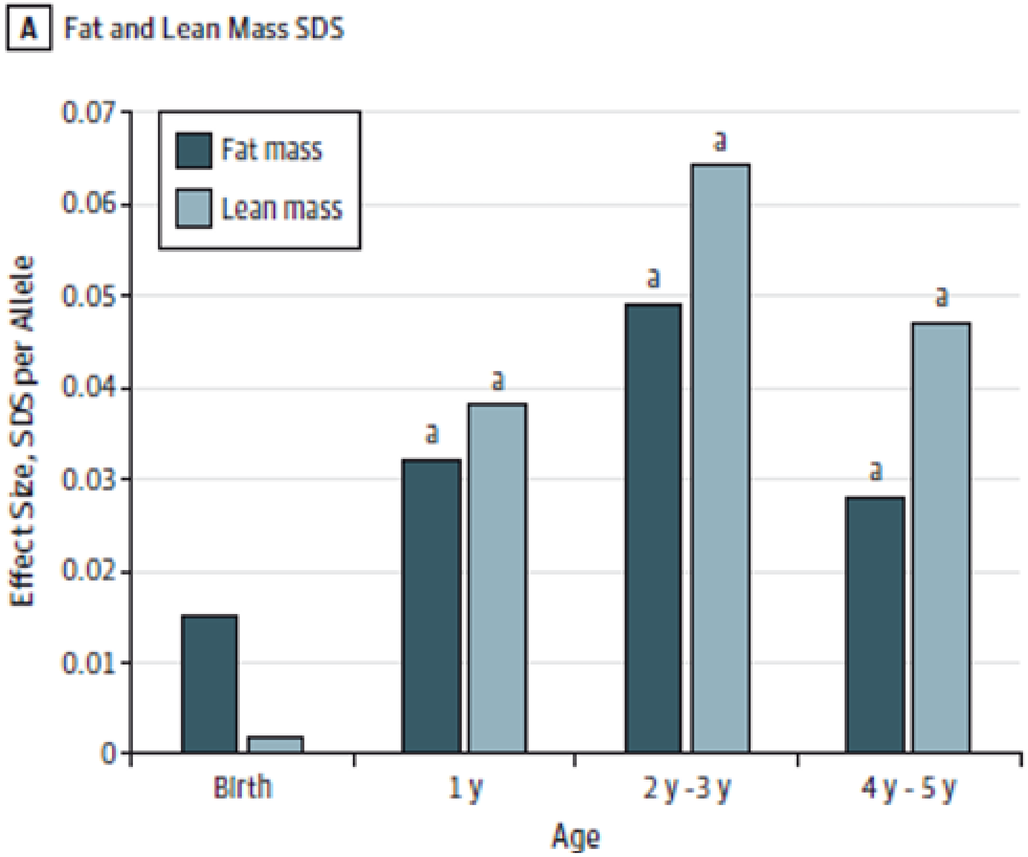
Higher adult obesity polygenic score promotes:

- **Early weight** gain
- **Early length** gain
- **Later BMI** gain



Elks et al, *JAMA Peds* 2014

'Rapid tempo' of linear growth in children with higher genetic susceptibility to obesity



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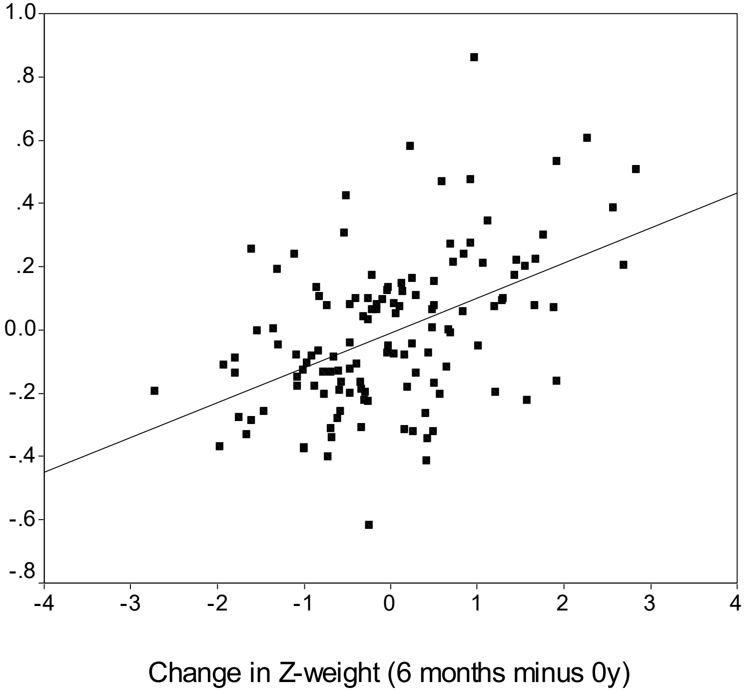
Elks et al, *JAMA Peds* 2014

Questions

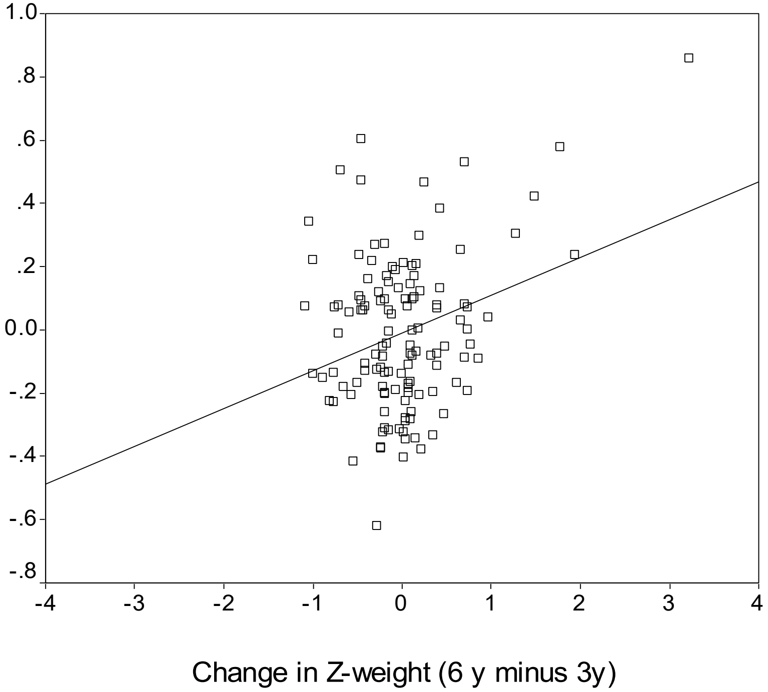
1. Initial definitions of rapid infant weight gain?
   - +0.67 SDS is *indicative* of rapid weight gain—not *definitive* (it depends on the outcome)
   - Which measure of weight? SDS or Kg
   - What about other infant growth parameters—*length, BMI, adiposity*?
   - **Which infancy time period best predicts later obesity?**

No critical window of rapid weight gain
– for metabolic syndrome score at 17 years



Infancy weight gain
0–6 months

R-square = 13.7%, P<0.0001



Early childhood weight gain
3–6 years

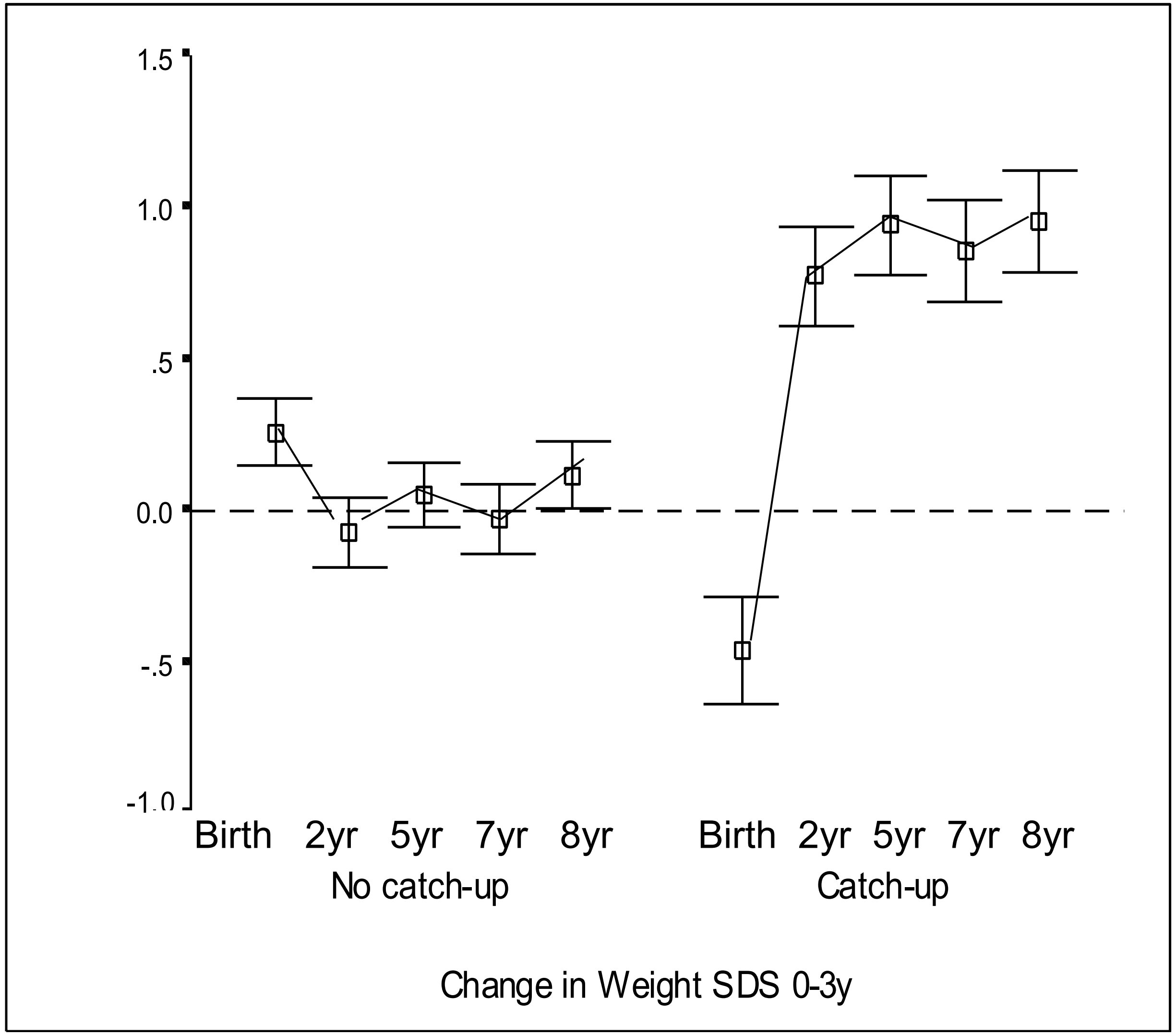
R-square = 9.1%, P=0.002

Ekelund et al., *J Clin Endo Metab* 2007

Questions

1. Initial definitions of rapid infant weight gain?
2. **Rapid infant weight gain** vs. **catch-up growth** in small term infants
3. Influence of early weight gain on later obesity and diabetes

Rapid infant weight gain vs. catch-up growth



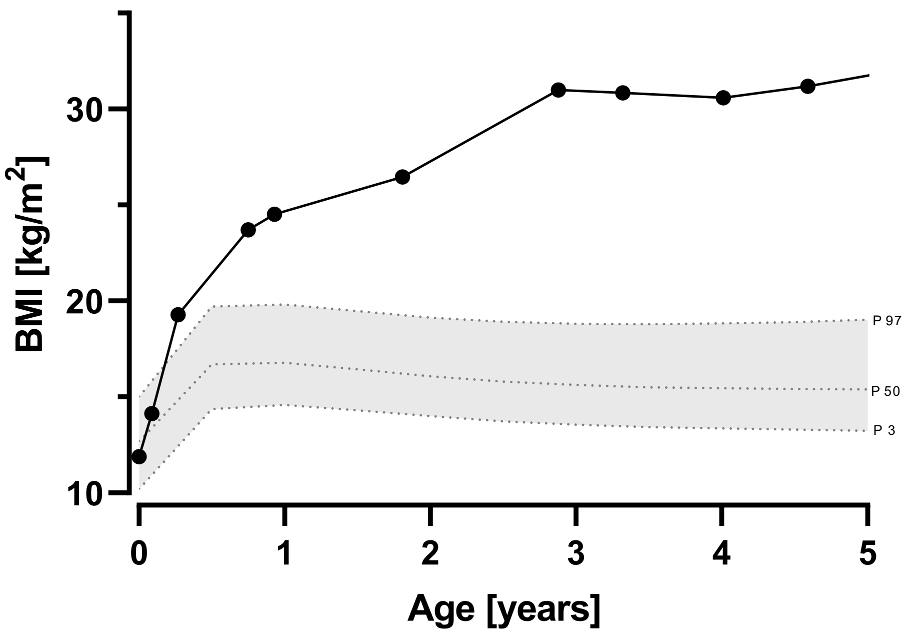
Ong KK et al. *BMJ* 2000

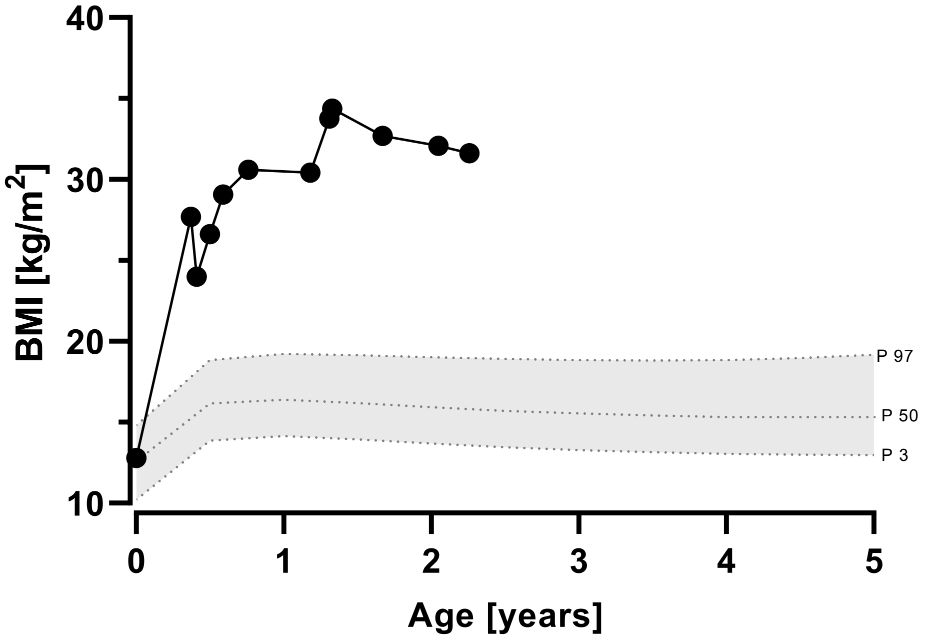
plus updated ALSPAC data at age 8y

Biological plausibility for *rapid infant weight gain*

Rapid weight gain from infancy in patients with rare monogenic obesity
- Early-onset severe obesity
- Excessive appetite ('hyperphagia')

E.g., bioinactive leptin mutations – Wabitsch et al. *NEJM* 2015; antagonistic leptin mutations – Funcke et al. *NEJM* 2023





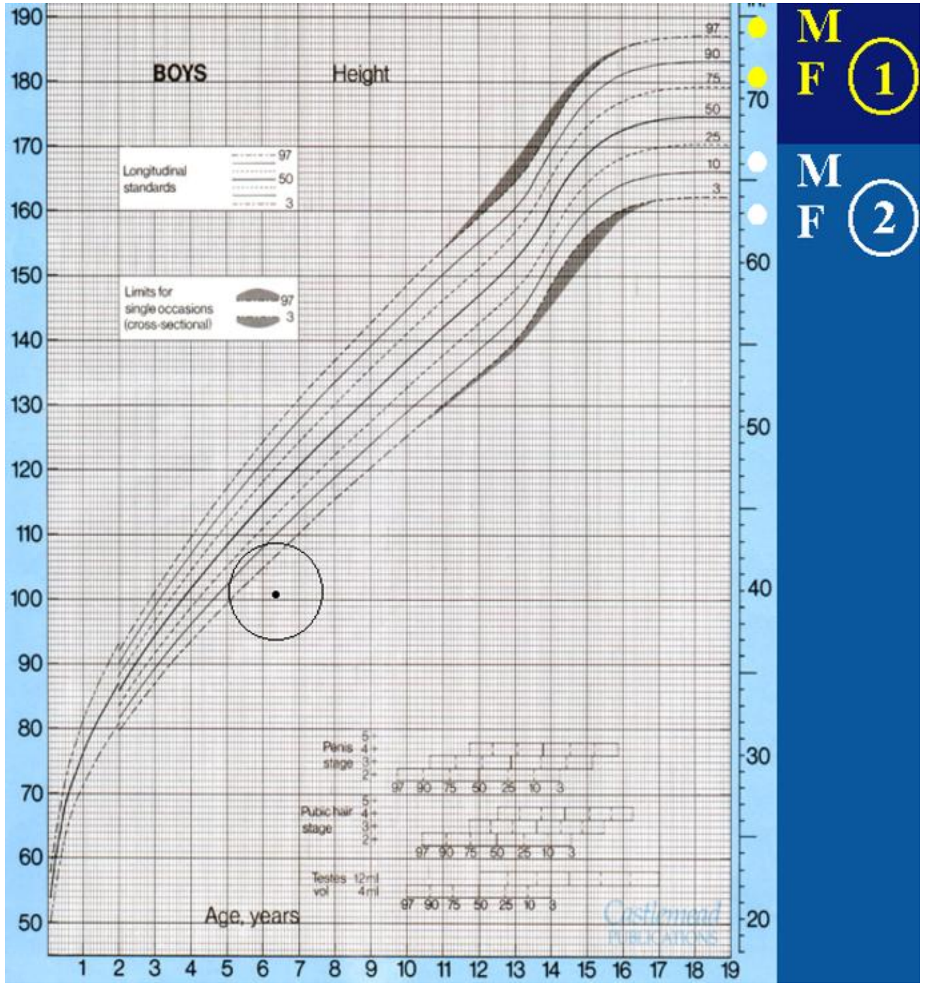
Additional unpublished data to Funcke et al. *NEJM* June 2023
Prepared and shared by Stefanie Zorn and Martin Wabitsch

Genetic correlations between birth weight and adult metabolic disease

- 190 genetic loci associated with BW
- **Genetic correlations**:
  - **Higher BW** and **Higher adult BMI**
  - **Lower BW** and **Higher systolic blood pressure** and **higher risk of coronary heart disease**
- Mechanisms: insulin signalling, glucose homeostasis, glycogen biosynthesis and chromatin remodelling.
- Fetal rather than maternal mechanisms

Dunger, Ong et al, *Nat Genetics* 1998; Horikoshi et al, *Nature* 2016; Warrington et al, *Nat Genetics* 2019

Use the Mid-Parental Height (MPH) centile to indicate sufficient infant weight?



Questions

1. Initial definitions of rapid infant weight gain?
2. Rapid infant weight gain vs. catch-up growth in small, term infants
3. **Influence of early weight gain on later obesity and diabetes**
   - **Positive associations with fat mass and metabolic syndrome score at age 17y** (SWEDES cohort.; Ekelund et al, *AJCN* 2006; Ekelund et al, *J Clin Endo Metab* 2007)
   - **Positive associations with genetic risk of adult obesity**

Summary

1. Initial definitions of rapid infant weight gain
   - **+0.67 SDS is *indicative*** of rapid weight gain – not *definitive (it depends on the outcome)*
   - Which measure of weight? ***SDS***
   - Other infant growth parameters – ***Weight*** *captures both adiposity and growth tempo*
   - Which infancy time period best predicts later obesity? – ***No obvious critical window***
2. Rapid infant weight gain vs. catch-up growth in small term infants – ***Both influence later metabolic disease****. Possibly individualize weight centile targets based on MPH?*
3. Influence of early weight gain on later obesity and diabetes – **YES**
   - But note differing effects of higher BW on later obesity (+ve) and diabetes (-ve)

Thank you!

Revisiting Rapid Infant Growth: Assessing Growth in Children Under Age 2

Rapid Infant Growth, Adiposity, and the Impact of Early Infant Feeding

Ellen W. Demerath, PhD
University of Minnesota School of Public Health

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Infant weight gain in context

Human infant growth is part of a unique adaptive life history strategy

Infancy

- Motor immaturity and total dependence at birth
- Rapidly growing, developmentally plastic brain with high metabolic demand
- Preferential accrual of adipose tissue before weaning to support brain's metabolic demand and reduce risk of mortality
- Active HPG axis

Childhood

One of the longest juvenile dependency periods in the animal kingdom

A unique growth period inserted between infancy and adolescence, through central active inhibition of the HPG axis/GnRH secretion

Slow gradual postcranial development while the child learns language, tool use, social norms, and complex cooperative survival strategies while still dependent

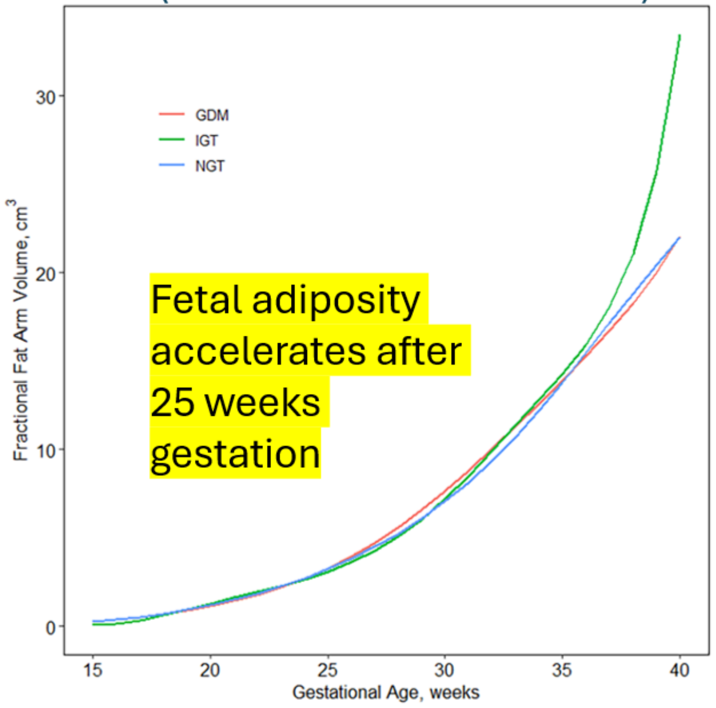
Puberty and Adolescence

Puberty: Sharp, explosive increase in height and weight brought on by release of GnRH suppression, influenced by peripheral metabolic signals (e.g., adiposity)

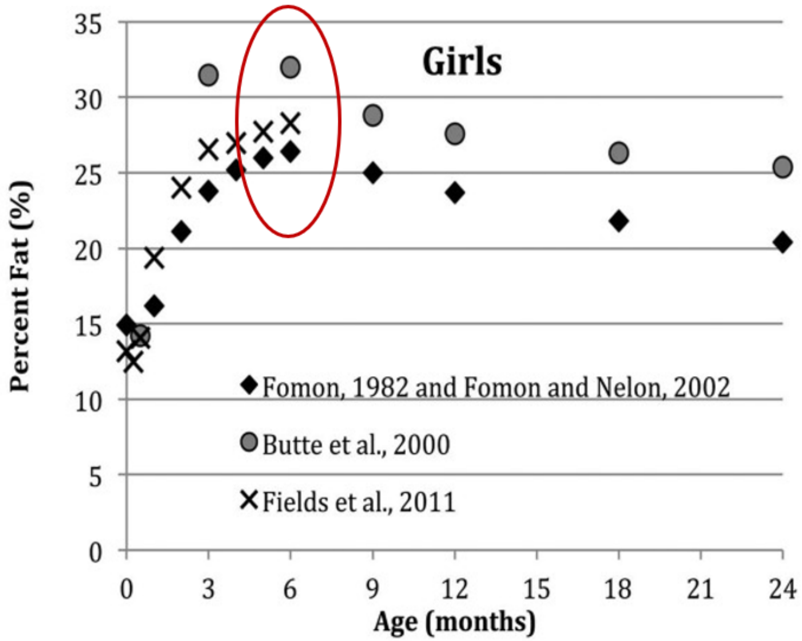
Adolescence: lasts far longer than transitional phase of other primates, with continued neural and social maturation

Ontogeny of adipose tissue: fetal life to infancy

United States NICHD Fetal 3D Ultrasound Study (Fractional fat arm volume)

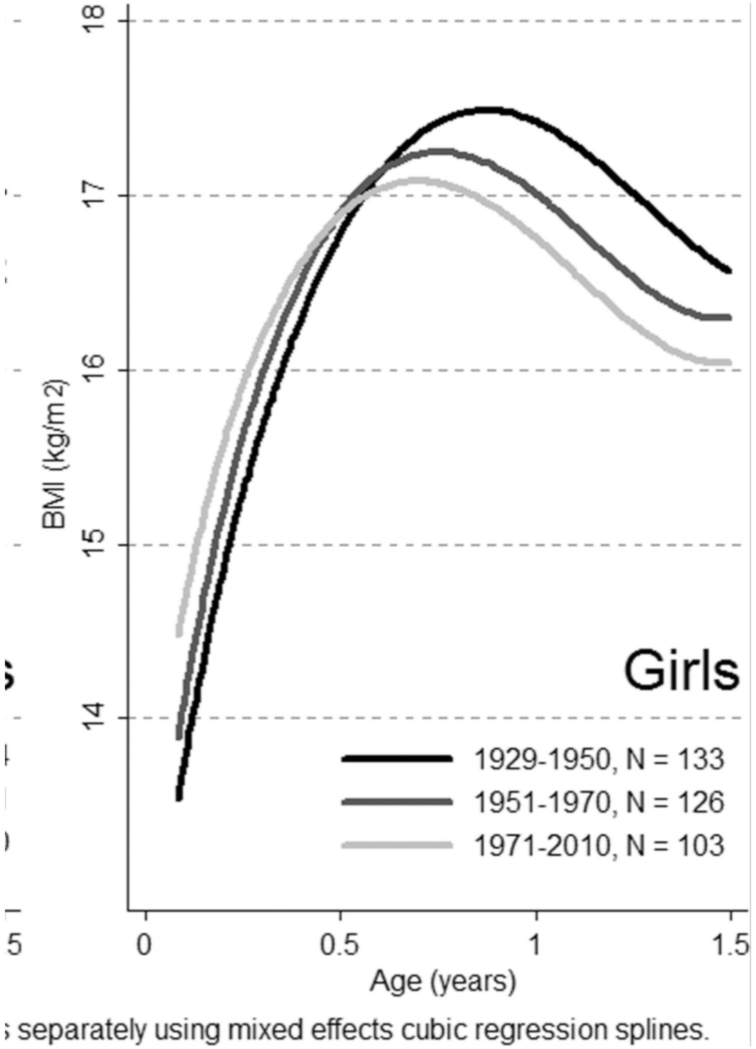


United States Body Composition Data



Wagner et al. Diabetes Care 27 November 2024; 47 (12): 2180–2188; Demerath and Fields. Am J Hum Biol. 2014 May-Jun;26(3):291-304

The infant BMI curve: population differences

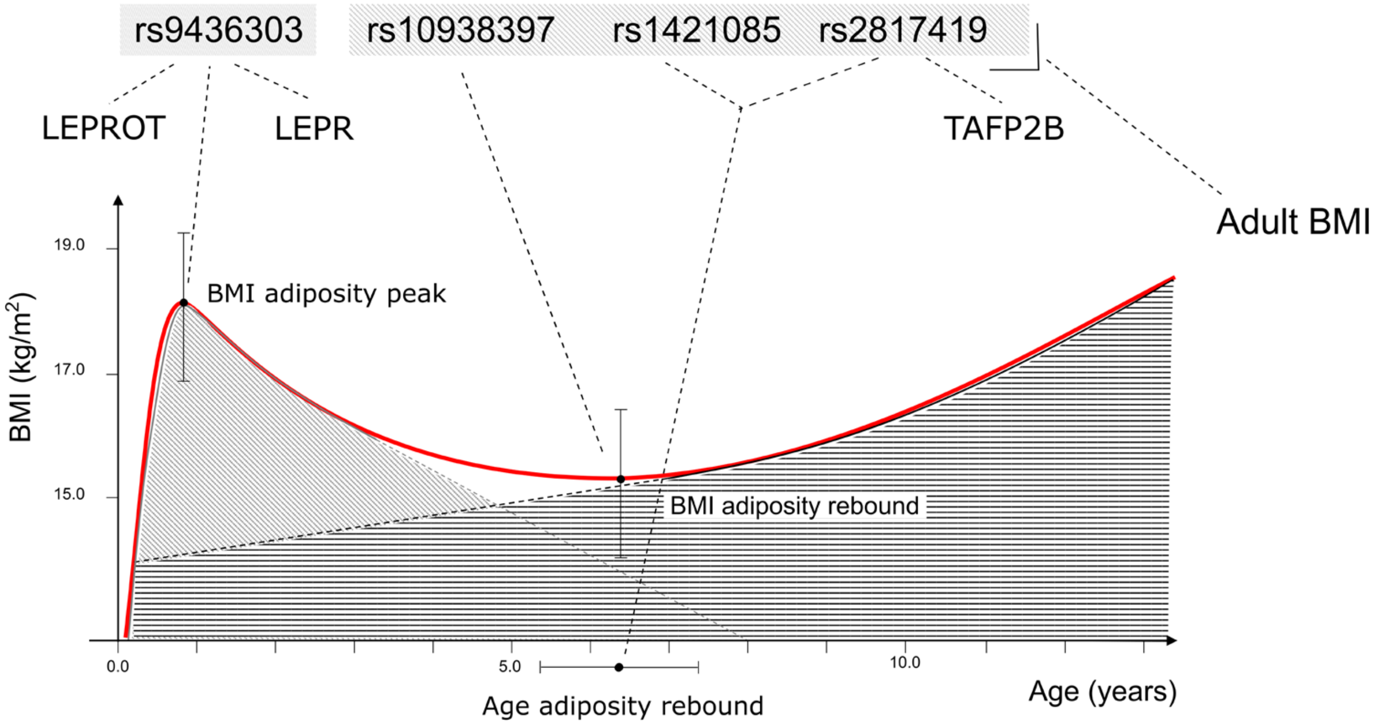


- Population differences in the timing, tempo, and magnitude of infant BMI growth suggest the optimal timepoints for assessment may vary

W. Johnson et al. AJHB 2013 ; 25(3): 378–388.

The infant – childhood BMI growth transition has a genetic basis

- Individual differences in timing and magnitude of the infant BMI peak are explained by genetic differences (high heritability)
- Genome-wide association study of individual infant BMI curve parameters suggest different sets of genes regulate BMI velocity and tempo in infancy vs early childhood and adulthood
- Clinical utility for discriminating unhealthy infant weight or BMI is not known



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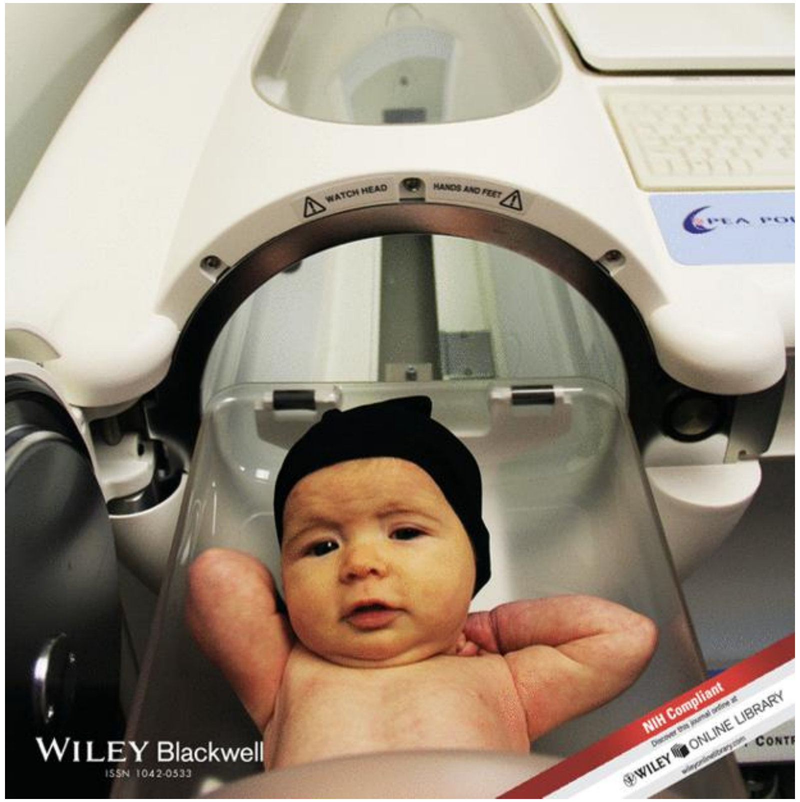
Couto Alves et al., Sci. Adv. 2019; ***5*** *: eaaw3095*

Infant body composition

- Infants exhibit very rapid tissue chemical composition changes (e.g. fat free mass hydration) and changing tissue deposition rates from 0-2 years, which is obscured by looking at weight and length and their changes.
- As obesity is, by definition, a condition of elevated adiposity, the obesity prevention research community has made large investments in refining methods to assess body composition in infancy and childhood to study its determinants and its potential to predict later obesity and other outcomes

How do we assess infant body composition?

- **Criterion 4-component model**
  - Total lipid mass, Total body water, Soft lean tissue mass. Bone mineral)
- **Simpler 2-3 component methods** are considered accurate from birth to 2 years
  - Deuterium dilution (DD)
  - Air displacement plethysmography (ADP)
  - Dual energy x-ray absorptiometry (DXA)



Ma et al., Am J Clin Nutr 2004; **79**: 653–660; Lyons-Reid et al., Clin Obes. 2021; 11:e12441; Wells et al., Eur J Clin Nutr. 2020;74:141–8. Demerath and Fields Am J Hum Biol. 2014;26:291–304.

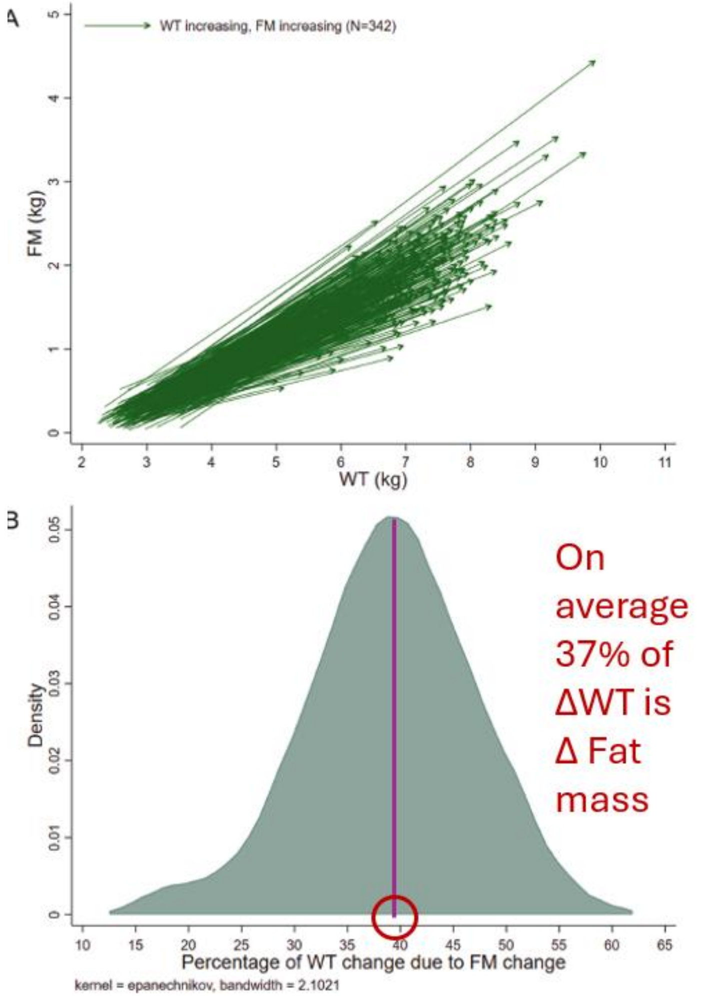
Recent focus on developing infant body composition reference charts

- International body composition references (0-24 months) created from children from 7 countries who grow like the WHO charts using ADP and DD
  - Fat mass and Fat-free Mass (kg)
  - Fat mass index and fat-free mass index (FMI)
  - Fat as a percent of body weight
- Body composition reference charts for term and preterm infants (30 weeks gestation-6 months) from 3 countries according to gestational, postnatal, and postconceptional age using ADP

Murphy-Alford et al., 2025 Am J Clin Nutr 117 (2023) 1262–1269; Norris et al., 2019 Am J Clin Nutr. May 1; 109(5):1353-1360.

Does a change in weight indicate a change in fat mass?

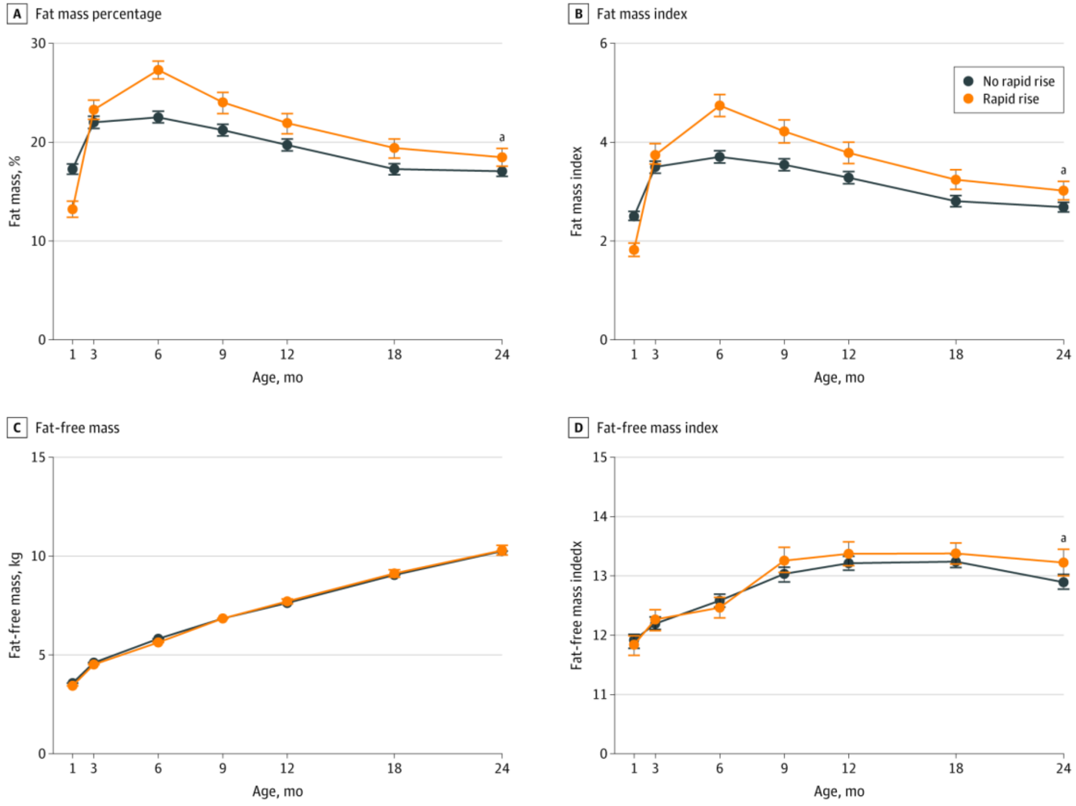
- Multi-centre international body composition charts (Murphy-Alford et al., 2023)
  - Adiposity assessed using ADP 0-6 mos
  - Rapid/slow weight gain defined: +/- 0.67 Z score change in WAZ against WHO standards from 0-6 months
- **Δ Fat mass comprised 37% of Δ weight,** on average, but with high inter-individual variation
- **Higher proportional fat gains among infants with rapid weight gain in first 6 months** (42%) than slow weight gain (35%)



Johnson et al., Eur J Clin Nutr (2025) 79:237–248;

Infants with rapid body fat gains 1-6 months display higher average adiposity through age 24 months

- Sophia Pluto Cohort Study (Netherlands)
- Longitudinal total body composition (ADP, DXA)
- Rapid increase in adiposity (ΔFM% > 0.67 Z, internal) **between both 1-6 and 3-6 months** was associated with higher FM% and FMI up sustained to 24 months
- No differences in fat-free mass
- Waning difference over time



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De Fluiter et al., JAMA Pediatr. 2020;174(12):1141-1148.

Infant fat mass and later child and adolescent health outcomes: a systematic review

- 30 studies mostly in healthy term infants with outcomes ages 2-16 y
- Higher FM in infancy was associated with higher FM and BMI at later ages in seven studies and no relationship in 3 studies
- Research on relationship of infant fat mass to other health outcomes (dyslipidemia, cognitive function) is lacking

Table 2 Overview of the associations between infant fat mass and later health outcomes and health biomarkers

Health outcomes	Fat mass/adiposity in infancy		
Outcome Variable	Increase	No relationship	Decrease
FM	7[35, 22*, 36, 37, 38, 26, 39]	3[22**, 6†, 40]	
FFM	1[6]	2[37, 35]	
BMI	5[41, 36‡, 26, 42, 40§]	3[36‡, 43, 40§]	
Blood pressure	2[25, 27]	5[44, 25, 24, 6, 27¶]	
T1DM		1[45]	
Adiponectin		1[22]	
Resistin		1[22]	
Leptin	1[22]		
Fasting glucose	1[25]	2[6, 26]	1[37]
Insulin	1[25]	3[25, 6, 24]	
HDL	1[6]	1[24, 26]	1[37]
C-peptide		1[6]	
HbA1c		1[6]	
LDL	1[6]	1[26]	1[24**]
Triglycerides		4[25, 26, 6, 24]	
Total cholesterol	2[25, 6]	1[26, 24]	
HOMA-IR (insulin resistance)	1[25]	2[26, 6]	
Lung function and asthma		1[46]	
Cognitive function/ processing speed		1[26, 27]	
P100 Latency		1[27]	

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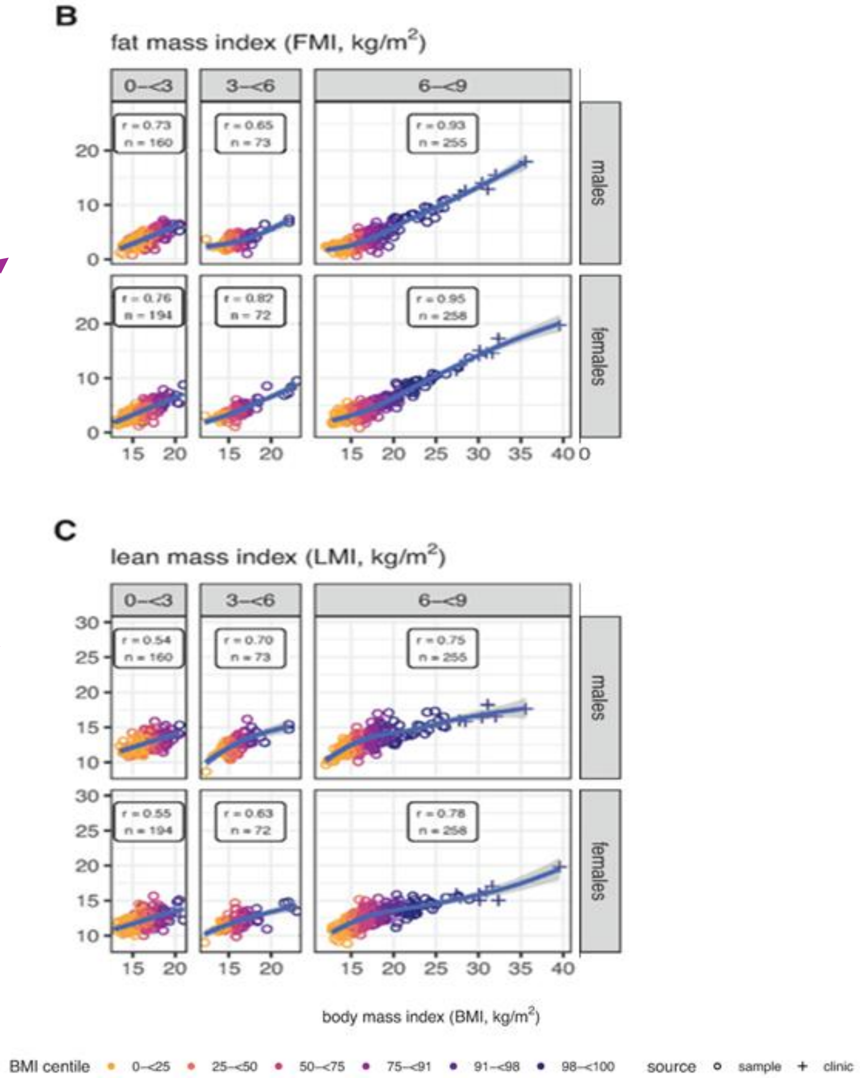
*Amati et al. Arch Dis Child 2024;**109**:125–129.*

Valid proxies for infant adiposity are elusive

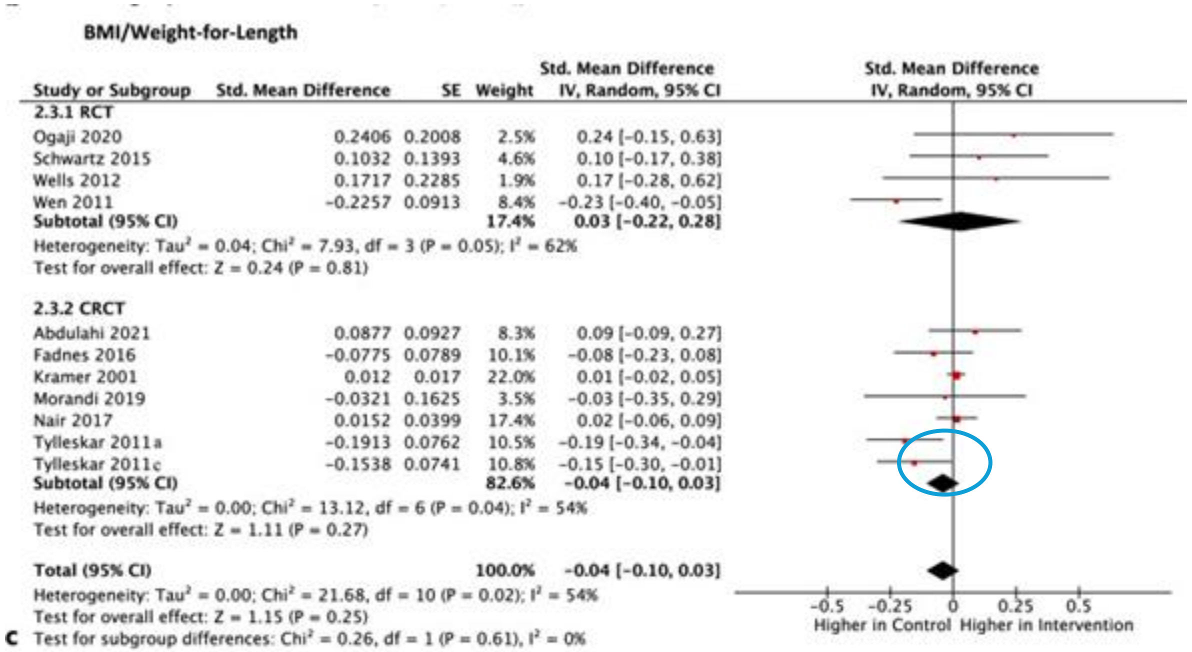
- It appears BMI-z or percentiles may be superior to WLZ for capturing infant adiposity, and there is a call for the US to adopt BMI-for-age growth curves for use in clinical practice
- However, there are normal age-related increases in size and relative weight during infancy and childhood, and this reflects orchestrated accrual of *both* lean (muscle, skeletal, and organ tissue) *and* fat tissue
- Thus, it should not be surprising that in childhood, anthropometric proxies like BMI are strongly positively correlated not only with adiposity (FMI), but also with lean mass (LMI), regardless of the method of measurement
- *This means individual anthropometric proxies (BMI, WLZ, etc) and more elaborate prediction models fail to provide valid indicators of adiposity, specifically, at the individual level*



Roy et al., J Pediatr. 2019 Jan;204:77-83.e1; Cauble et al., BMC Pediatr. . 2017 Mar 27;17(1):88. Wright et al., Am J Clin Nutr 2022;116:122–131; *Demerath and Fields. Am J Hum Biol. 2014 May-Jun;26(3):291-304.*

Relationships of infant feeding to infant adiposity

Systematic review of randomized breastfeeding trials suggests null relationship between breastfeeding and BMI, WLZ, and obesity



- 11 studies included weight, length and/or BMI outcomes
- Most were in low or middle countries
- No effect of breastfeeding promotion interventions on infant weight, length, or BMI/relative weight
- Few individual or group randomized trials of breastfeeding promotion with infant growth outcomes in high income countries including US

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Dib et al. Ann Nutr Metab. 2024;80(2):57-73.

In contrast, systematic reviews of observational studies continue to find inverse breastfeeding-obesity relationships

- **Obesity**: 3 existing systematic reviews and 25 individual cohort studies
  - Moderate strength of evidence for reduced risk
  - 4% reduction in the risk of early childhood obesity for every additional month of breastfeeding.
- **Rapid infant growth**: 3 existing reviews and 14 individual cohort studies
  - Low strength of evidence for reduced risk
  - Potential lower risk of accelerated growth and rapid weight gain in infancy and early childhood associated with breastfeeding
- **Needed**: Assessment of complexity of infant feeding behaviors (e.g., using infant cues vs scheduled feeds)

Patnode CD, Henrikson NB, Webber EM, et al. Breastfeeding and Health Outcomes for Infants and Children: A Systematic Review. Pediatrics. 2025;156(1): e2025071516

Beyond quantity to quality: human milk and formula composition

- Human milk composition is variable
  - Macronutrients
  - Hormones and cytokines
  - HMOs
  - Essential fatty acids
  - SCFAs
  - Micronutrients
  - miRNAs
  - Xenobiotics (e.g., PFAS)
- Increasing evidence that milk composition variation impacts infant growth and adiposity variation

- Formula market in the US is responding to demand for non-standard (cow-milk based) formulas
  - Reduced protein
  - Plant based
  - Partially/Extensively hydrolyzed protein
  - *Lactose-free*
  - *Reduced lactose*
- Some reports that infants consuming non-standard formulas have higher WLZ and BMI

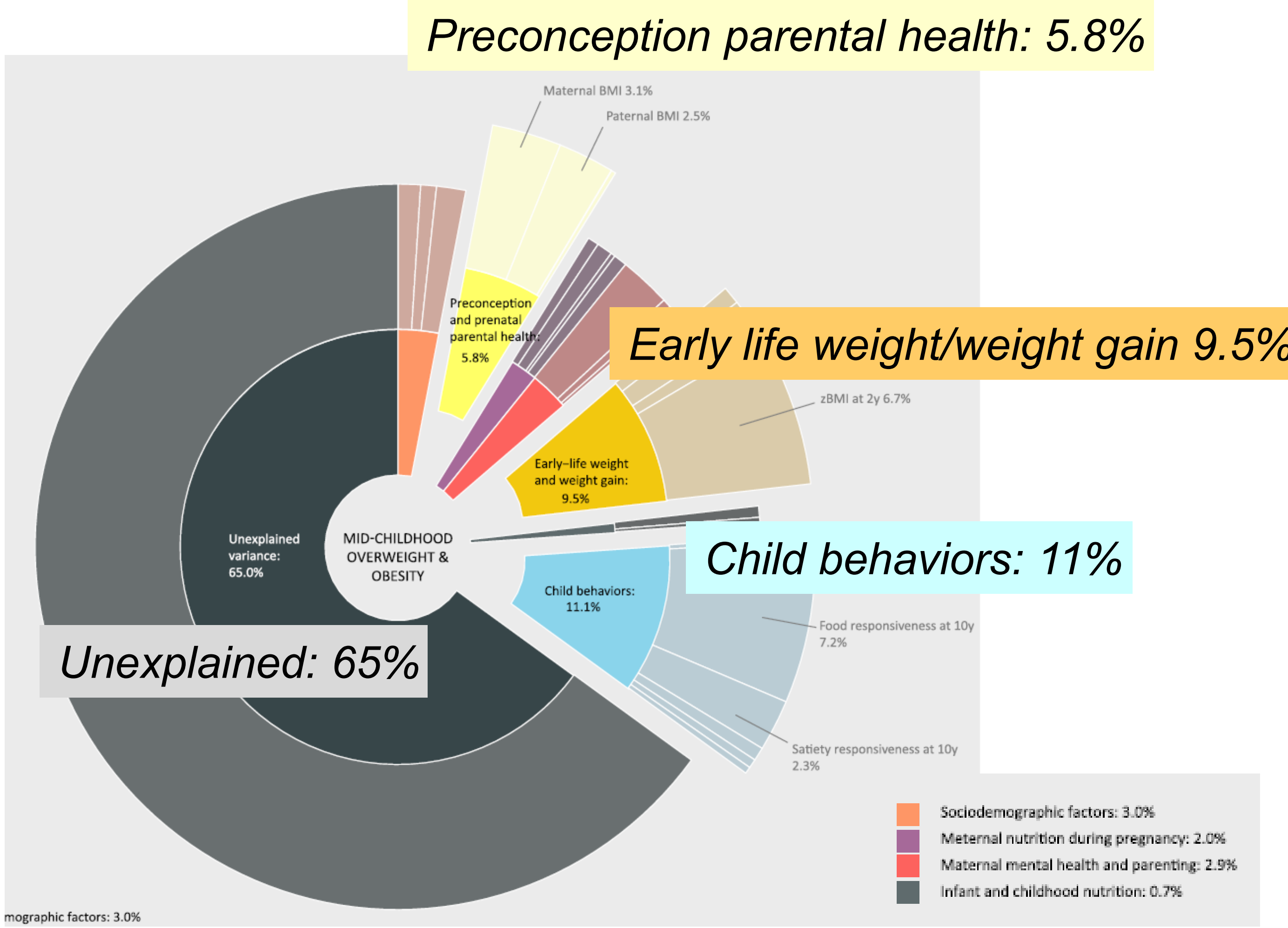
Anderson et al. Am J Clin Nutr 116 (4):1002-9; Rani et al., Nutrients. 2025 Sep 30;17(19):3111.

Brockway et al., Adv Nutr. 2024 Jan;15(1):100127; Brockway et al., Adv Nutr. 2024 Jan;15(1):100127. Strzalkowski et al. Clin Exp Allergy. 2022 Nov;52(11):1291-1301.

Are there additional factors that could stratify the risk of obesity among infants with rapid infant growth?

How well do early life risk factors capture childhood obesity risk?

- Generation R cohort data (N=5,698)
- Early life prediction modeling of obesity (BMI%>95, WHO) at age 10 years
- Many early life factors play a role, not only weight gain
- Total variance explained in odds of age 10 overweight / obesity:
  - 33.7%
- Severe childhood obesity is of primary concern for public health because it is rising and has the most severe health consequences; could focusing more on defining infant growth deviations that lead reliably to this outcome overcome prediction and efficacy?



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Mou et al., Obesity Reviews, 2025; 26:e13958;; Münte et al., JAMA Netw Open. 2025;8(7):e2521170; Smego et al., J Pediatr. 2017 Apr;183:87-93.

Conclusions

- The human life history strategy is marked by rapid infant adipose tissue gains, and subsequently slower growth velocities during an extended juvenile phase
- Much work has been done to develop accurate infant body composition methods, create reference data to aid interpretability of results, and has established moderately strong adiposity tracking from early infancy to early-middle-childhood
- Common anthropometric proxies (WLZ, BMIZ) and their changes, although positively correlated with adipose tissue levels, are not specific to adipose tissue, making individual-level estimation of fat or fat free mass erroneous.
- Use of measured infant body composition to predict future child health is thus problematic outside the laboratory but is nonetheless critical for understanding mechanisms and as an outcome for intervention studies.
- Breastfeeding has numerous benefits for infants and their nursing mothers, and numerous observational studies suggest it is associated with decreased childhood obesity, but clinical trial results cast doubt on the causal nature of these relationships.
- More work is needed on the impact of variations in formula and human milk *composition* as they relate to growth rate variation and future obesity and health

Thank you!

ORIGINAL ARTICLE
Pediatric Obesity

Obesity A Research Journal THE OBESITY SOCIETY WILEY

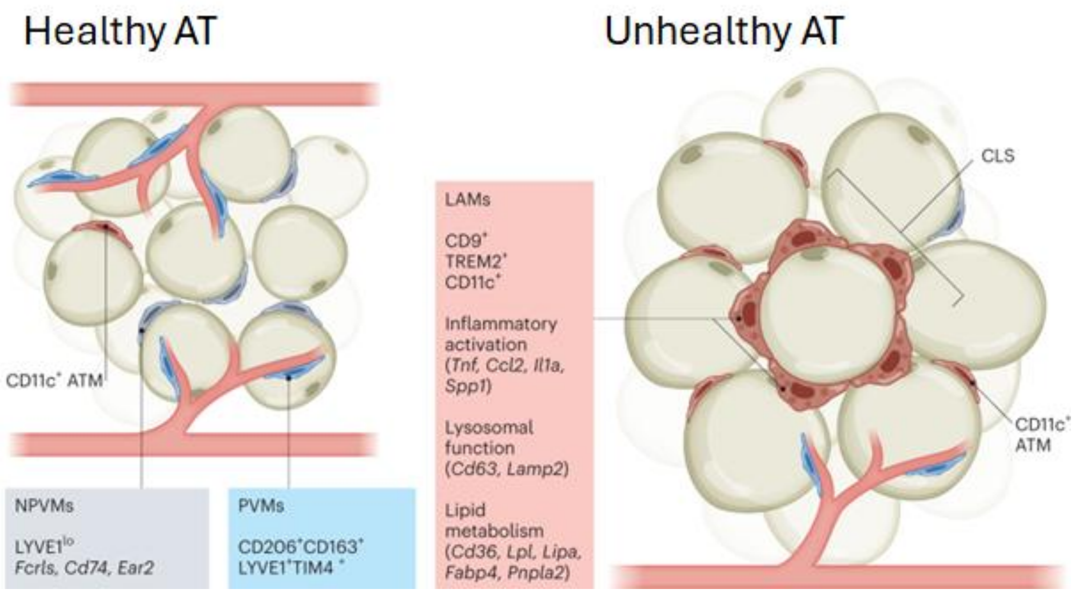
Rapid infant weight gain or point-in-time weight status: Which is the best predictor of later obesity and body composition?

- Regardless of RIWG metric or age interval, positive predictive value for obesity at age 11 was low (<30%) and sensitivity was typically <50%
- Little consistency in the associations between RIWG and later BMI, FMI, or LMI, with no statistically significant differences for most time points examined, regardless of metric used.
- By contrast, BMI status at the end of each time point was consistently associated with 1.9- 2.5-kg/m^2 higher BMI and 1.1-1.5-kg/m^2 higher FMI at 11 years of age for every time point examined.
- Higher AUC and aOR for point in time obesity status than RIWG
    - Higher F statistics for head-to-head models suggested greater predictive power for BMI and FMI at all timepoints

Taylor et al., Obesity (Silver Spring). 2023;31:2583–2592.

It isn't all about quantity: Adipose tissue function

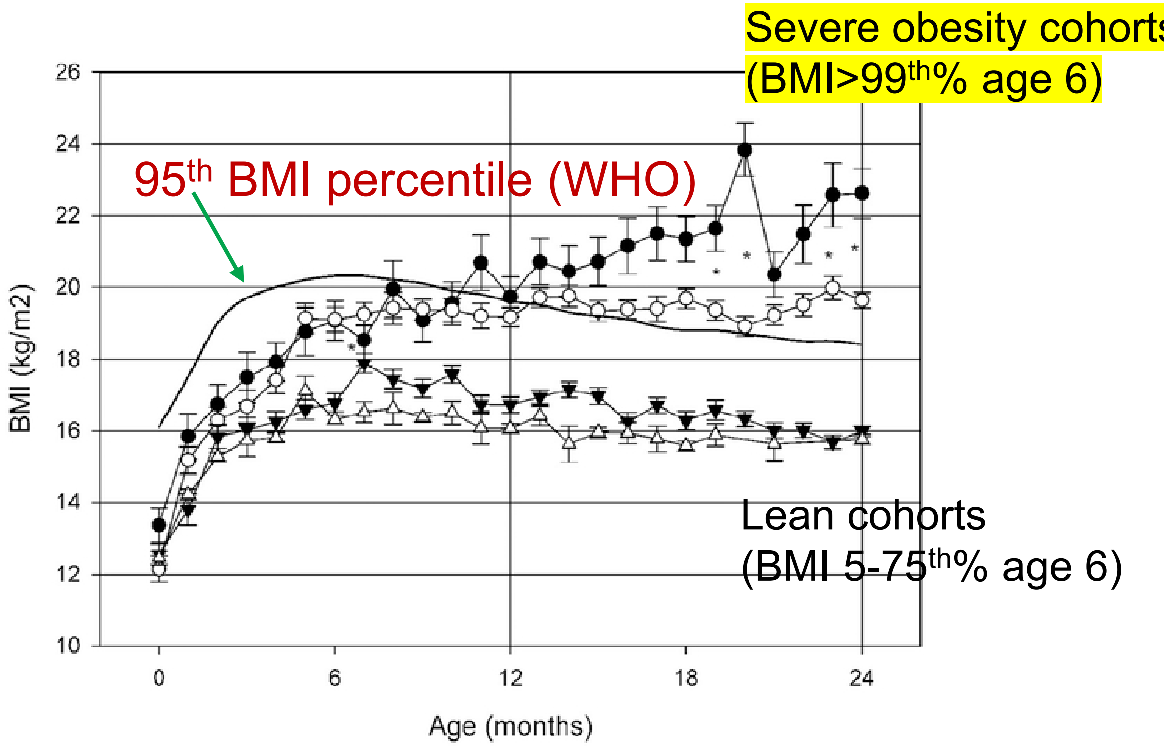
- As elevated body fatness increases and endures, adipose tissue changes in its cellular composition and immune cell function, with development of crown-like structures (CLS)
- These changes are already evident in children at high BMI
  - Greater number of adipose tissue CLS, collagen levels and other changes in children in overweight and obese category (Mujkic et al., 2023)
- We do not currently have noninvasive techniques to identify individuals with unhealthy adipose tissue



Mujkić et al. International Journal of Environmental Research and Public Health. 2021; 18(7):3627. Chavakis et al., Nat Immunol 24, 757–766 (2023).

Early detection of *severe* childhood obesity deserves more attention

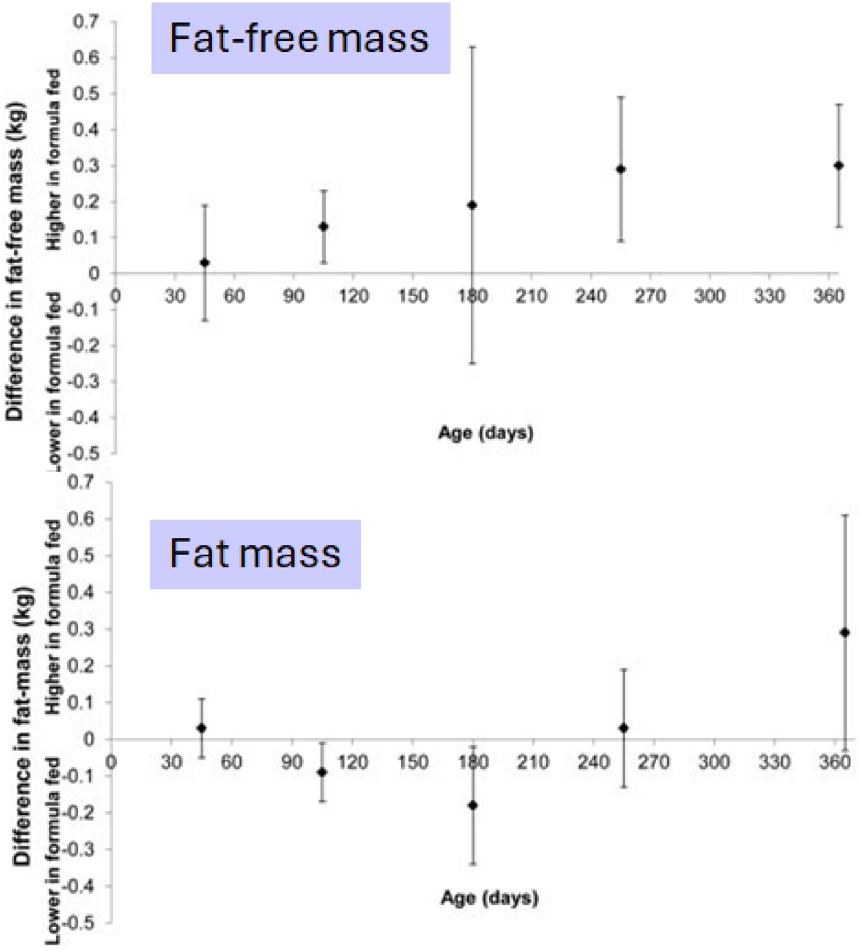
- Prevention of severe childhood obesity is of particularly great public health urgency
- Increasing prevalence of severe obesity in the US (Class 2 or higher- BMI>120% of the WHO 95th BMI for age and sex percentile) particularly in adolescents:
  - ~6% in 2008
  - ~8% in 2023
- Smego et al. (2017) tested whether infant BMI trajectories and obesity status in infancy predicted severe obesity (BMI>=99th percentile, WHO chart) at age 6
- **BMI growth pattern diverged by 4-6 months**
- **Later infancy BMI ≥ 85% and Weight for Length ≥ 85%** moderately sensitive (33-77%) and **highly specific (74-87%) for severe obesity** in early childhood



Münte et al., JAMA Netw Open. 2025;8(7):e2521170; Smego et al., J Pediatr. 2017 Apr;183:87

Influence of formula feeding on obesity and body composition

- Observational studies show protective effect of breastfeeding against excess adiposity
- 2012 systematic review meta-analysis (15 studies)
- Healthy, term (37-42 w.) infants 0-12 months of age
    - Formula-fed infants had lower fat mass (kg) and 1-2% lower body fat percentage than did their breastfed counterparts at 3–4 and 6 mo but this effect was no longer apparent at 12 mo, with a trend toward higher fat mass in formula-fed infants.
    - Formula-fed infants had higher fat-free mass throughout the first year of life than did breastfed infants



Gale et al. (2012) *Am J Clin Nutr.* 95 (3):656-669

NCCOR WORKSHOP

Revisiting Rapid Infant Growth: Assessing Growth in Children Under Age 2

Researchers in Rapid Infant Growth & Early-Life Obesity Risk – Biological Perspective: *Development of Eating Behavior*

Julie Lumeng, MD
University of Michigan

NCCOR

Eating Behavior in Infancy: Concepts

- Baby Eating Behavior Questionnaire
  - Food Responsiveness
  - Enjoyment of Food
  - Satiety Responsiveness
  - Slowness in Eating
- Sucking
  - Suck frequency
  - Suck duration
  - Burst duration
  - Amplitude
  - Smoothness
  - Variability
- Meal characteristics
  - Size
  - Duration
  - Frequency
- Homeostatic control
  - In response to change in feeding frequency
  - In response to change in caloric density
- Ability to delay gratification
- Reward value of food
  - Hedonic value of sweet taste
  - Soothing effect of sweet taste
  - Willingness to work for food
  - Food cue salience
- Eating in the absence of hunger
  - Amount eaten
  - Latency to eat
  - Bite size
  - Speed of eating
  - Eating engagement
  - Positive affect
  - Negative affect
  - Variety
- Nursing Child Assessment Feeding Scale
  - Clarity of cues
  - Responsiveness to caregiver

Eating Behavior in Infancy: Associations with Growth

- Baby Eating Behavior Questionnaire
    - **Food responsiveness**
    - **Enjoyment of food**
    - **Satiety responsiveness**
    - **Slowness in eating**
- **"Vigorous" sucking style**
- Meal characteristics
    - **Size**
    - **Frequency**
- Homeostatic control
    - **In response to change in caloric density**
- **Ability to delay gratification *(with intake)***
- Reward value of food
    - **Soothing effect of sweet taste**
    - **Willingness to work for food**
    - **Food cue salience**
- Eating in the absence of hunger
    - **Amount eaten**
    - **Negative affect**
- Nursing Child Assessment Feeding Scale
    - **Clarity of cues**

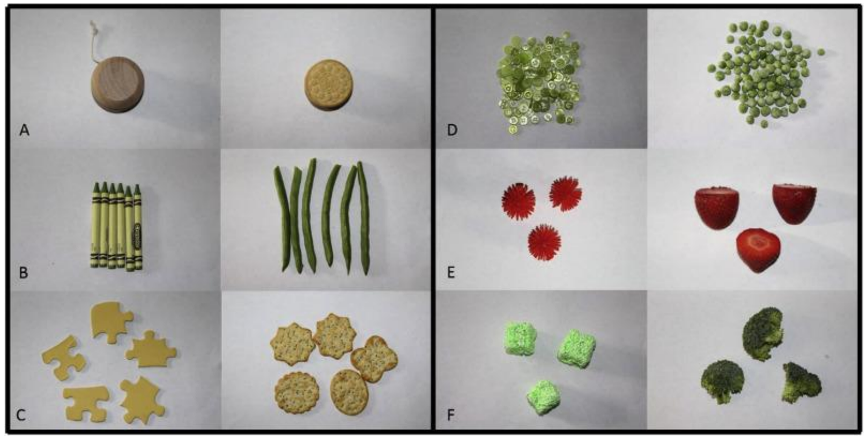
Green = positive association with growth
Red = negative association with growth

Eating Behavior in Infancy: Biological Contributors

- Sucrose
    - Analgesic effects
    - Hedonic effects
    - Moderator of face recognition
- Oxytocin
    - “Bonding hormone”
    - Appetite suppressant
- Cortisol
    - Stress hormone
    - Drives appetite
- Gastric capacity and emptying
- Genetics
- Sucking
    - Potential “signatures”
    - Prepotent sucking (opportunistic feeding)
    - Change in sucking pattern in response to milk emitted from nipple
- Blood glucose
- Cholecystokinin
    - Mediator of food learning
    - Calming, sedating
- Leptin
- Adiponectin
- Ghrelin

Approaches to Measurement: Salience of Food Cues

- Infants show preference for food vs. non-food stimuli
- Greater preference for food (vs. non-food) stimuli predicted by greater infant weight gain, greater food responsiveness, and formula feeding



Buvinger et al, *Appetite*, 2017

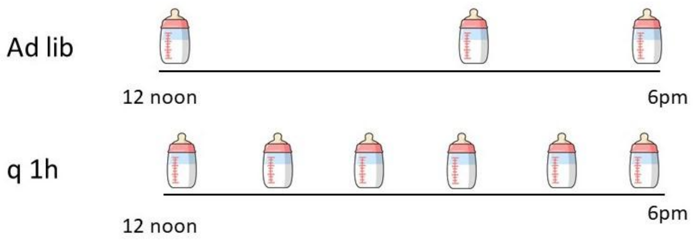
Approaches to Measurement: Analgesic Effects of Sucrose and Weight Gain

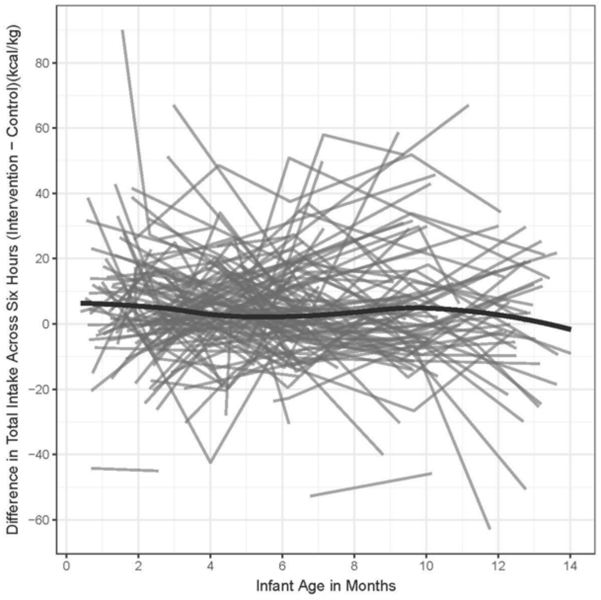
- Videotaped response to sucrose during newborn heelstick
- Stronger analgesic effect of sucrose predicted greater future weight gain

Lumeng et al, *Appetite,* 2020

Approaches to Measurement: Regulation of Energy Intake in Response to Feeding Frequency

- Infants fed ad lib or every one hour for 6 hours
- Infant ate ~5kcal/kg more over 6 hours when offered feedings more frequently.
- Stable throughout infancy

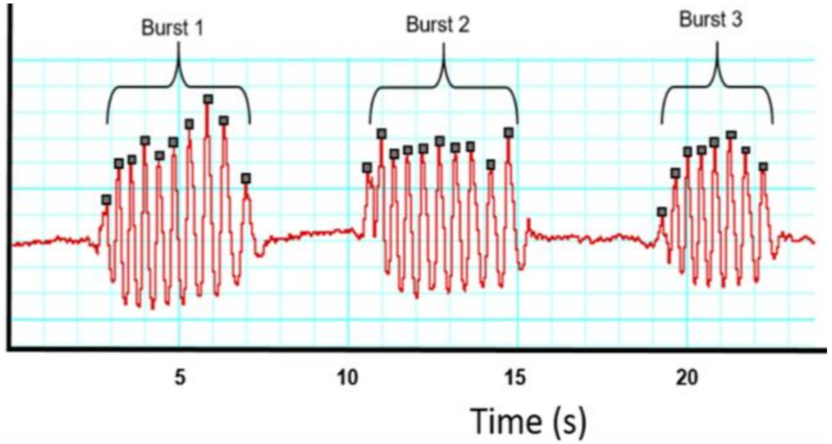




Reynolds et al, *JAMA Pediatrics,* 2023

Approaches to Measurement: Willingness to Work for Food in Infancy

- More (vs. less) challenging nipple reduced intake, increased suck pressure, shortened burst duration, and lengthened feeding
- Greater willingness to work for food predicted more weight gain



Lumeng et al, *Appetite,* 2020

Approaches to Measurement: Ability to Delay Gratification for Food in Infancy

- Two waiting periods: pre-feeding and mid-feeding pause
- From birth to 4 months, pre-feeding distress decreases and mid-feeding distress increases.
- Intake does not correlate with distress until 4 months.

Stein et al, *Frontiers in Nutrition,* 2020

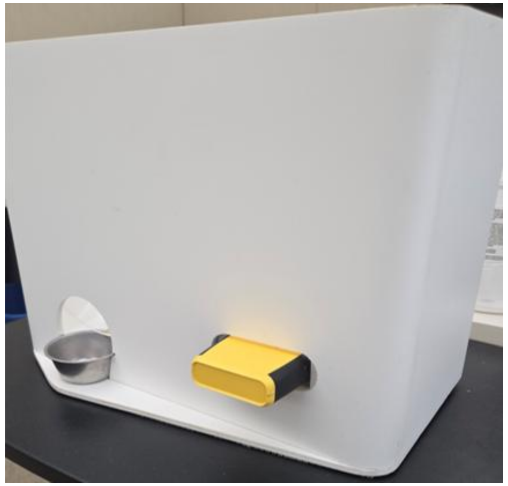
Approaches to Measurement: Eating in the Absence of Hunger

- Intake was positively associated with variety, eating duration, rate, and engagement, and bite size.
- Intake and avidity for eating dessert were predicted by enjoyment of food and dietary sweets intake.
- Intake was predicted by food-related tantrums.

Asta et al, *Appetite,* 2025

Approaches to Measurement: Relative Reinforcing Value of Food

- By 12 months (but not 9 months), relative reinforcing value of food was positively associated with food reinforcer consumption and enjoyment of food.
- By 12 months (but not 9 months), absolute reinforcing value of food was positively associated with WLZ.



Crandall et al, *Appetite,* in press

Summary

- Infant eating behaviors appear to be trait-like, show individual differences, and have predictive value for growth.
- Infant eating behaviors may be early indicators of risk of rapid weight gain and could be intervened upon before weight gain manifests.
- The biological and environmental contributors to infant eating behaviors require substantial additional study.