

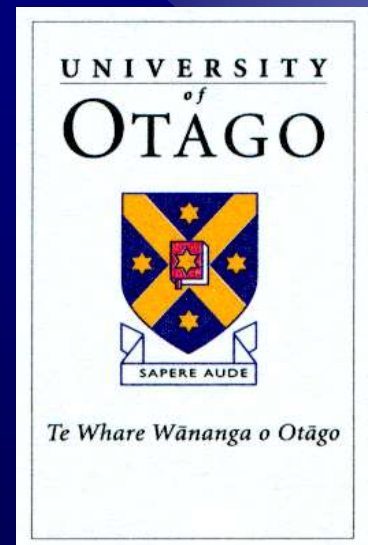
# Growth at Adolescence

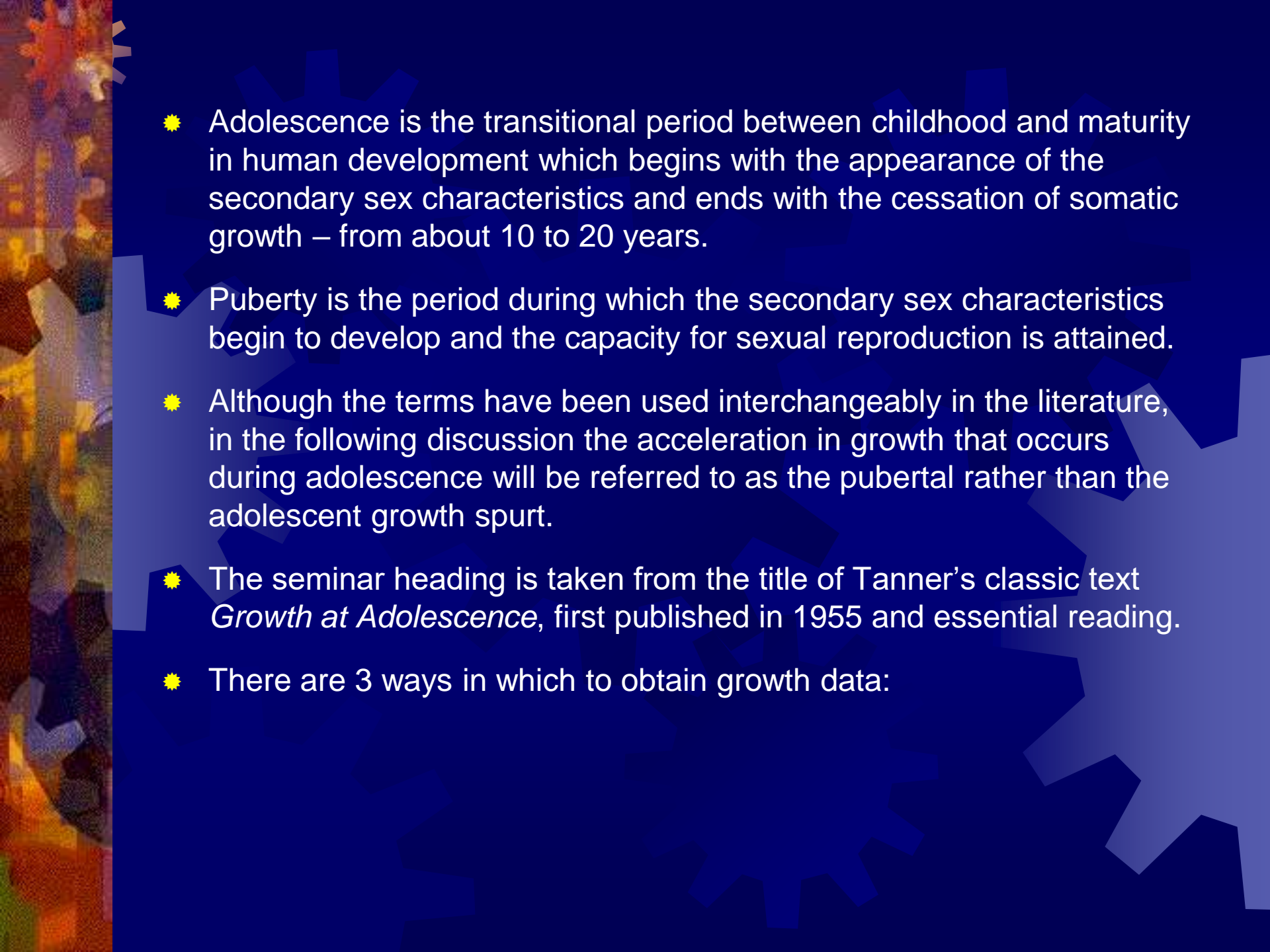
By Murray C Meikle

Biological Foundations of Orthodontics  
and Dentofacial Orthopaedics

Seminar 8

2004

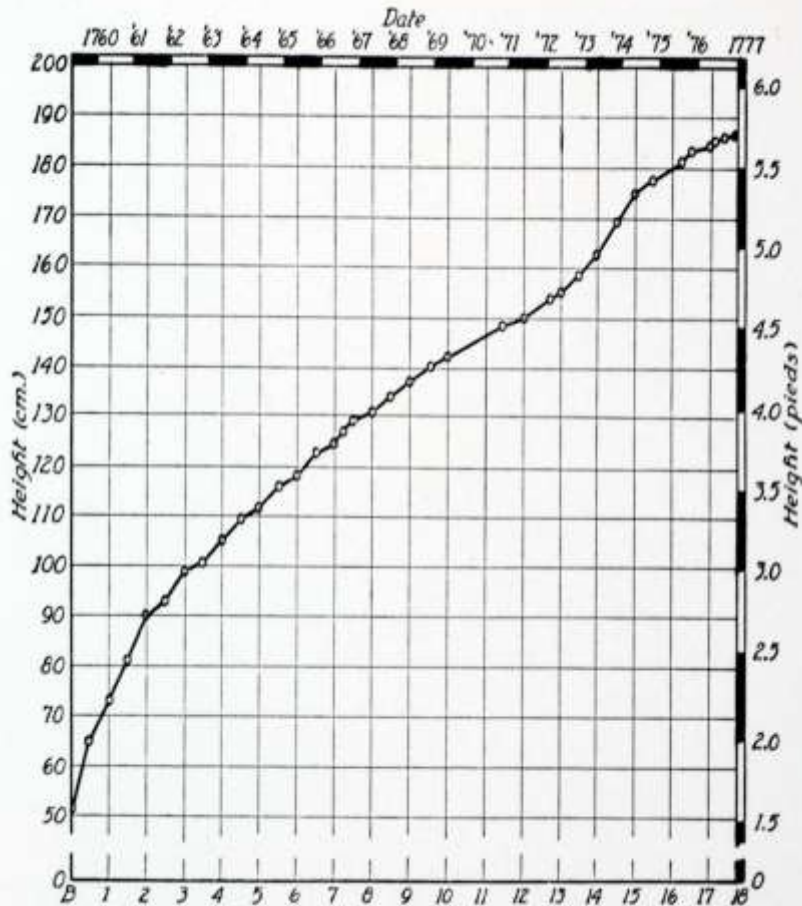


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- Adolescence is the transitional period between childhood and maturity in human development which begins with the appearance of the secondary sex characteristics and ends with the cessation of somatic growth – from about 10 to 20 years.
  - Puberty is the period during which the secondary sex characteristics begin to develop and the capacity for sexual reproduction is attained.
  - Although the terms have been used interchangeably in the literature, in the following discussion the acceleration in growth that occurs during adolescence will be referred to as the pubertal rather than the adolescent growth spurt.
  - The seminar heading is taken from the title of Tanner's classic text *Growth at Adolescence*, first published in 1955 and essential reading.
  - There are 3 ways in which to obtain growth data:

# Methodology

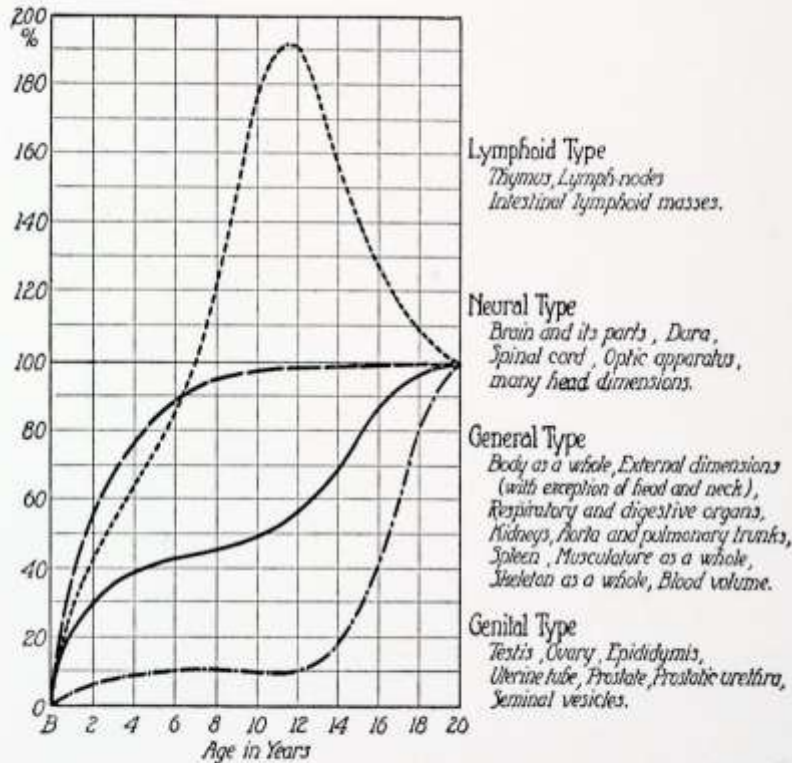
- ✿ Cross-sectional studies are concerned with growth at the population level rather than the growth pattern of the individual. Since it is not possible to measure everyone, a cross-sectional survey is limited to a sample or subset of the population chosen at random. This means that sampling can be done in a relatively short period of time. To construct national standards a random sample of 1000 boys and 1000 girls at each age group is required.
- ✿ Longitudinal studies involve the measurement of the same individual over a number of years. This will take several years to complete, is expensive and some participants will drop out of the programme. However, the data they provide is essential to construct growth velocity curves and to identify individual variation in growth rate.
- ✿ The third type of growth study is the mixed-longitudinal. This is a combination of cross-sectional and longitudinal methods; in practice this means that subjects at different ages are studied longitudinally for shorter periods (say 3–4 years), which can then be added to each other.

# Montbeillard's son



- The first longitudinal study of human growth was made by Comte Philibert Guéneau de Montbeillard, who measured the height of his son from birth to 18 years. It was published by George-Louis Leclerc, Comte de Buffon in the fourth supplement to Buffon's *Histoire Naturelle* (1777).
- The figure shows four stages: (1) a period of rapid increase during infancy and early childhood; (2) a middle period from 3 to 12 in which growth is constant; (3) acceleration around puberty from 12 to 15 years; and (4) a terminal period of slow increase.
- From Scammon (1927). *American Journal of Physical Anthropology* **10**, 329–336.

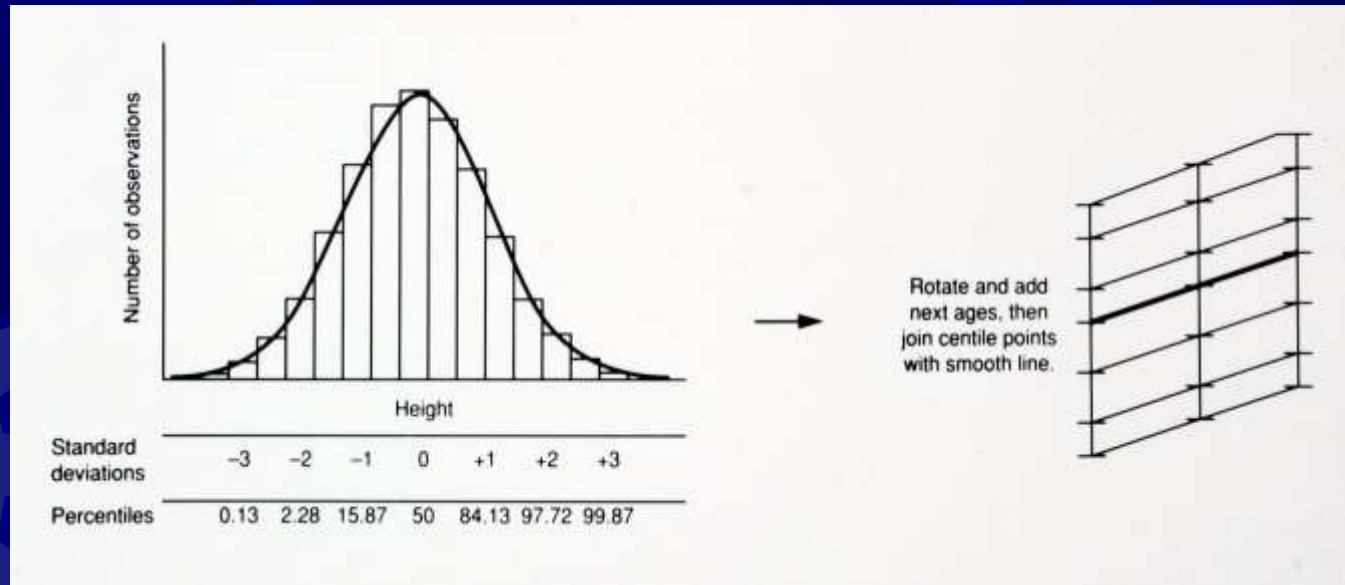
# Scammon's growth curves



From Scammon (1930). In: *The Measurement of Man*. pp175-215.

- To understand the various patterns of postnatal growth, Scammon reduced the growth of the human body to four basic curves.
- Lymphoid tissues show a rapid growth in infancy to an apex at puberty and a decline thereafter.
- The brain and its membranes, spinal cord, eye and its muscles plus the cranial vault exhibit neural growth.
- The general type follows a sigmoid or S-shaped curve.
- The genital type of growth shows a slight increase in infancy, a latent period of about 10 years followed by rapid growth at puberty.

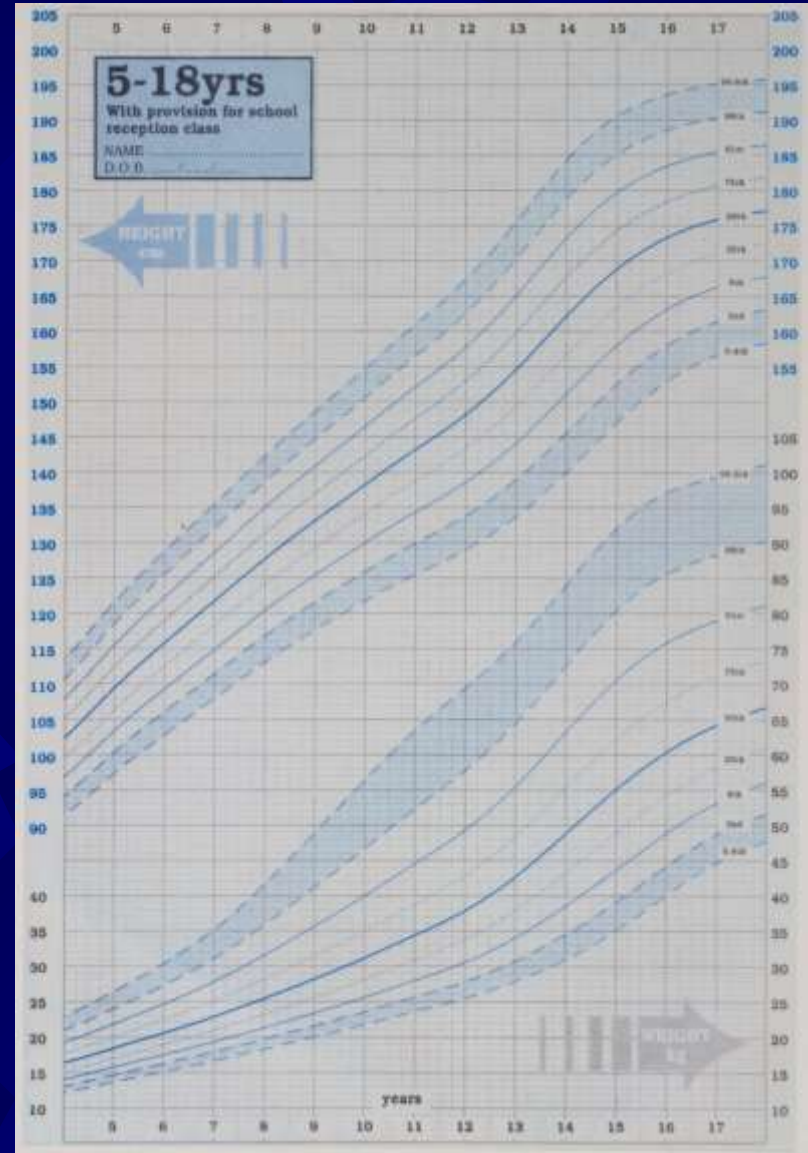
# Growth standards and growth curves



- Standards for height and weight are available for many populations worldwide. They were developed to determine if the physical growth of a child is within normal limits for age, sex, population, and social class.
- Height is normally distributed throughout the population to form the familiar bell-shaped or Gaussian curve. Percentiles are calculated and related to the SD as shown. The percentile plots are then rotated by 90 degrees to provide one age/percentile distribution, and the process repeated for each age group to produce the charts shown overleaf.
- From Wales (2002). *Clinician's Guide to Growth Disorders*.

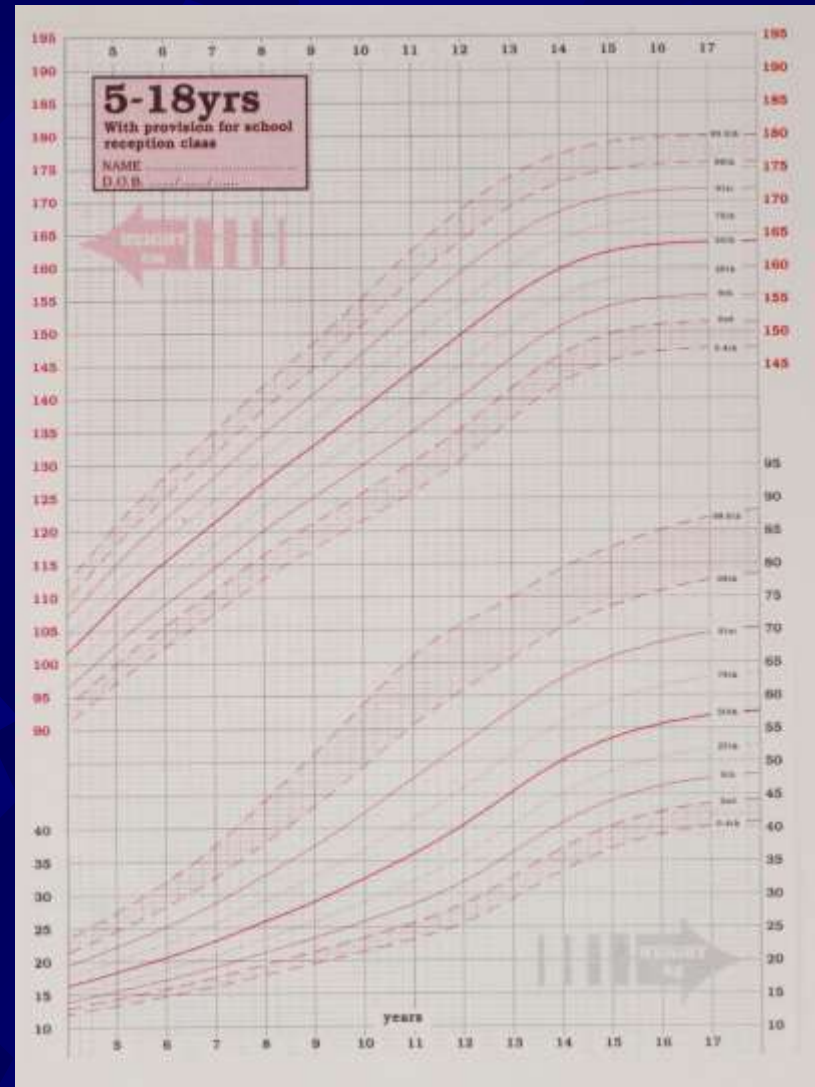
# UK90 growth curves

- Most clinicians will be familiar with the Tanner–Whitehouse growth charts first published in 1966. However, because of the secular trend towards earlier maturity and increasing height, these are now obsolete. The Buckler–Tanner update (1995) of these standards does allow for the secular trend, and are very similar to the UK90 growth charts shown here.
- UK90 growth chart for boys are currently recommended for use in the UK. These are based on cross-sectional data collected between 1978 and 1990.
- Courtesy of the Child Growth Foundation.

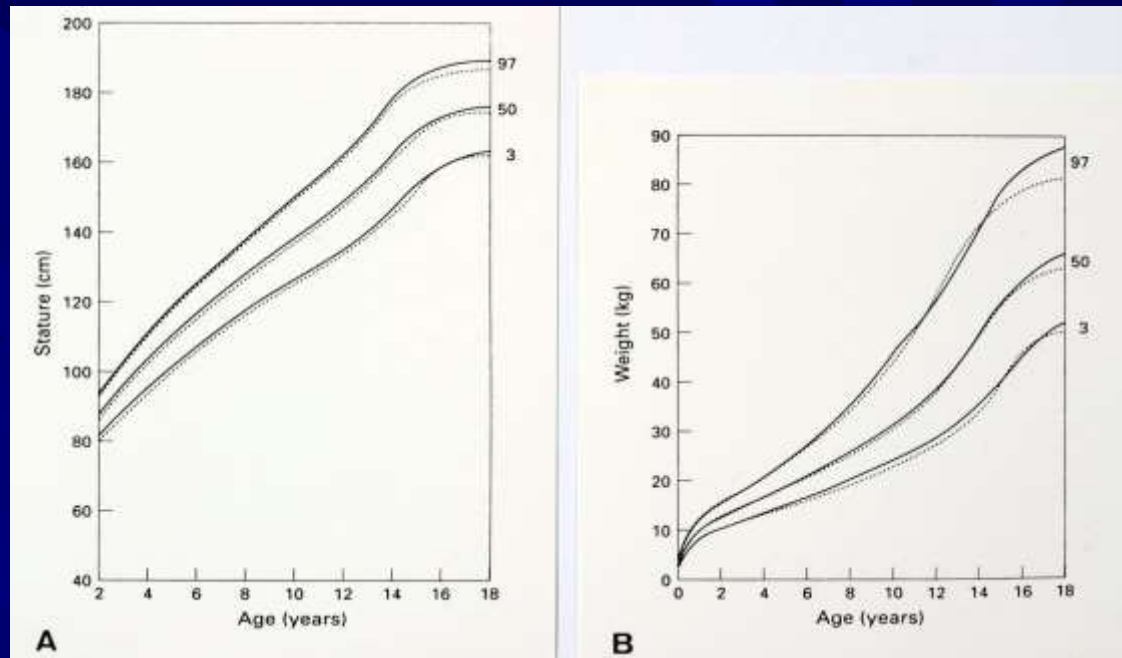


# UK90 growth curves for girls

- There are nine height percentile lines and since height is normally distributed are equally spaced approximately two-thirds of a SD apart.
- Weight is not normally distributed in either the male or female samples as there are more heavy individuals in any given population (a trend that on present evidence is likely to continue); the percentile lines are therefore unequally spaced.
- Courtesy of the Child Growth Foundation.



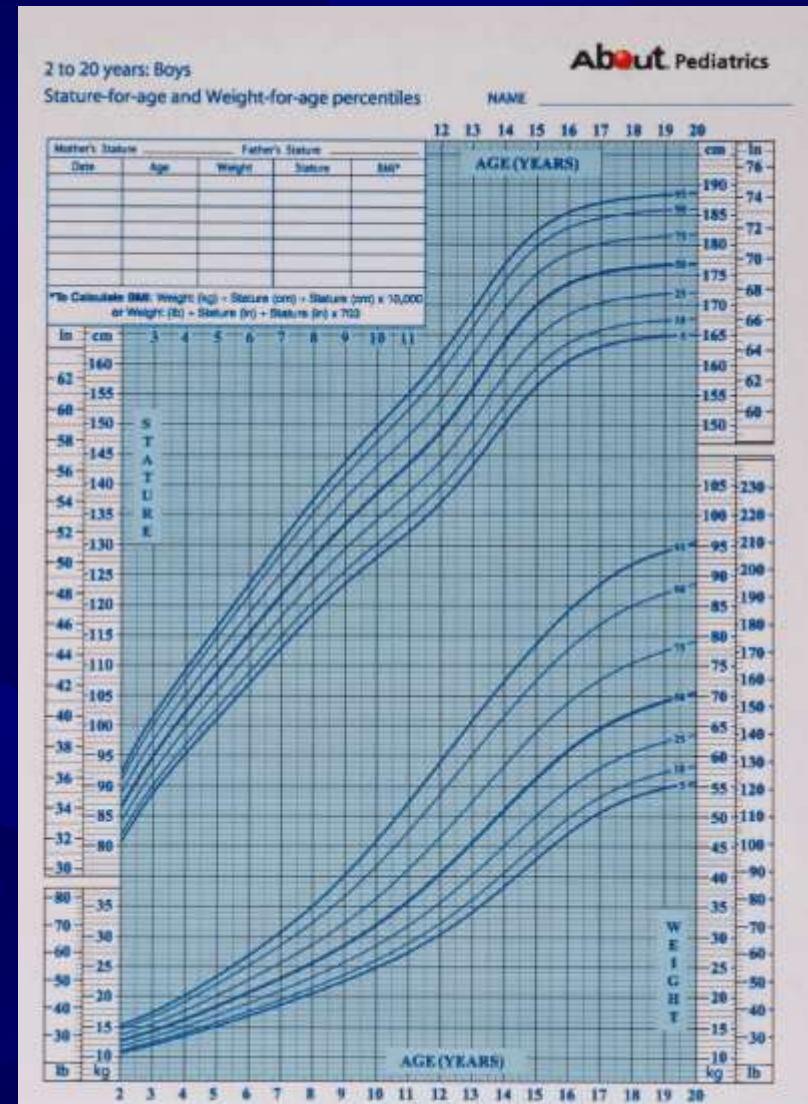
# Tanner-Whitehouse and UK90 growth curves



- For boy's stature, the 1990 50th percentile is greater than the Tanner-Whitehouse standards at all ages, the smallest difference being 0.8 cm at 16 and the greatest 1.7 cm at age 18.
- There was an increase in weight overall; the 50th percentile for UK90 for example, was greater at all ages after 2 years with a difference at age 18 of 3.2 kilograms.
- From Freeman *et al.* (1995). *Archives of Disease in Childhood* 73, 17–24.

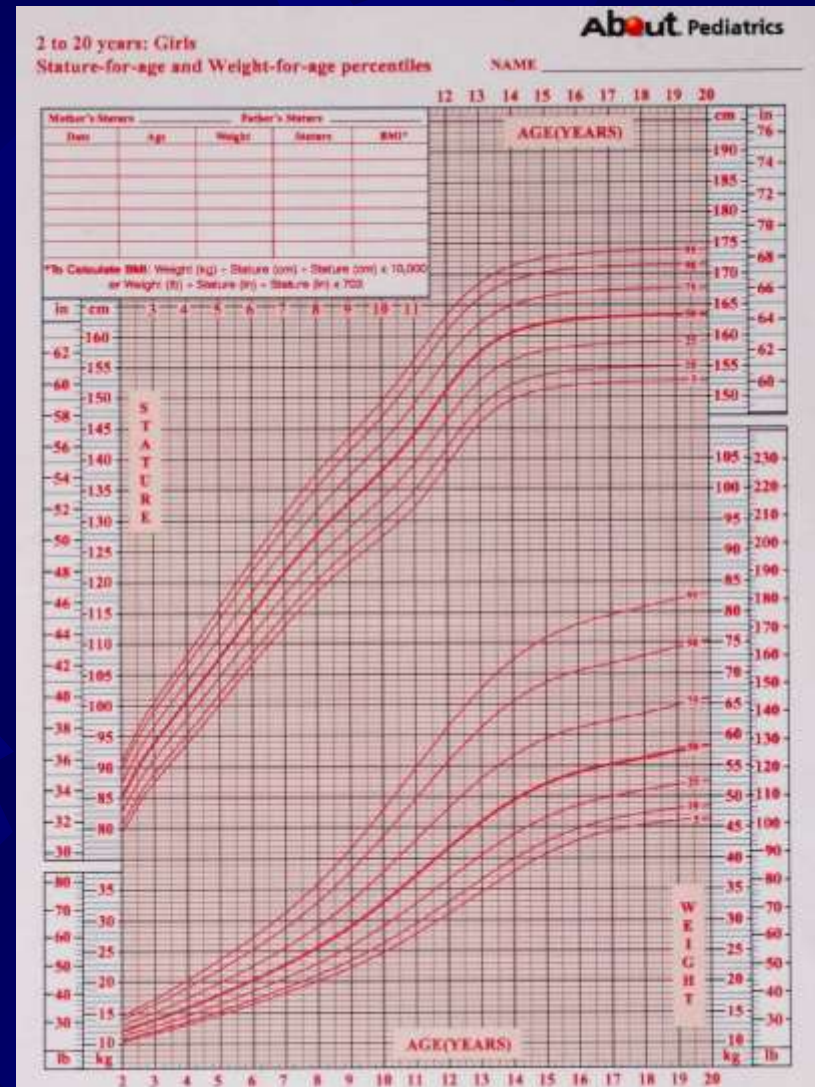
# CDC 2000 growth charts

- In the US growth charts were developed by the National Center for Health Statistics in 1977, and were based on a cross-sectional study of children from 1971 to 1974.
- The 2000 CDC (Center for Disease Control and Prevention) growth charts represent the revised version of the 1977 NCHS data.
- At 17 the average height (50<sup>th</sup> percentile) for boys is 175 cm compared to 176 cm in UK90; the average weight at 17 is 65 kg compared to 64 kg in UK90.
- These growth charts can be downloaded from the NCHS website ([http://www.cdc.gov/growth\\_charts](http://www.cdc.gov/growth_charts)).



# CDC 2000 growth charts for girls

- At 17 the average height for girls in CDC 2000 is 163 cm compared with 164 cm in UK90; the average weight is 55 kg compared to 57 kg for UK90 and again is not normally distributed.
- There are seven height and weight percentile lines compared to nine in UK90.
- Developed by the National Center for Health Statistics in collaboration with the Center for Disease Control and Prevention.

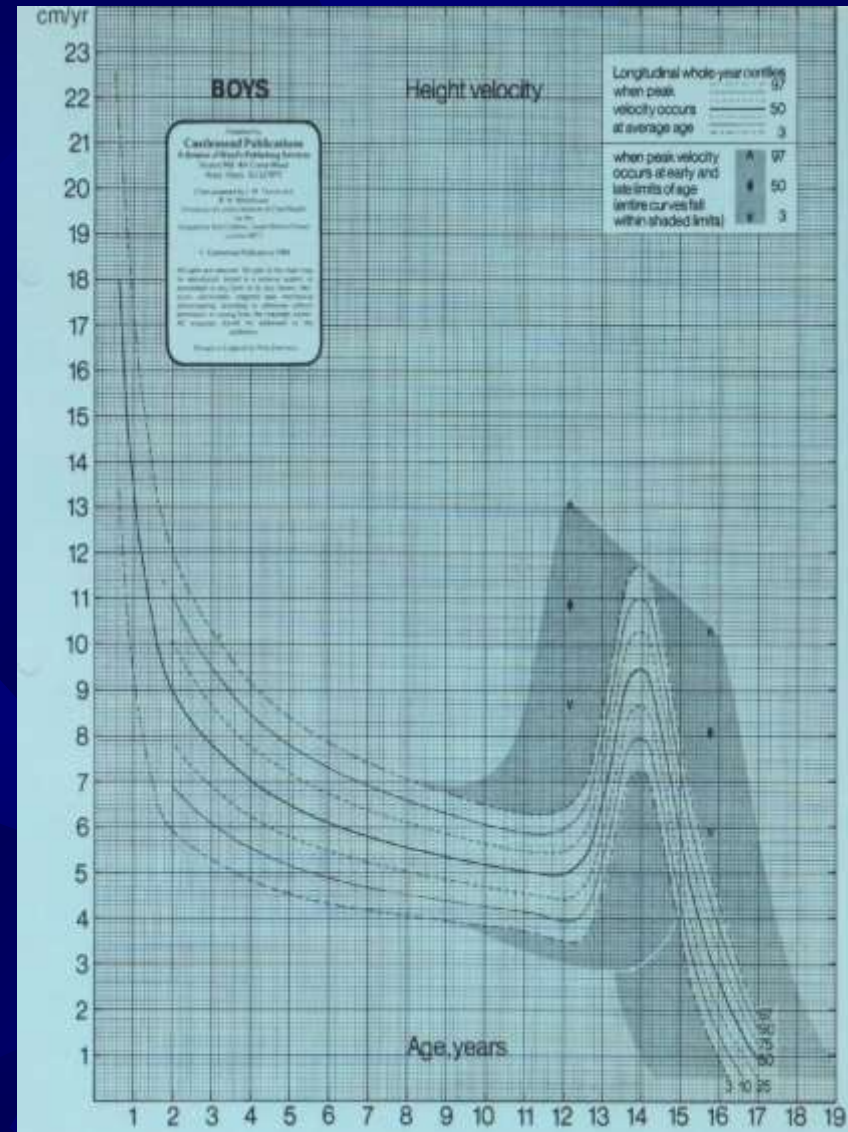


# Height velocity charts

- ✱ The percentile curves on height charts are useful for evaluating the cumulative or attained height of a child at a given age in the population at large, but do not reveal the distinctive features of pubertal growth. The dynamics of pubertal growth are best represented by height velocity charts.
- ✱ These are constructed from longitudinal observations conducted on a relatively small number of individuals by plotting increase in height per annum against age.
- ✱ Such studies are time-consuming and costly. The data on which the currently available charts in the UK are based was collected by Tanner and Whitehouse from the Harpenden Growth Study in the 1950s, and consisted of measurements of height made on 49 boys and 41 girls. It is clearly out of date.

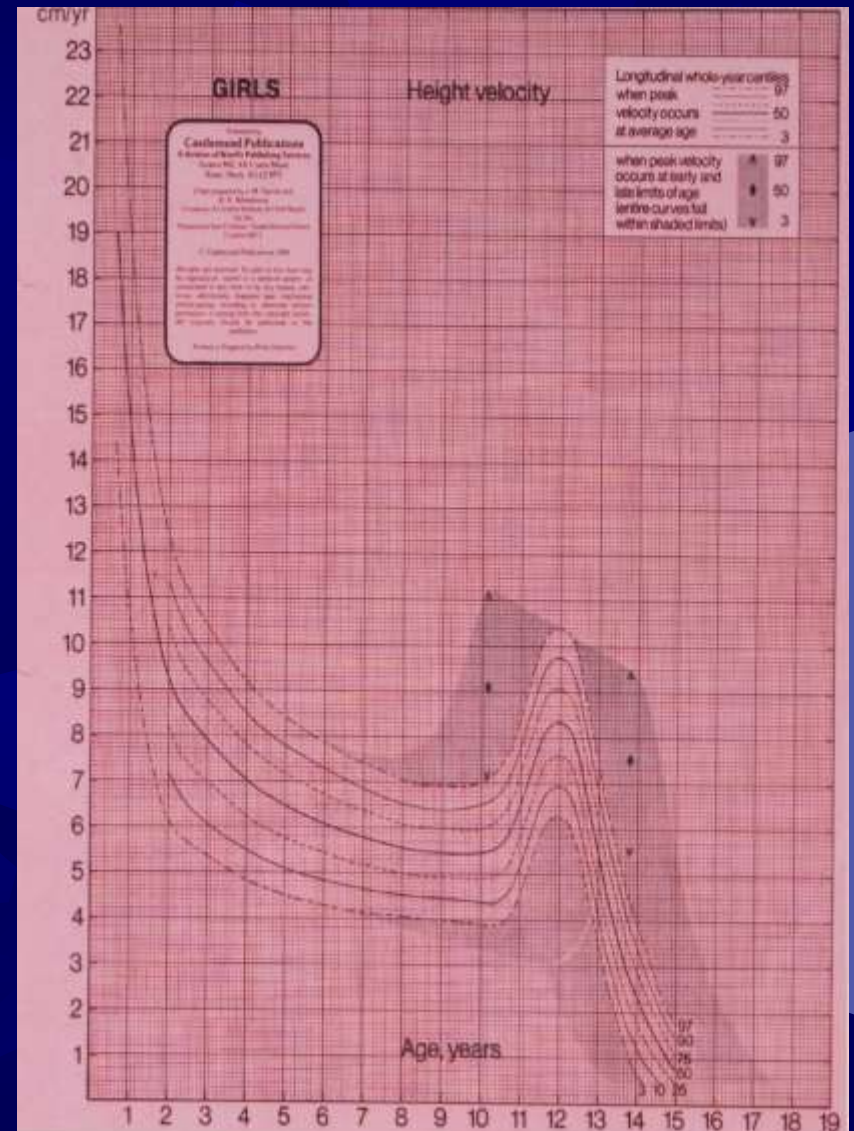
# Height velocity charts for boys

- Since that time there has been a secular increase in height of 1.7 cm. However, spread over 18 years this difference is unlikely to produce significant changes in the Tanner–Whitehouse height velocity charts, making them still broadly applicable.
- Pubertal growth characteristics that can be quantified from HV charts include: age at takeoff (onset of growth acceleration); age at peak height velocity; peak height velocity; duration of puberty; and the contribution of pubertal growth to final adult height.
- From Tanner and Whitehouse (1976). *Archives of Disease in Childhood* **51**,170–179.



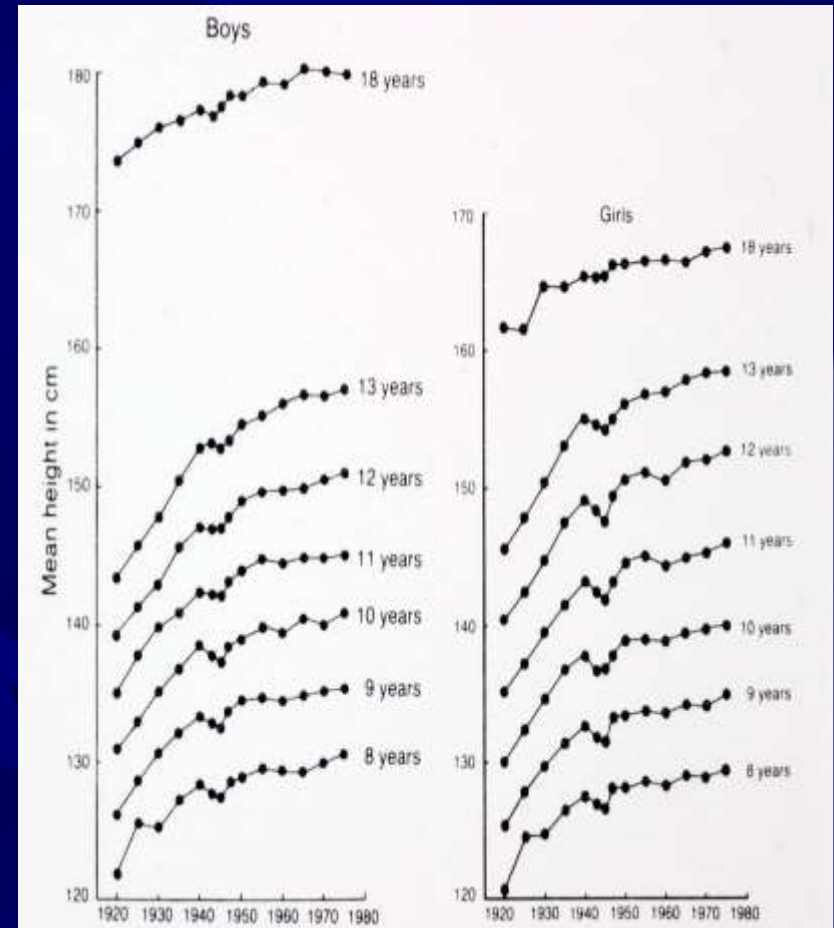
# Height velocity charts for girls

- Peak height velocity for girls in the Harpenden Growth Study occurred at a mean age of 12 years; this was 2 years earlier than the boys and represents sexual dimorphism in the timing of the pubertal growth spurt.
- A child with a spurt at the average time follows one of the percentile curves. If he/she has an earlier or a later spurt the curve will follow the same shape but will be in one of the shaded areas; to the left abnormally early and to the right abnormally late.
- From Tanner and Whitehouse (1976). *Archives of Disease in Childhood* 51,170–179.

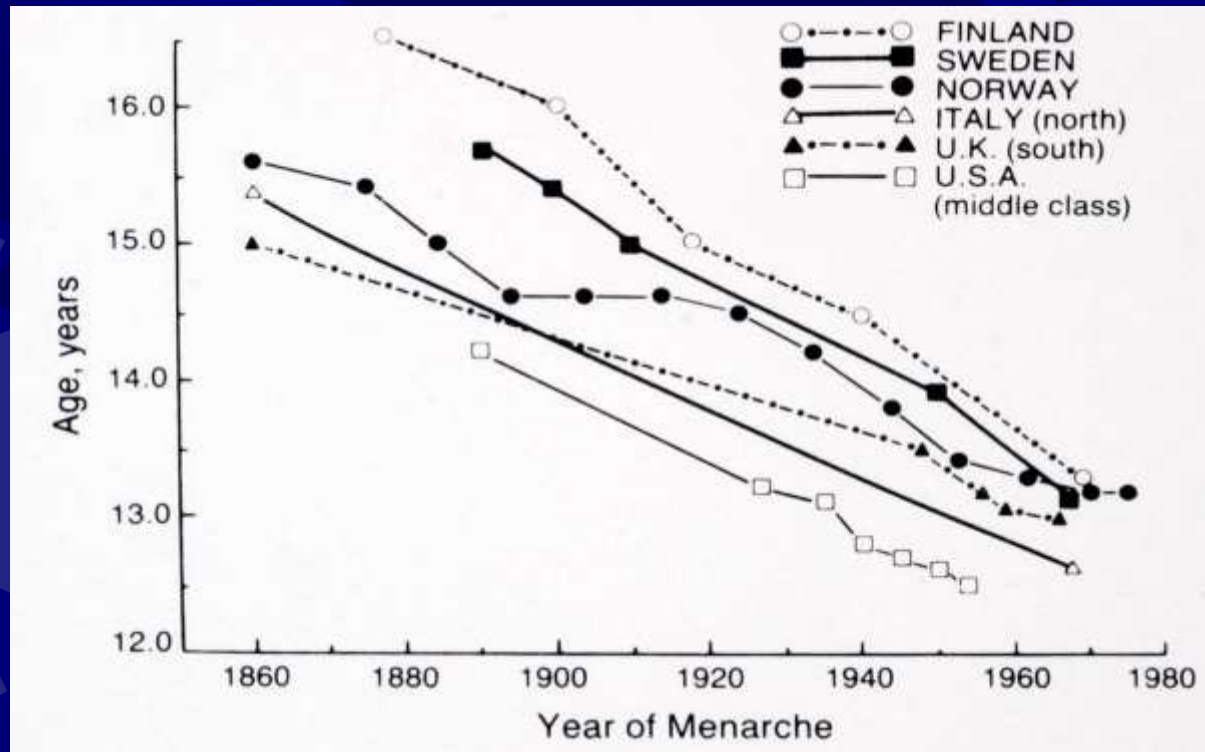


# The secular trend

- The term secular trend refers to the fact that over the last 100–200 years, children have been getting taller and growing to maturity more quickly. The main determinants are social and economic.
- In the industrialized world the trend has effectively come to an end.
- The figure shows growth data from Oslo. The increase in height was interrupted by the Second World War; the slow but steady post war increase has now reached a plateau in both boys and girls.
- From Brundtland *et al.* (1980). *Annals of Human Biology* 7, 307–322.



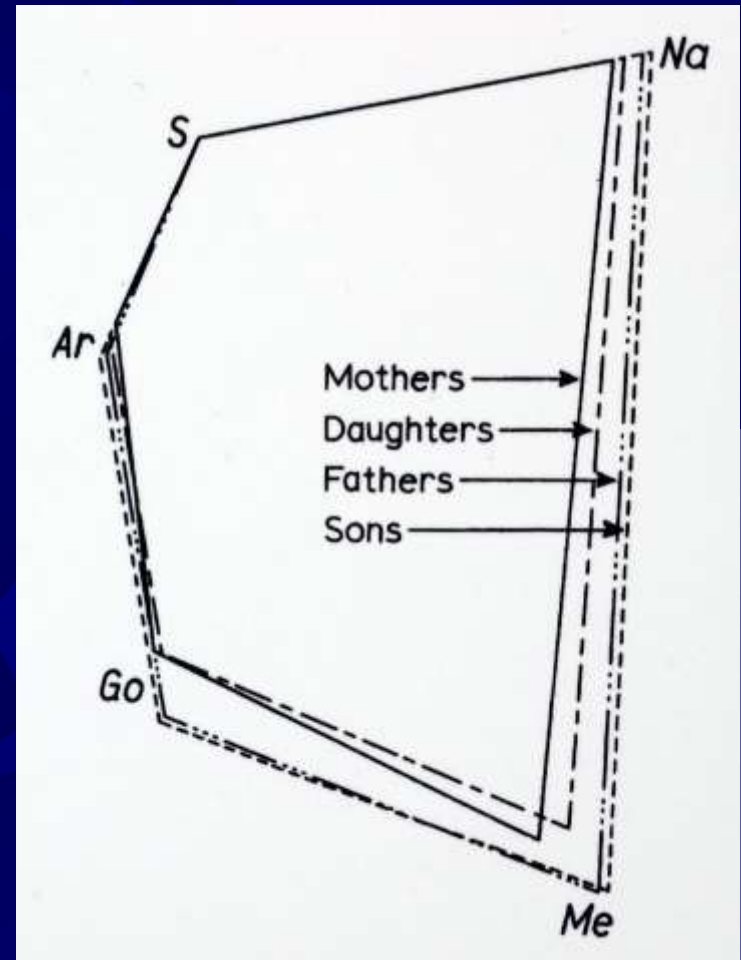
# Secular trend in age at menarche



- Secular trend in age at menarche from 1860–1970. The earlier data are based on recollected age, but the general trend is clear and from 1880 averaged 1–4 months per decade. In recent years the trend has slowed down or stopped in most European countries.
- From Tanner (1989), *Foetus into Man*.

# Secular trend in facial dimensions

- Parallel to the secular increase in body height, there has been secularization of the morphology of the cranium, including changes in the cranial base and face. This has not occurred, however, on the scale of the axial skeleton.
- Measurements of facial dimensions from lateral skull radiographs of a sample of adults and their children in 37 families, show that 25-year-olds have faces that are larger than their 55-year-old parents.
- Facial polygons based on mean dimensions for fathers (N=31) and their sons (N=48); and mothers (N=27) and their daughters (N=38).
- From Hunter and Garn (1969). *The Angle Orthodontist* 39, 320–323.

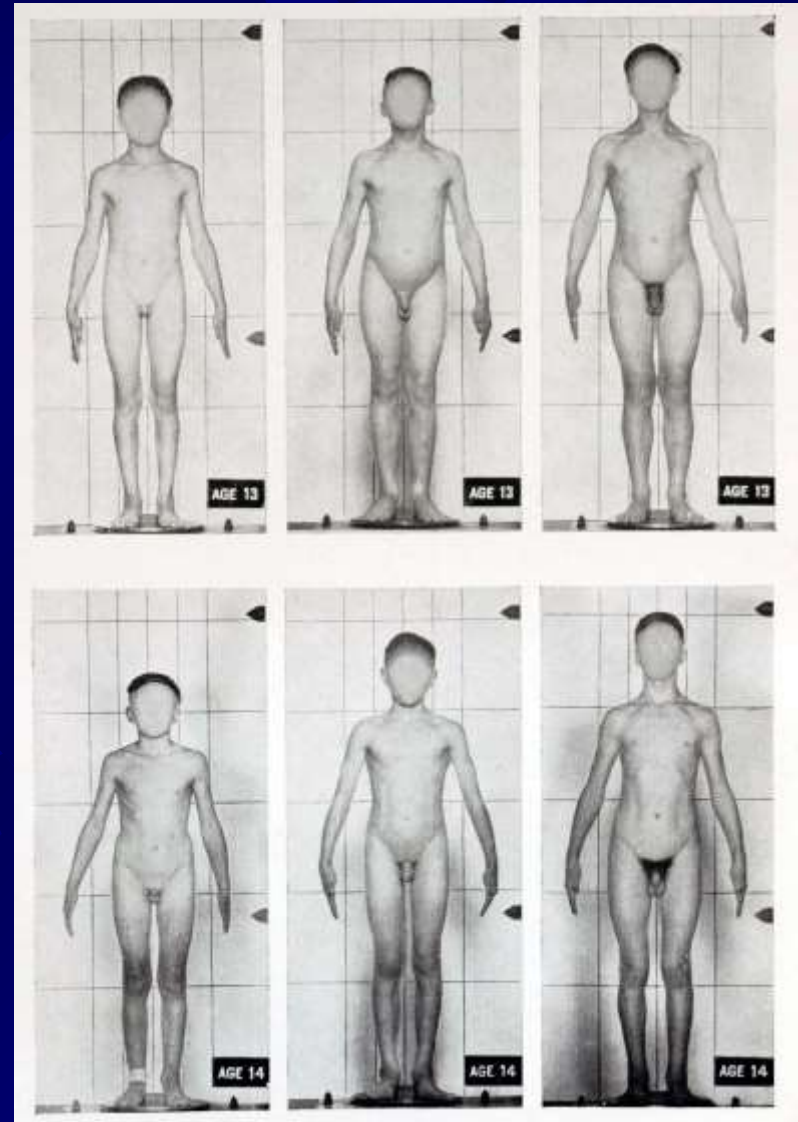


# The assessment of skeletal age

- ✿ The existence of early-maturing as well as late-maturing individuals makes for a wide difference in the onset of puberty. It is therefore difficult to determine the developmental status of a child solely on the basis of their chronological age, which does not necessarily reflect the amount of progress a child has made towards physiological maturity.
- ✿ The most commonly used indicator of physiological maturity has been the skeletal age, a measure of how far along the bones of the hand and wrist are in the course of development as recorded by their X-ray appearance.
- ✿ Orthodontists who wish to know the skeletal age of their patients are turning increasingly to the use of cervical vertebral staging. This has the advantage over the wrist film in that it can be assessed from a lateral skull radiograph.

# Variability in physical maturation

- At the age of 13 and 14 there is enormous variability amongst any group of boys as shown in this figure, which illustrates differing degrees of physical maturation at the same chronological age.
- The upper row shows three boys all aged 13 years to 13 years 3 months; lower row, three boys all aged 14 years 0 months.
- At each age the left-hand boy is pre-pubertal, while the right-hand boy approaches maturity.
- From Tanner (1962). *Growth at Adolescence*.



# Early versus late maturation

- ✿ It has been reported that early-maturing boys and girls are on average taller than their late-maturing peers from early childhood to about 15 years in girls and 17 in boys, but there is no difference in final stature for either sex (Tanner, 1962).
- ✿ The findings of a study by Hägg and Taranger (1991), however, who followed the growth of 183 Swedish urban children (103 boys and 80 girls) who were grouped into early-, average- and late-maturers on the basis of their age at PHV, suggests that on average, late maturing boys end up being taller. In girls the final height did not differ between the groups.
- ✿ The average final heights for boys were 177.5, 179.8 and 184 cm respectively in early-, average- and late-maturation. The difference compared to earlier reports appears to have been due to the participants having been followed for a longer period of time.

# Prediction of the pubertal growth spurt

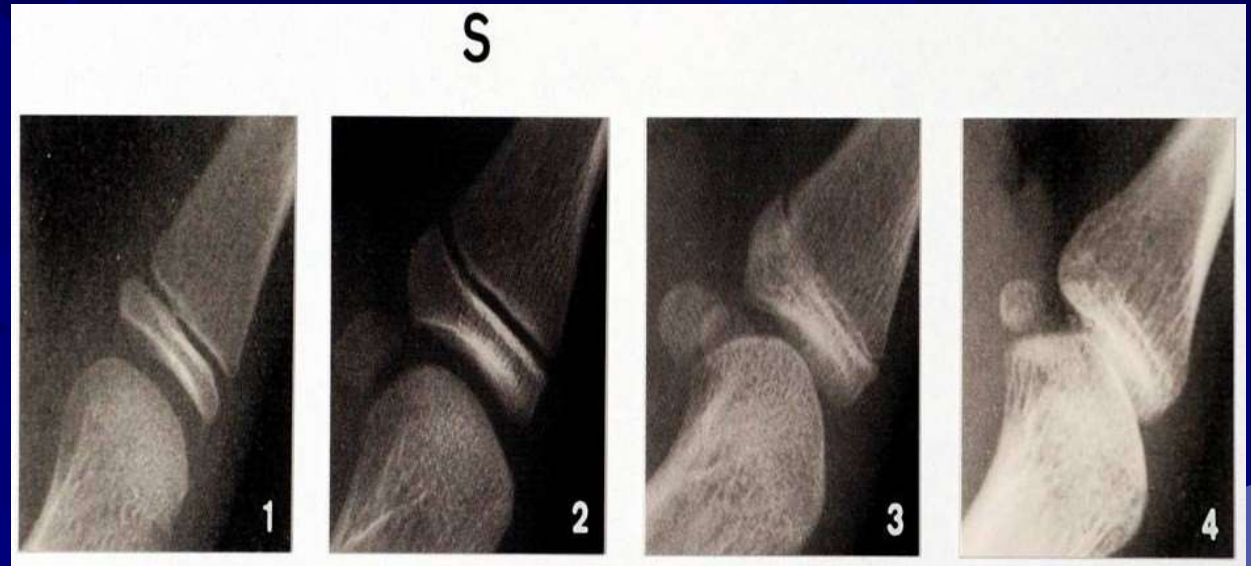
- ✱ An association between peak height velocity and a pubertal spurt in facial growth has been well-documented.
- ✱ Being able to predict the onset of the pubertal growth spurt would therefore be of great benefit to the timing of certain types of orthodontic treatment, particularly those involving growth modification for Class II malocclusions.
- ✱ A single height measurement will indicate on which percentile curve a patient lies in comparison to other children, but to determine where they might be on their growth velocity curve requires serial measurements which are not normally available to the clinician.
- ✱ What would be ideal is a simple marker(s) of skeletal maturation to indicate whether or not the pubertal growth spurt had been reached or passed.

# Atlas of skeletal maturity



- These hand standards were published in 1937 as the *Atlas of Skeletal Maturation (Hand)*, which provided the first practical guide for the clinician to assess skeletal age.
- The most widely used atlas is the Greulich and Pyle *Radiographic Atlas and Skeletal Development of the Hand and Wrist* (1959).
- A. Radiograph of a boy with a skeletal age of 12 years and 6 months. B. Boy with a skeletal age of 13 years and 6 months. Ossification of the sesamoid bone is visible (arrow).

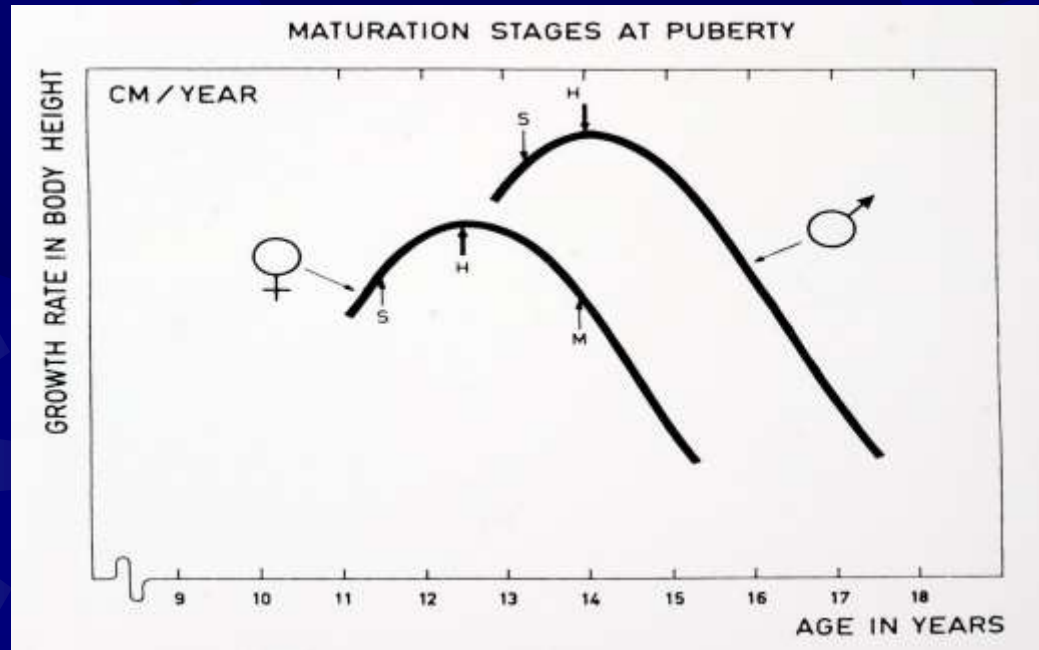
# Ossification events and peak height velocity



- ✿ Björk and Helm (1967) in a small number of Danish children, found that ossification of the ulna sesamoid bone occurred about one year before PHV in both sexes. They concluded this indicated fairly reliably that maximal pubertal growth was imminent, or had been reached. S, onset of ossification.
- ✿ However, Garn and Robinson (1962) found a wide range in the timing of ossification in 179 children from the Fels Research Institute Growth Study, Philadelphia.

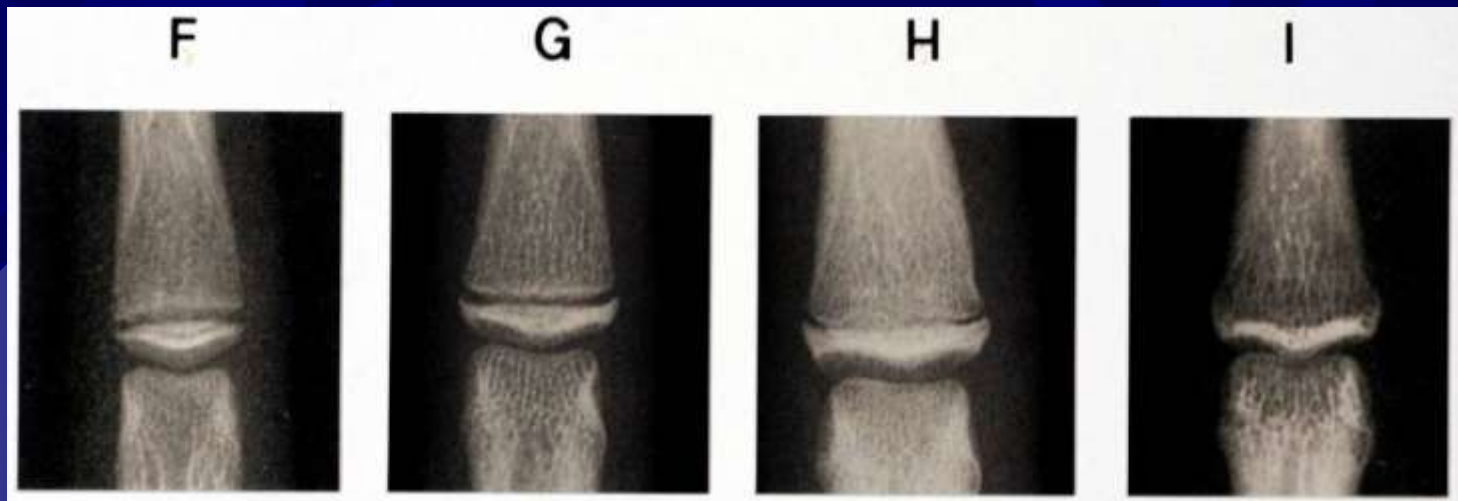
From Tanner *et al.* (2001) *Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 method)*.

# Sexual dimorphism at puberty



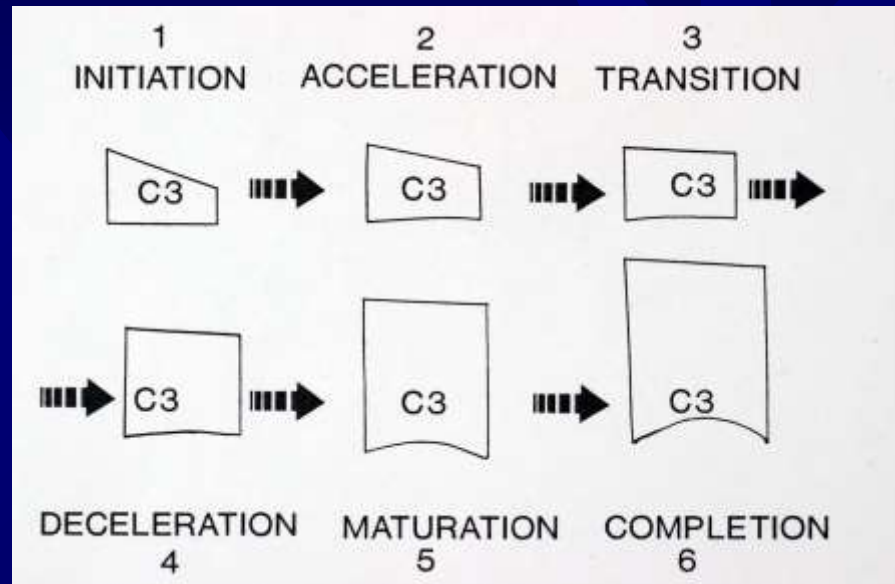
- Sexual dimorphism in PHV and physical maturation based on a longitudinal study of 20 girls and 32 boys at the Royal Dental College, Copenhagen.
- Menarche (M) occurred about one year after PHV, and was considered to be a reliable indicator that the pubertal spurt had been reached or passed. H, maximal pubertal growth in height (PHV); S, ossification of the sesamoid bone.
- From Björk and Helm (1967). *The Angle Orthodontist* **37**, 134–143.

# Ossification stages of MP3



- In a subsequent mixed-longitudinal study of 52 boys, Helm *et al.* (1971) concluded that ossification of the sesamoid bone by itself was not a reliable indicator of PHV, but an improved estimate could be obtained from the maturation stages of the middle phalanx of the third finger (MP3).
- Stage F, the epiphysis is as wide as the metaphysis.; stage G, the epiphysis caps the metaphysis; stage H, fusion has begun; stage I, fusion of the epiphysis and metaphysis is complete. If stage F–G is attained the subject is likely to be in the pubertal growth spurt.
- From Tanner *et al.* (2001), *Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 method)*.

# Cervical vertebrae as maturational indicators



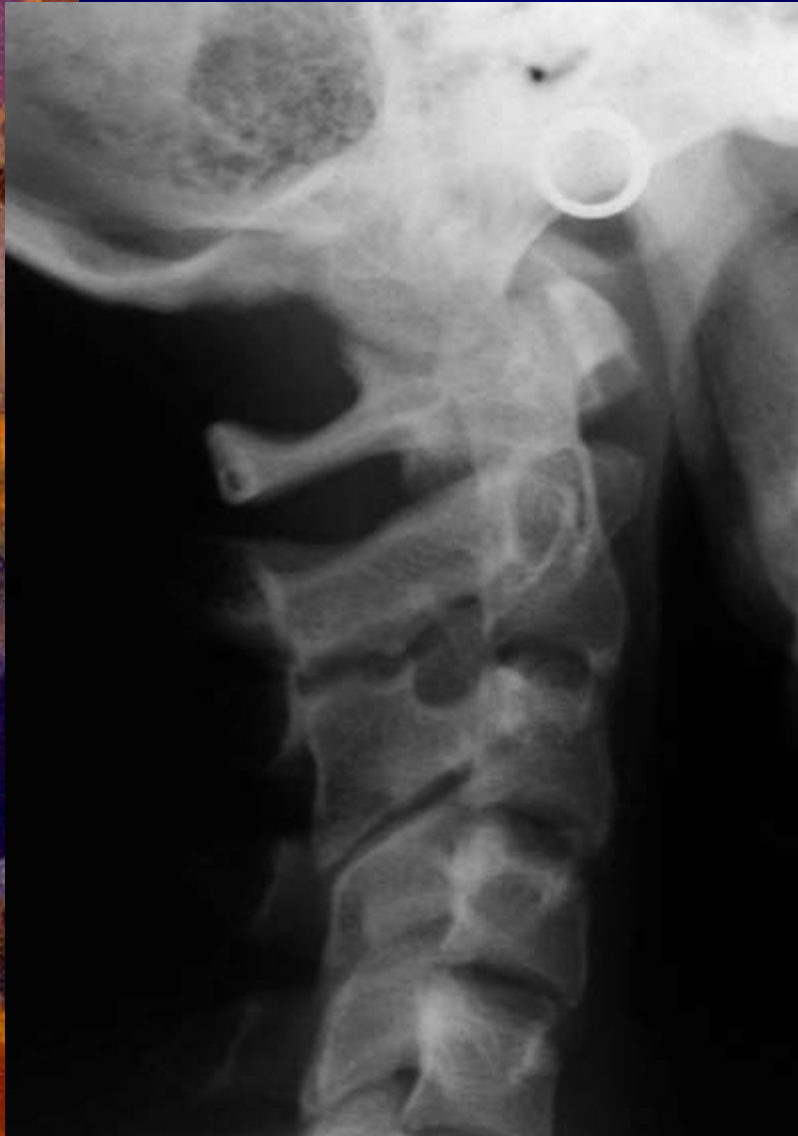
- The advantage of relating spurts in facial growth to maturation stages of the cervical vertebrae, is that it can be done on a single headfilm without an additional x-ray exposure.
- The method is based on changes in the morphology of the second, third and fourth cervical vertebrae (Lamparski, 1972); specifically (1) the presence or absence of a curvature of the inferior border; (2) the shape of the vertebral bodies, and (3) the width of the intervertebral space.
- From Hassel and Farman (1995). *American Journal of Orthodontics and Dentofacial Orthopedics* **107**, 58–66.

# Pre-pubertal cervical vertebrae



- Cervical vertebrae in a lateral skull radiograph from a male patient aged 10 years with a Class II division 1 malocclusion.
- A slight concavity has developed in the inferior borders of C2 and C3; other inferior borders are flat. The vertebral bodies are trapezoidal or wedged-shaped, with wide spaces between individual vertebrae. This patient is assessed as being in the acceleration or transitional stage (2–3).
- Stages 1–3 occur prior to peak velocity for mandibular dimensions so this patient is a good candidate for growth modification. However, there is wide individual variation (O'Reilly and Yanniello, 1988).

# Post-pubertal cervical vertebrae



- ✦ Cervical vertebrae from a female patient aged 14 years 2 months with a Class II division 1 malocclusion.
- ✦ Deep concavities can be seen at the inferior borders of C2, C3 and C4, and the dimensions of the vertebral bodies are greater vertically than horizontally. The space between the individual vertebrae is much reduced.
- ✦ This patient is assessed as having reached the completion phase of cervical vertebral development; pubertal growth has been completed.



- Cervical vertebrae from a female patient aged 15 years 5 months with a Class III malocclusion.
- Concavities have developed in the lower borders of C2, C3 and C4, but the shape of C3 and C4 remains trapezoidal and the intervertebral spaces remain relatively wide.
- This patient is assessed as having entered the deceleration phase (cervical maturation stage 4) and is therefore post-PHV. Although older chronologically than the female in the previous slide (aged 14 years 2 months), skeletally she is less advanced.

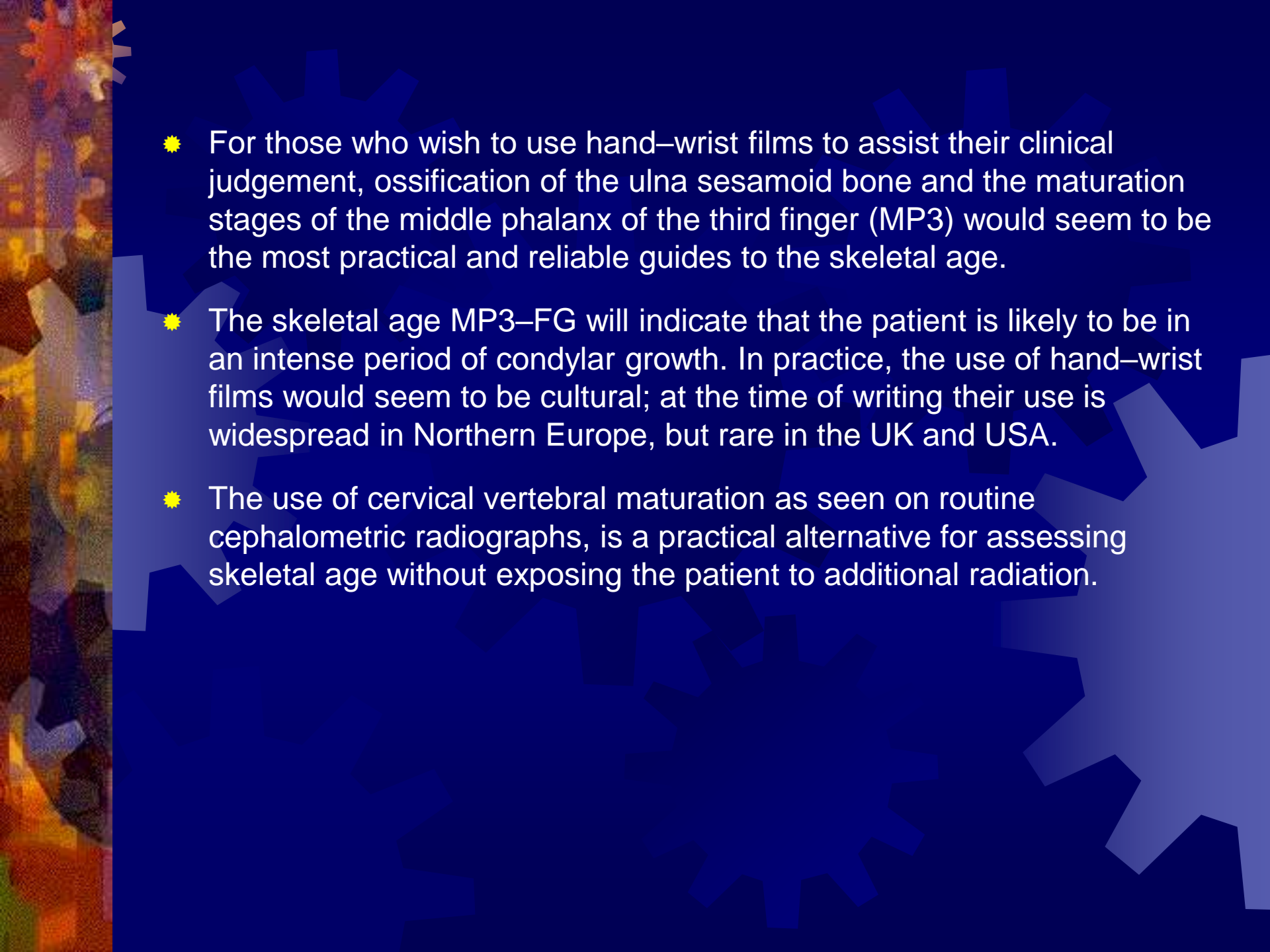
# Obesity and the pubertal growth spurt



- The mouse on the right is a homozygous mutant ( $Ob^{-/-}$ ) which does not produce leptin. Because the gene is recessive, heterozygous mutant ( $Ob^{+/-}$ ) and wild-type littermates are normal. In homozygous mutants, lack of leptin signalling in the hypothalamus leads to obesity and diabetes.
- The first *ob/ob* mouse arose by a chance mutation in 1949 (Ingalls *et al.*, 1950). Mutant mice are phenotypically indistinguishable from unaffected littermates at birth, but are hyperphagic (compulsive overeating) and gain weight rapidly, reaching three times that of unaffected mice.

# Implications for orthodontic treatment planning

- ✱ The idea that orthodontic treatment should be made to coincide with the pubertal growth spurt has always been a theoretical rather than a practical ambition. Individuals show unlimited variation in the timing of their growth spurt and few clinicians enjoy the luxury of monitoring their patients longitudinally to establish PHV before starting treatment.
- ✱ In practice most orthodontists will begin growth modification with headgear or functional appliances when they think it appropriate, bearing in mind the age of the patient at first consultation, and the anticipated levels of co-operation.
- ✱ Orthodontists do not necessarily need to know the exact skeletal age of their patients. What they need to know is whether the patient is likely to grow during treatment and plan accordingly.

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- ✱ For those who wish to use hand–wrist films to assist their clinical judgement, ossification of the ulna sesamoid bone and the maturation stages of the middle phalanx of the third finger (MP3) would seem to be the most practical and reliable guides to the skeletal age.
  - ✱ The skeletal age MP3–FG will indicate that the patient is likely to be in an intense period of condylar growth. In practice, the use of hand–wrist films would seem to be cultural; at the time of writing their use is widespread in Northern Europe, but rare in the UK and USA.
  - ✱ The use of cervical vertebral maturation as seen on routine cephalometric radiographs, is a practical alternative for assessing skeletal age without exposing the patient to additional radiation.