Craniofacial Growth

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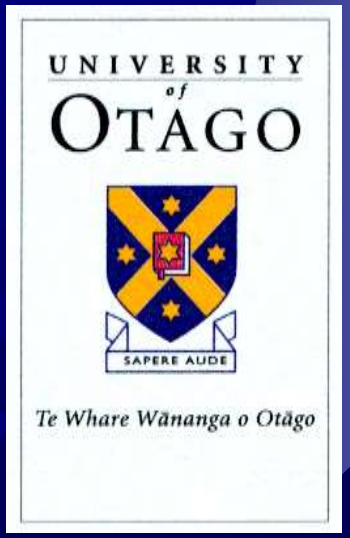
Biological Foundations of Orthodontics and Dentofacial Orthopaedics

Seminar 10

2004

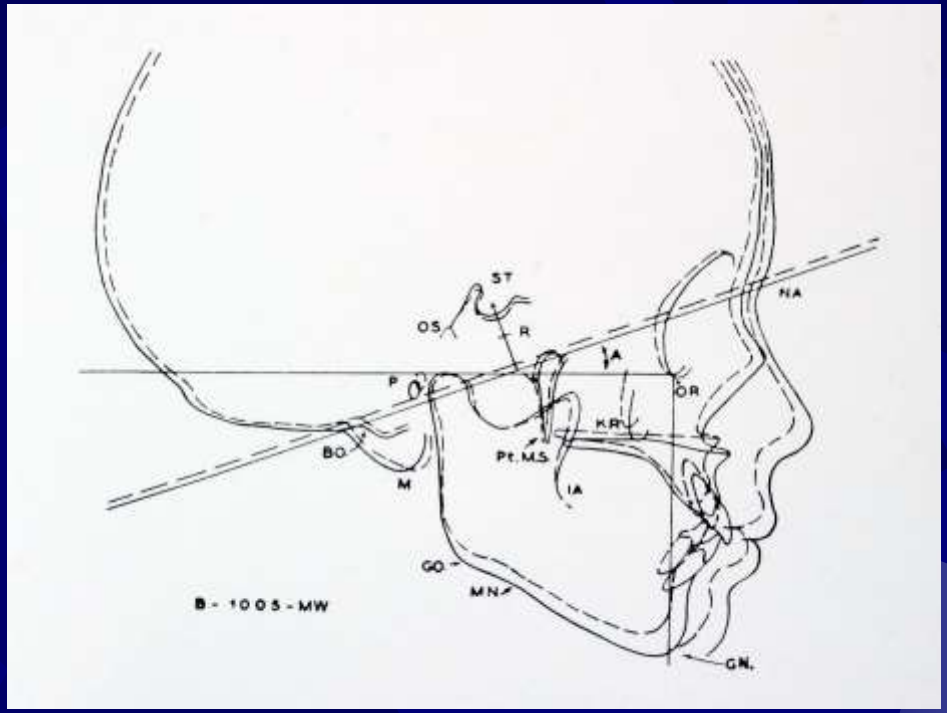


Conceptual foundations

- Following the introduction of the cephalostat in 1931 by Broadbent and Hofrath, orthodontic research became dominated for the next 40 years by studies of craniofacial growth using cephalometric radiography. Many were by-products of the major US growth studies; others originated from universities around the world, particularly in Scandinavia. The aim of this seminar is to review the key investigations from this period, and how they have influenced our thinking and clinical practice.
- Cephalometric radiography proved to be an excellent method for distinguishing between treatment changes and normal dentofacial growth. Several studies were published in the 1930s which were to have a significant impact on orthodontic concepts of facial growth, and whether it could be altered by orthodontic treatment.

The face of the normal child

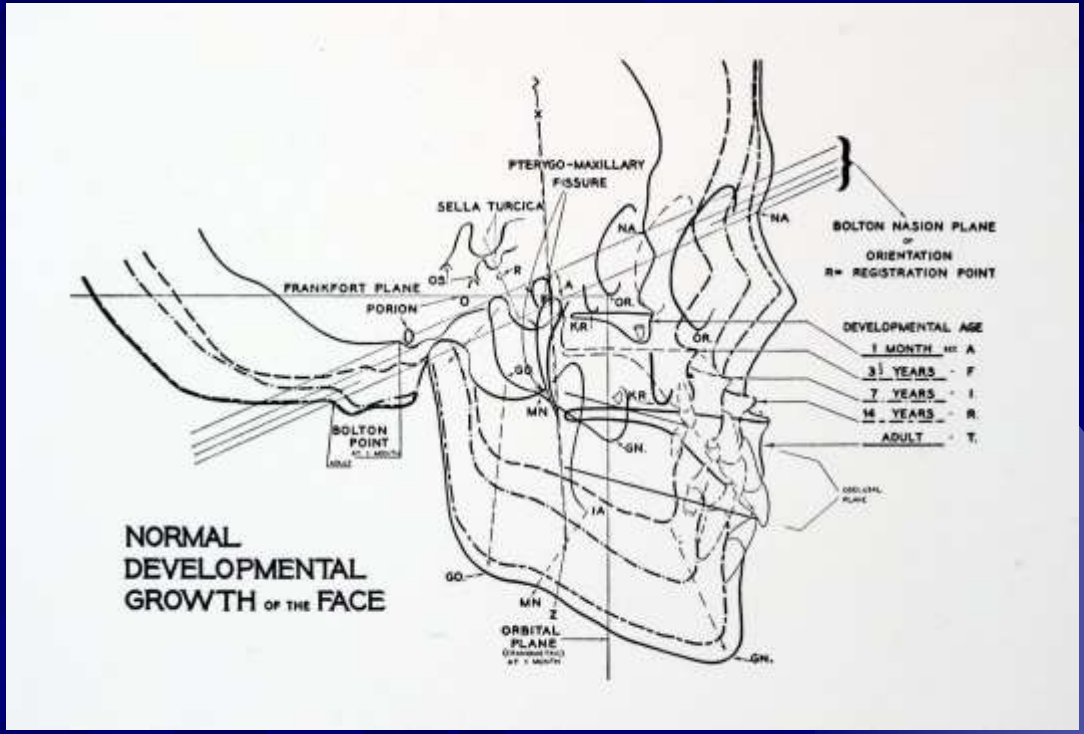
From Broadbent (1937), *The Angle Orthodontist* **7**, 183–208.



- In 1937 Broadbent published *The Face of the Normal Child*. This shows a subject from the Bolton Study deemed representative of the 200 or more children studied between the ages of 9 and 14.5.
- Serial headfilms superimposed on the Bolton–nasion plane and registration point R. It shows a uniform increase in size of the face, the growth of which follows an orderly downward and forward path.

Normal developmental growth of the face

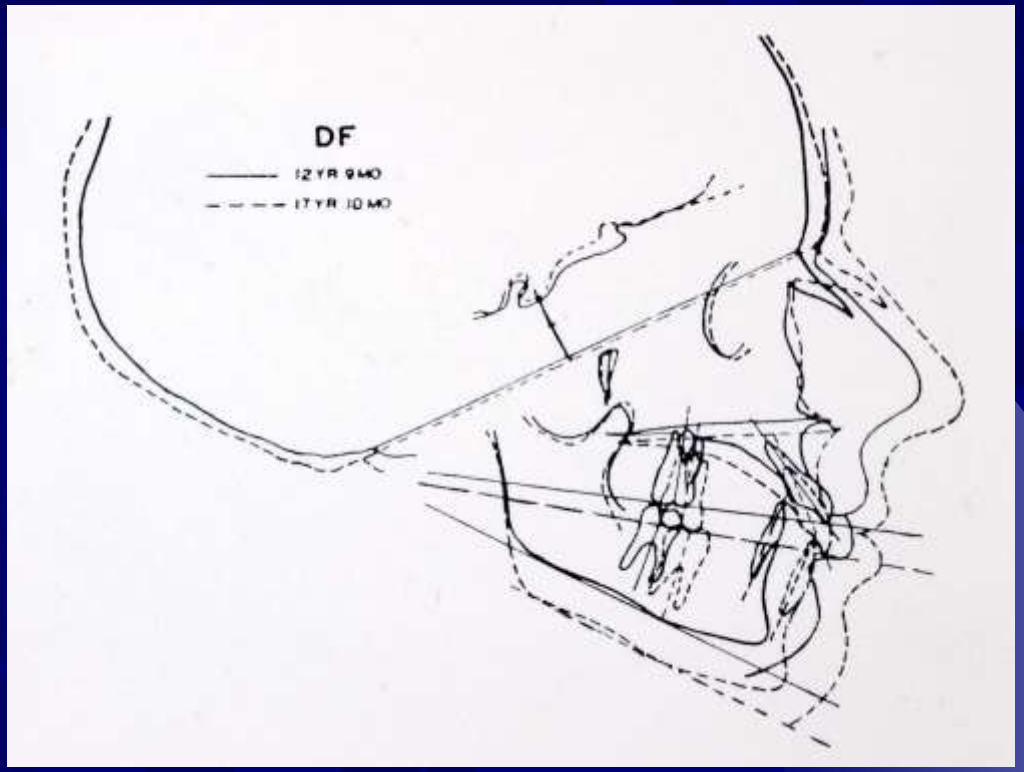
From Broadbent (1937), *The Angle Orthodontist* **7**, 183–208..



- The paper also contains one of the most famous series of headfilm tracings in cephalometry, which served to reinforce the idea that facial growth followed an orderly downward and forward direction.
- The figure is also androgynous; the only difference between boys and girls in the Bolton study was one of comparative size.

Cephalometric appraisal of orthodontic results

From Brodie *et al*. (1938), *The Angle Orthodontist* **8**, 261–351.

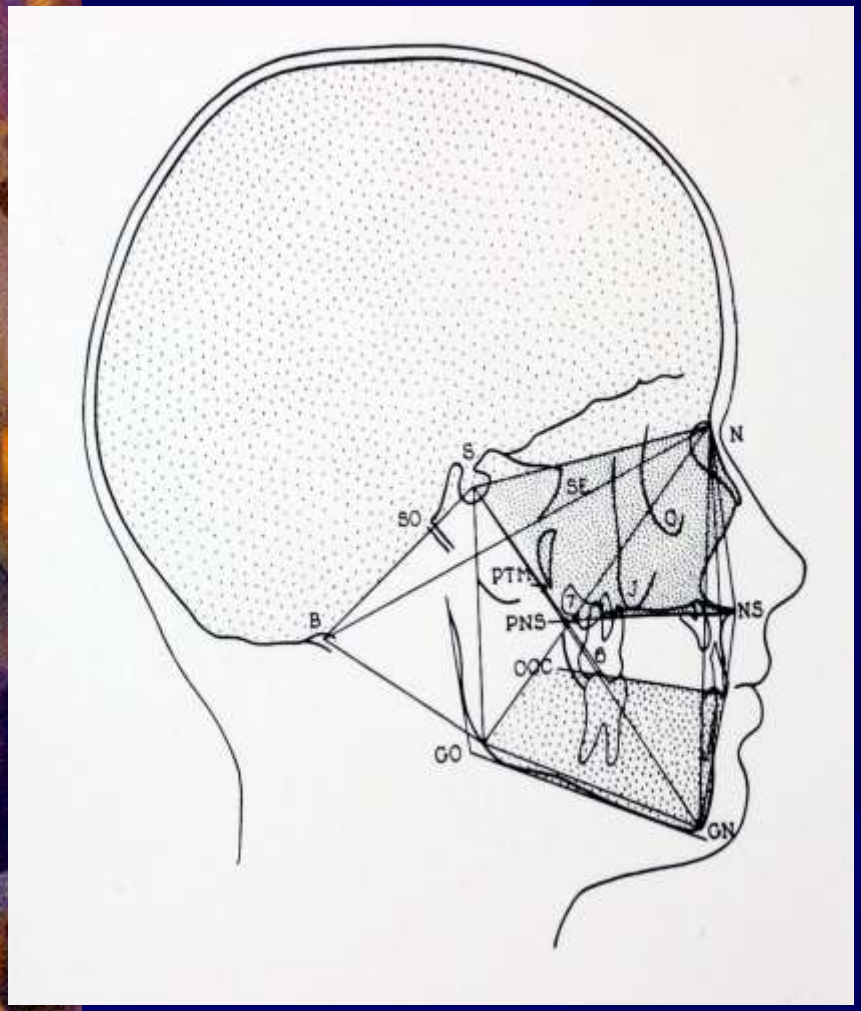


- The first cephalometric study of orthodontic results was published in 1938 by Brodie, Downs, Goldstein and Myer. 23 patients treated by the graduate students at the University of Illinois.
- In keeping with the Angle philosophy prevalent at the time, all had been treated non-extraction, irrespective of the degree of crowding or the skeletal relationship.

Conclusions of Brodie *et al.*

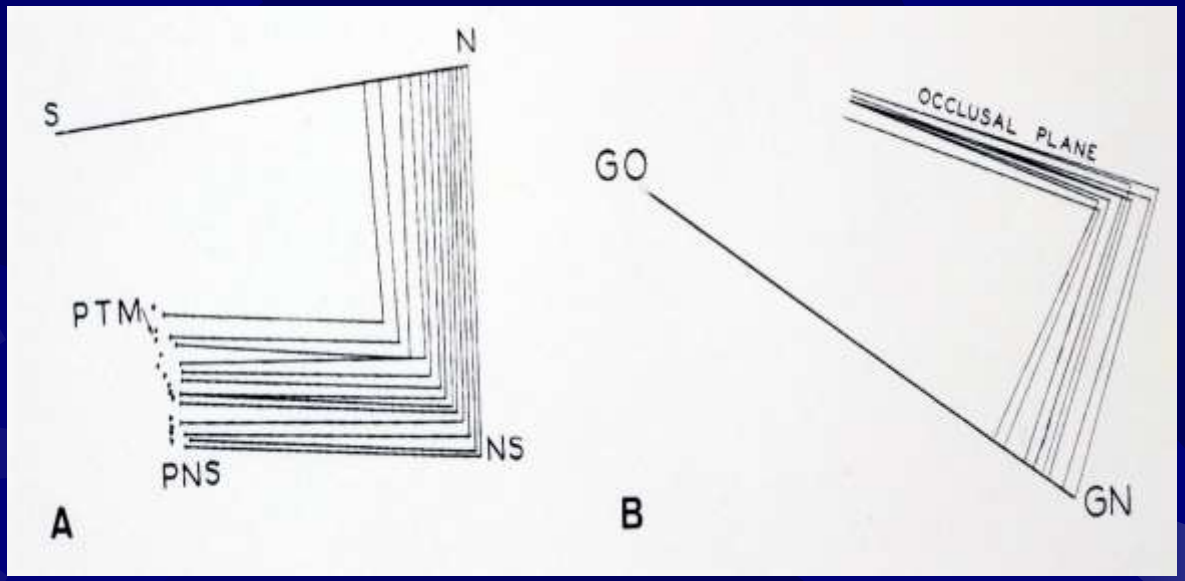
- Several important observations regarding orthodontic treatment were made, most of which are still valid today.
- Tooth movement was not as great as clinical observation had suggested, and the best aesthetic results were obtained in those cases where growth was most active.
- Intermaxillary elastics tipped the occlusal plane. However, the occlusal plane tended to return to its original position subsequent to treatment.
- Disturbed axial inclinations (*i.e.* tipping) of teeth showed a tendency to right themselves following treatment.
- The old dogma of growing bone by moving teeth was replaced by a new one – the effects of orthodontic treatment were restricted to the dentoalveolar process and tooth movement. Some clinicians still believe this.

Growth pattern of the human head



- In the first published longitudinal study of facial growth, Brodie selected the headfilms of 21 males from the Bolton Study covering the period three months to eight years.
- The head was divided into four areas for analysis; calvarial, nasal, occlusal, mandibular as shown here. From this figure one can see the framework for future cephalometric analyses beginning to emerge.
- The most surprising outcome of the study was the apparent regularity in the growth pattern of the face and cranium.
- From Brodie (1940), *American Journal of Orthodontics and Oral Surgery* **26,** 744–757.

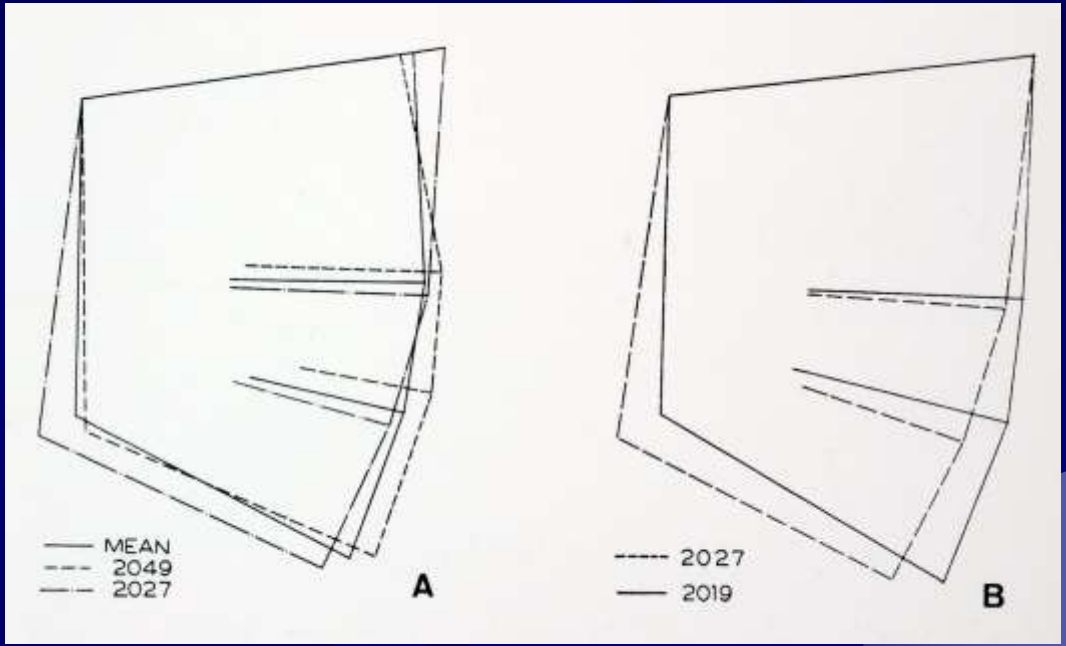
Growth of the nasal area



- Brodie found that while there was a slight decrease in the angle S–N–NS during the first 6-9 months indicating a relative retreat of the nose, the angle then stabilized and did not change thereafter.
- The angle N–NS–PNS showed stability; the nasal floor maintained a constant relationship to the anterior cranial base (S–N).
- The most pronounced change In the mandible was seen at gnathion (GN), where the chin appeared to gain on the lower incisal edge up to 4 years of age.

Facial polygons

From Brodie (1940), *American Journal of Orthodontics and Oral Surgery* **26,** 744–757.

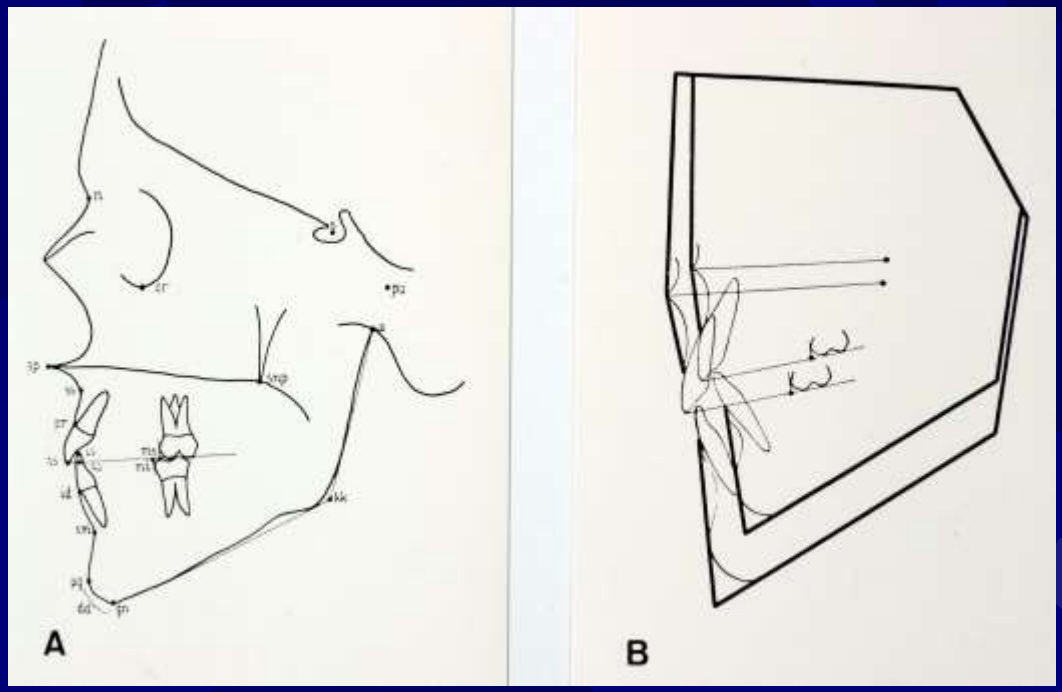


- Brodie recognized these observations were derived from mean values and indicated general trends. He then looked at individuals.
- (A). Shows the facial pattern of two individuals with the greatest deviation from the mean. It also shows how variance in the length of S–N will influence angular measurements of the face. (B) Two cases with identical S–N distances, but quite distinct facial types.

Immutability of the skeletal pattern

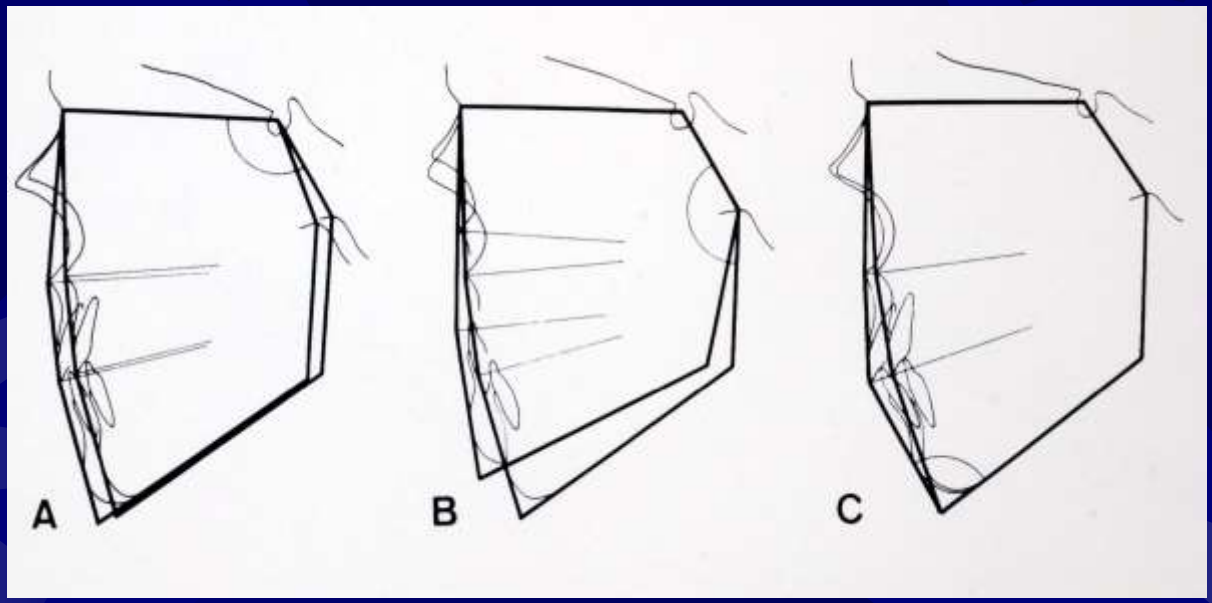
- At the same time that Brodie and his colleagues had been carrying out their clinical investigations, Johnson (1940), *American Journal of Orthodontics and Oral Surgery*, who had been working with Stockard at Cornell University, crossbreeding various dog types, showed by means of hybridization experiments, that the genetic constitution was a vital factor in the development of skull form and dental occlusion.
- Johnson's findings together with the conclusions from the University of Illinois that (1) the morphogenetic pattern of the individual was established at an early age and that once attained did not change, and (2) that orthodontic treatment was limited to dentoalveolar remodelling, were interpreted as implying the immutability of the skeletal pattern and the inability of the clinician to change it in any way.
- These conclusions were to have a profound effect on orthodontic practice in the United States for the next 30 years.

The face in profile



- For his doctoral dissertation Björk studied facial growth in 322 12-year-old Swedish boys, and 281 army conscripts (aged 21–23 years); the results were published in *The Face in Profile* (1947). *Svensk Tandläkare-Tidskrift* **40** (Suppl 5B). pp. 1–180.
- Björk introduced a new point articulare, where the mandible crosses the basiocciput. The facial polygons of 12-year-old boys and conscripts (B) showed there was increased maxillary and mandibular prognathism during adolescence, an important cause of lower incisor crowding.

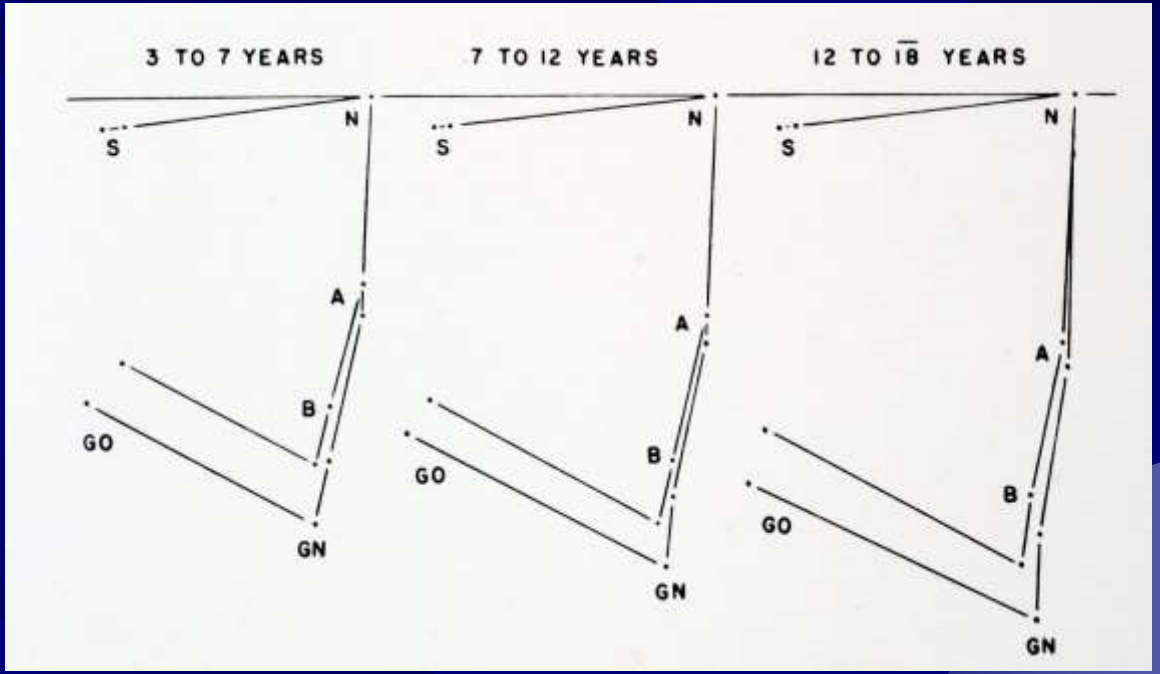
Facial prognathism



- Between the ages of 12 and 22, maxillary prognathism (S–N–Pr) increased on average by 1.2 ± 0.31º, and mandibular prognathism (S–N–Po) by 2.8 ± 0.32º, straightening the facial profile.
- The degree of prognathism tended to be influenced rather less by jaw length than by changes in angular relationships at the saddle angle N–S–Ar (A), and joint angle S–Ar–Go (B). A change in the chin angle significantly altered dentoalveolar prognathism (C).
- From Björk (1947), *The Face in Profile. Svensk Tandläkare-Tidskrift* **40** (Suppl 5B). pp. 1–180.

Growth of the human bony profile

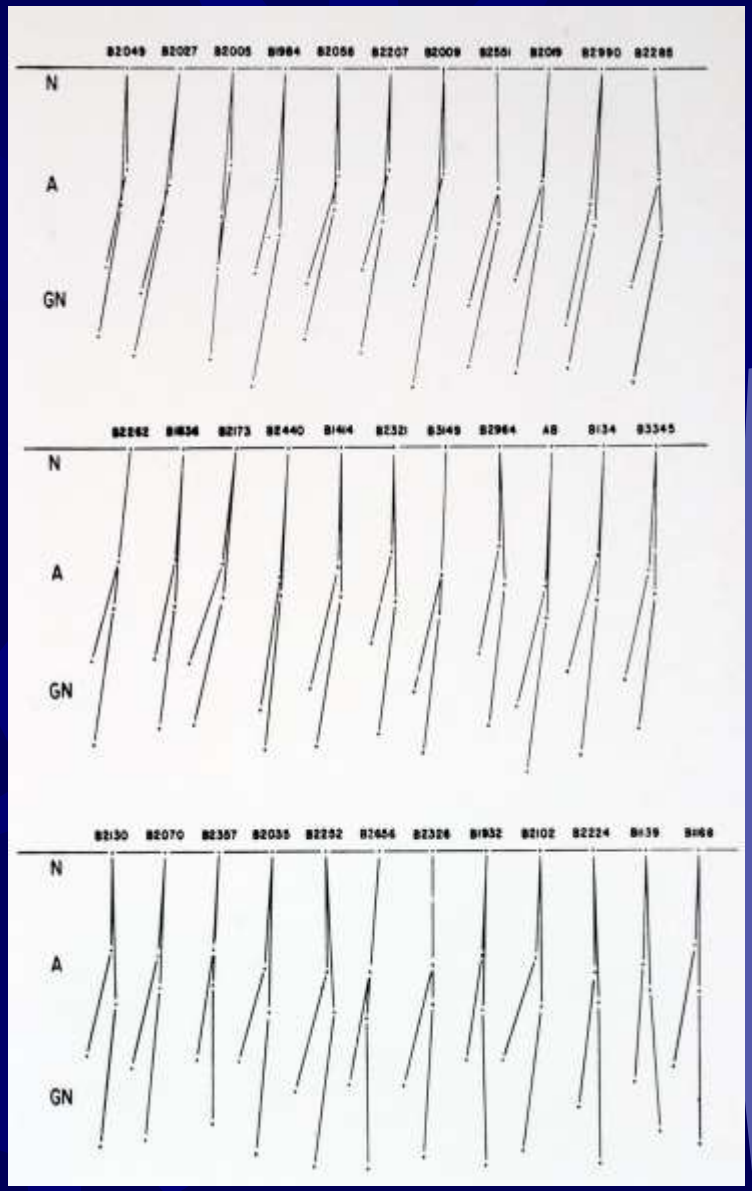
From Lande (1952), *The Angle Orthodontist* **22**, 78–90.



- Lande studied profile changes in 34 males from the Bolton Study aged 3–18 years. From 3–7 years no significant changes in the anteroposterior position of points A, B or Gn were recorded.
- From 7–12 years Gn moved forward 1.3 mm, while points A and B remained unchanged. From 12–18 years point A moved forward 1 mm, point B moved forward 2.2 mm, and Gn moved forward 3.7 mm. In other words, there was a progressive decrease in the convexity of the face.

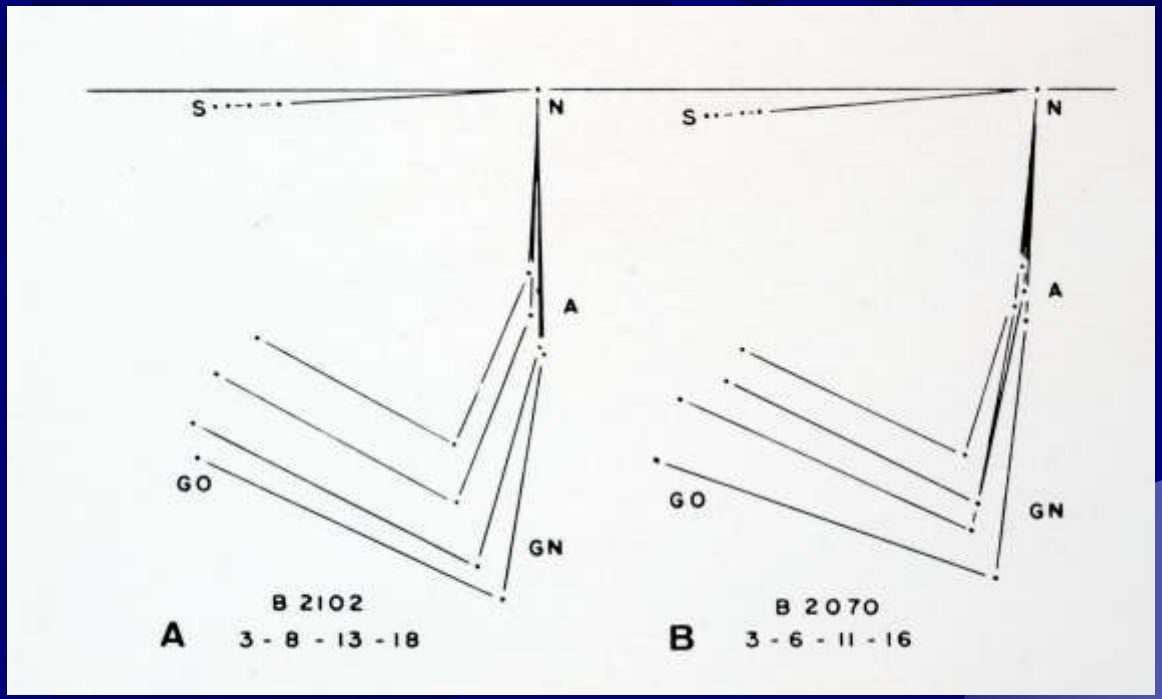
Individual variation in facial prognathism

- Expressing data as mean ± SD may be statistically *de rigeur*, but lacks the visual impact of ranking the data in order of forward movement of gnathion. I rate this as one of the most important figures in the literature.
- Change in the position of Gn ranged from –3.7 mm (B2049) to +12.75 mm (B1168). Change in point A ranged from –4.25 mm (B2005) to +3.25 mm (B2252).
- The figure shows the wide range of individual variation compared to the mean profile changes.
- From Lande (1952). *The Angle Orthodontist* **22**, 78–90.



Variability in facial growth direction

From Lande (1952), *The Angle Orthodontist* **22**, 78–90.



- The majority of cases did not vary in overall direction of change, but considerable variation occurred within the individual subjects.
- In patient B2102 Gn moved downwards and forwards in the same direction in an orderly, consistent manner. Patient B2070 shows a more irregular growth pattern; between 6 and 11 years Gn moved downwards and backwards. Changes in the mandibular plane angle also varied.

Facial growth at puberty

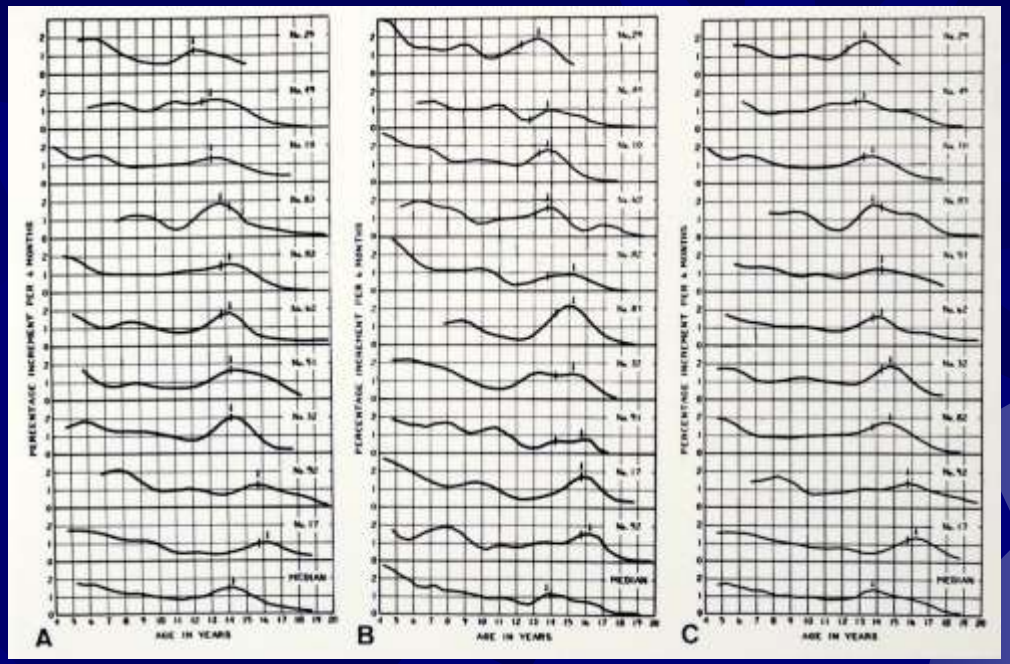
- Several major cephalometric growth studies have shown a high degree of association between the pubertal growth spurt in body height and a corresponding increase in growth velocity for facial dimensions, although the timing may be asynchronous.

- The studies of Broadbent and Brodie suggested that the face grew in a gradual consistent manner. The cephalometric standards from the University of Michigan (Riolo *et al*., 1974) and the Bolton Study at Case Western Reserve University (Broadbent *et al*., 1975), similarly show a gradual increase in facial dimensions with no identifiable circumpubertal change.

- This has lead to some clinicians to question whether pubertal spurts in facial growth actually exist. The aim of the next section is to examine the evidence and how these differences of opinion might be reconciled.

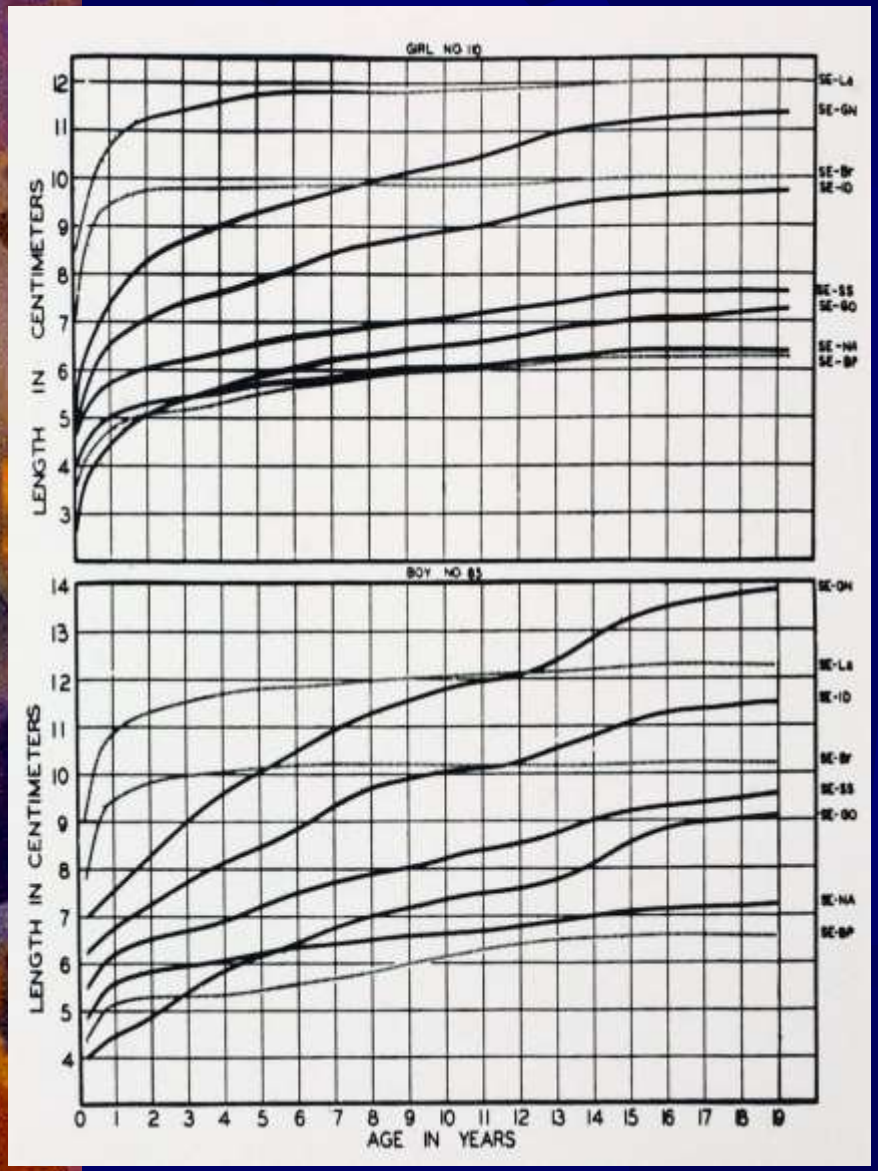
Child Research Council, Denver

From Nanda (1955), *American Journal of Orthodontics* **41**, 658 – 673.



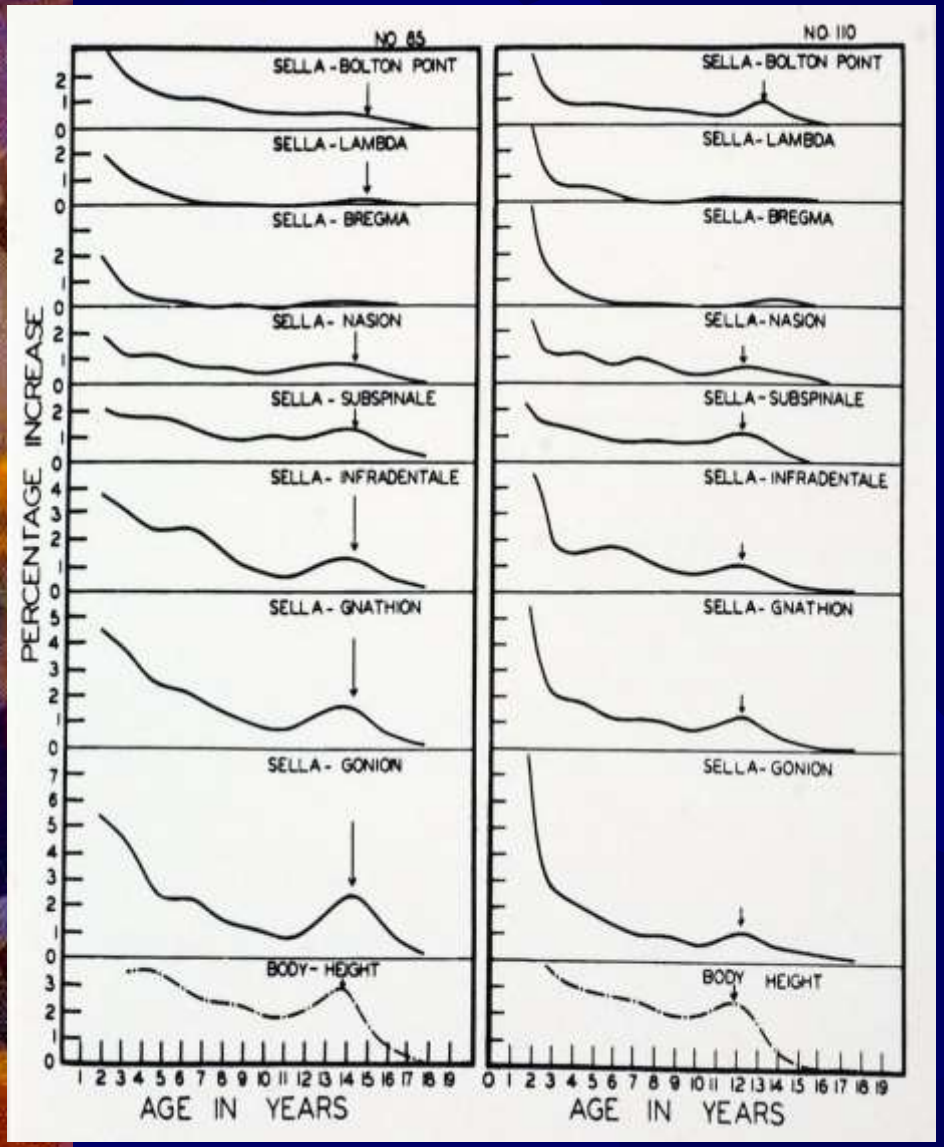
- Nanda (1955) measured 7 linear dimensions in 10 males and 5 females from the CRC growth study at the University of Colorado, active between 1927 and 1967.
- The figure shows (A), N–Gn; (B), Go–Gn; (C), S–Gn for the 10 boys ranked according to the age at which their circumpubertal maximum occurred (indicated by the arrow). PHV (Peak Height Velocity) is represented by the vertical line. Spurts in facial growth were small and generally occurred a little after PHV.

Longitudinal growth of the face



- In Bhamba's series of 25 males and 25 females also from the CRC Growth Study, eight cranial and facial dimensions were measured from the middle of the sella turcica.
- The figure represents the growth curves of the facial (solid) and cranial dimensions (stippled) of girl 110 and boy 85. The cranial dimensions complete most of their growth by 4 years (a neural pattern), whereas the facial dimensions show a skeletal pattern of growth with an acceleration at puberty.
- From Bhamba (1961). *Journal of the American Dental Association* **63**, 776–799.

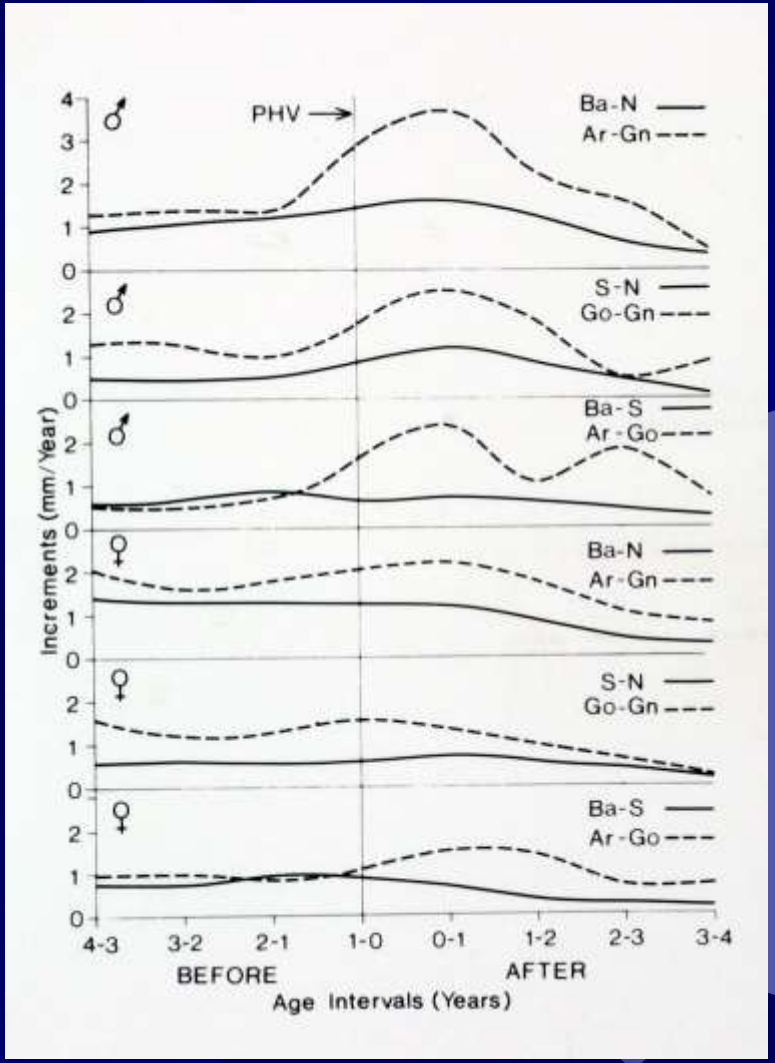
Growth velocity curves



- Growth velocity curves for boy 85 and girl 110 expressed as percentage increase.
- Bhamba confirmed Nanda's findings of a definite pubertal spurt in facial growth and that the face continues to grow after growth in height is complete.
- Although the numbers involved in both investigations were modest, these longitudinal data showed that small facial growth spurts do exist; the key point is that these changes become less obvious or disappear when the data is pooled.
- From Bhamba (1961), *Journal of the American Dental Association* **63**, 776–799.

Fels Research Institute, Ohio

- Several studies based on 34 male and 33 females in the Fels Institute growth study have been published.
- These have shown that pubertal spurts occur during growth of the cranial base and mandible in most children. However, the timing of PHV and craniofacial spurts varied widely, and in some did not occur until the 3rd year following PHV.
- The figure shows spurts in mandibular length were more common in boys than girls, and were larger and tended to occur after PHV.
- From Lewis *et al*. (1985), *The Angle Orthodontist* **55**, 17–30.

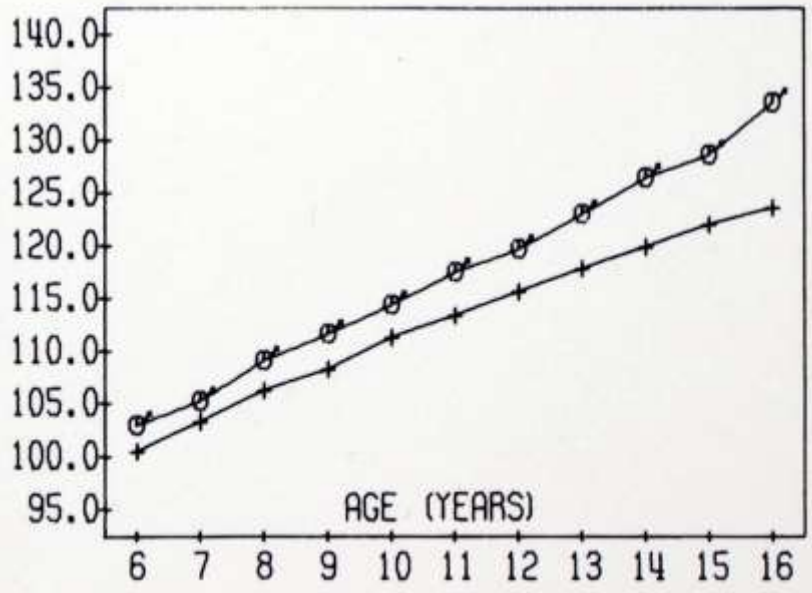


What do facial growth standards tell us about pubertal growth?

- During the 1970s two volumes of facial growth standards were published. One from the University of Michigan Growth Study (Riolo *et al*., 1974), the other from the Bolton-Brush Growth Study at Case Western Reserve University, Ohio (Broadbent *et al*., 1975). Both have become reference manuals for clinical and research purposes. In a discussion of whether mandibular growth spurts exist, Bishara (2001) refers to these studies to support the view that pubertal spurts in facial growth do not occur.
- Facial growth curves are useful if one wishes to know the average growth for a given population, but like growth curves for height, they reveal little if anything about the dynamics of pubertal growth, or the growth of an individual patient.

Michigan Growth Standards

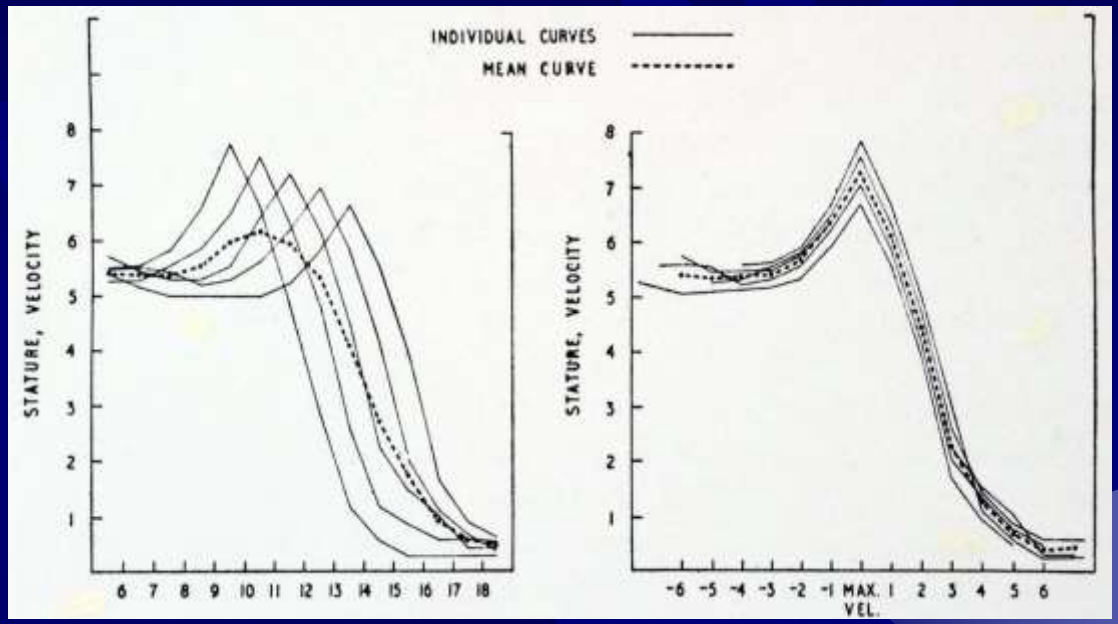
Age	N	Male Mean mm	S.D. mm		Age	N	Female Mean mm	S.D. mm
6	37	103.0	4.5	*	6	25	100.5	4.1
7	44	105.3	3.6	*	7	31	103.3	4.4
8	44	109.2	3.8	**	8	36	106.3	4.7
9	47	111.7	3.9	**	9	31	108.3	5.0
10	46	114.5	3.9	**	10	35	111.3	4.9
11	43	117.6	4.3	**	11	30	113.4	4.7
12	44	119.7	4.5	**	12	27	115.7	4.6
13	43	123.1	5.5	**	13	29	117.8	4.3
14	40	126.5	5.7	**	14	25	119.9	4.0
15	33	128.7	5.0	**	15	19	122.0	4.9
16	23	133.6	5.4	**	16	9	123.6	4.0



- The University of Michigan Study began in 1953 and of the original sample, 83 individuals (47 male, 36 female) from the age of 6–16 were used to compose the atlas.
- This figure shows the cumulative changes in the linear dimension Co–Gn; there is no evidence for a pubertal spurt in mandibular growth.
- However, although the growth curves in the atlas are based on longitudinal measurements of individual participants, they are presented in a cross-sectional manner. The linear measurements surprisingly, are also subject to a 12.9% enlargement.
- From Riolo *et al*. (1974), *An Atlas of Craniofacial Growth*. Monograph 2. Craniofacial Growth Series, Center for Human Growth and Development, University of Michigan, Ann Arbor.

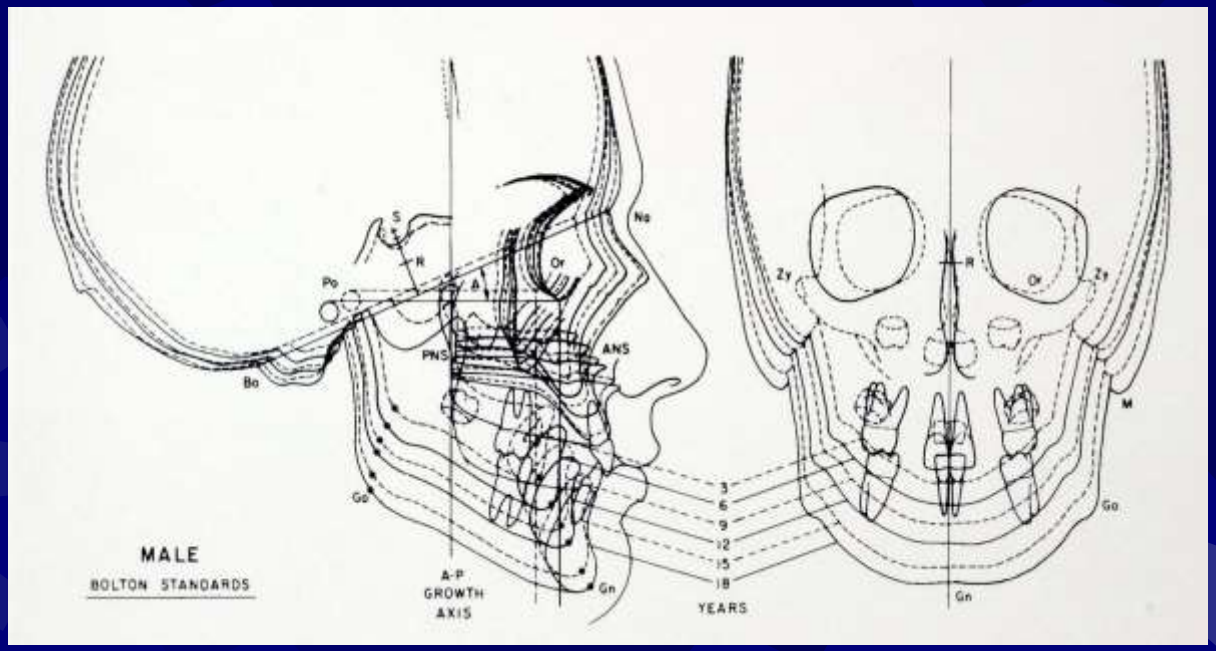
Differences in the tempo of growth

From Tanner (1962), *Growth at Adolescence.*



- The problem with how these growth data were presented is the wide personal variation in the timing and magnitude of growth at puberty. Ignoring these differences, produces growth standards that make the anatomical and physiological changes of puberty disappear.
- The above shows the relation between individual and mean velocities of 5 boys during their growth spurt. In (A) height curves are plotted against age; boys of the same age can vary widely in the timing of puberty. The mean curve ignores individual differences. In (B) the curves are plotted according to their time of maximum velocity.

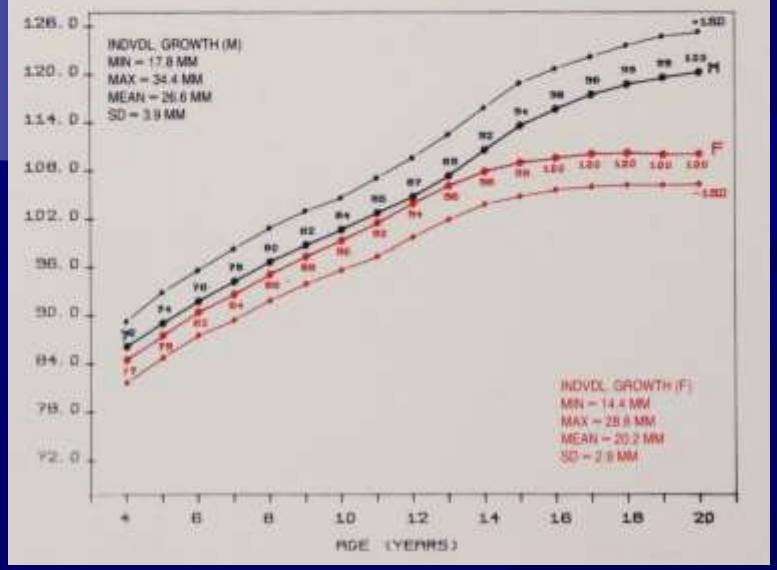
Male Bolton Growth Standards



- The Bolton Atlas shows a small consistent increase in the magnitude of facial dimensions in both males and females with no evidence of growth spurts.
- However, the authors do point out that (1) each individual is a variable entity, and will show changes in growth magnitude at varying times; and (2) the method of averaging tracings into one outline tracing has obliterated these individual variations.
- From Broadbent *et al*. (1975), *Bolton Standards of Dentofacial Developmental Growth.*

King's College London Growth Standards

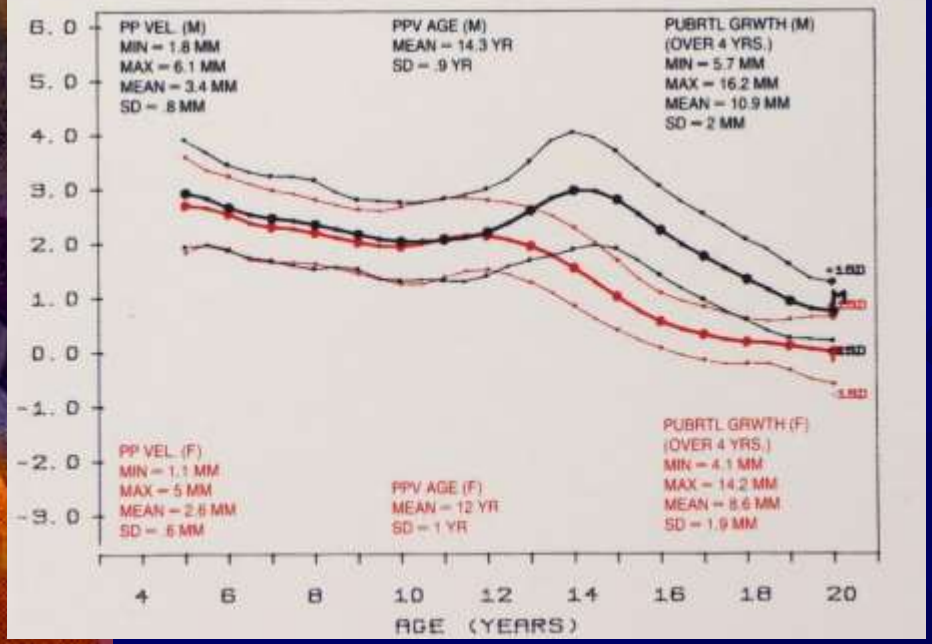
AGE YRS	MALE N	MEAN MM	SD MM	SE MM	SIG	FEMALE AGE YRS	N	MEAN MM	SD MM	SE MM
4	26	86.3	3.0	0.6	*	4	30	84.3	2.9	0.5
5	45	89.2	3.7	0.6	**	5	49	87.3	2.8	0.4
6	54	91.9	3.7	0.5	**	6	59	90.2	2.9	0.4
7	57	94.4	3.9	0.5	**	7	61	92.4	3.2	0.4
8	57	96.8	4.1	0.5	**	8	60	94.9	3.3	0.4
9	58	98.9	4.1	0.5	*	9	63	97.1	3.4	0.4
10	58	100.8	3.8	0.5	*	10	63	99.1	3.7	0.5
11	58	102.9	4.2	0.6	*	11	63	101.3	4.2	0.5
12	58	104.9	4.7	0.6	-	12	63	103.7	4.2	0.5
13	58	107.5	5.0	0.7	-	13	63	105.9	4.2	0.5
14	58	110.7	5.1	0.7	**	14	63	107.7	4.1	0.5
15	58	113.7	5.2	0.7	**	15	63	108.8	4.2	0.5
16	58	115.8	4.9	0.6	**	16	62	109.4	4.0	0.5
17	57	117.6	4.6	0.6	**	17	59	109.9	4.1	0.5
18	48	118.9	4.7	0.7	**	18	53	110.0	4.0	0.5
19	39	119.7	5.0	0.8	**	19	42	109.8	3.8	0.6
20	27	120.4	4.9	0.9	**	20	31	109.9	3.8	0.7



- The KCL Growth Study began in 1952; 528 subjects of Caucasian origin were examined at birth, 6 months and annually thereafter. Cephalometric growth data on 121 subjects were published by Bhatia and Leighton in *A Manual of Facial Growth* (1993).
- All linear measurements were adjusted to natural size. For boys at 14, the mean value for Co–Gn in the Michigan atlas is 126.5 mm, in the KCL atlas 110.7 mm.
- These growth curves show the cumulative changes in the mandibular linear dimension Co–Gn; A small spurt in mandibular growth during puberty is evident in males, less so in females.

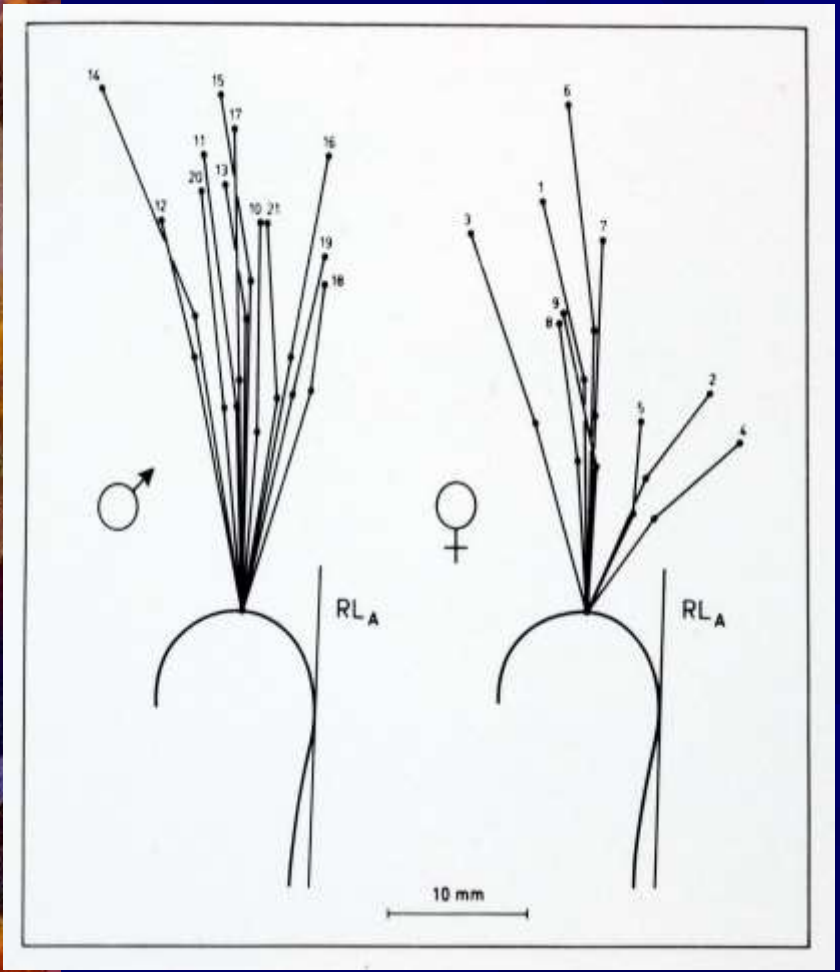
Growth velocity curves for Co–Gn

MALE					FEMALE			
AGE YRS	N	MEAN MM	SD MM	SIG	AGE YRS	N	MEAN MM	SD MM
5	33	2.9	1.0		5	37	2.8	0.9
6	47	2.7	0.8		6	53	2.7	0.7
7	57	2.5	0.8		7	60	2.4	0.7
8	57	2.3	0.8		8	62	2.3	0.6
9	58	2.2	0.6		9	63	2.2	0.6
10	58	2.0	0.7		10	63	.21	0.7
11	58	2.1	0.8		11	63	2.2	0.7
12	58	2.2	0.8		12	63	2.3	0.6
13	58	2.6	0.9	**	13	63	2.1	0.7
14	58	3.0	1.1	**	14	63	1.7	0.7
15	58	2.8	0.9	**	15	63	1.2	0.6
16	58	2.2	0.8	**	16	62	0.7	0.5
17	57	1.7	0.8	**	17	59	0.5	0.5
18	48	1.3	0.7	**	18	53	0.3	0.4
19	39	0.9	0.7	**	19	42	0.3	0.5
20	27	0.7	0.5		20	30	0.1	0.6



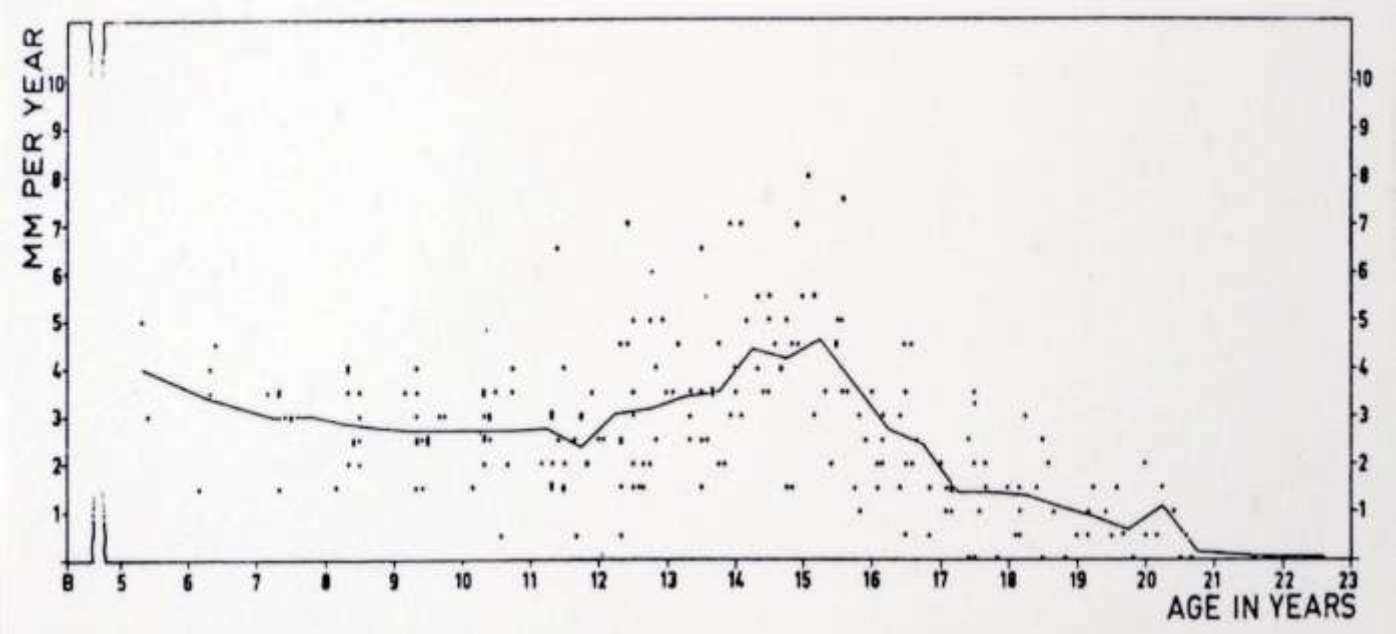
- Another advantage of the KCL manual is that it includes linear dimensions expressed in the form of velocity curves, as shown here for Co–Gn.
- Although they are not tempo-conditional standards, and the data is expressed cross-sectionally, a detectable spurt in mandibular growth starting at the age of 12 is evident, particularly in the males, and at age 10 in the female sample.
- From Bhatia and Leighton (1993), *A Manual of Facial Growth*. *A Computer Analysis of Longitudinal Cephalometric Growth Data*. Oxford University Press, Oxford.

How reliable are mandibular growth measurements ?



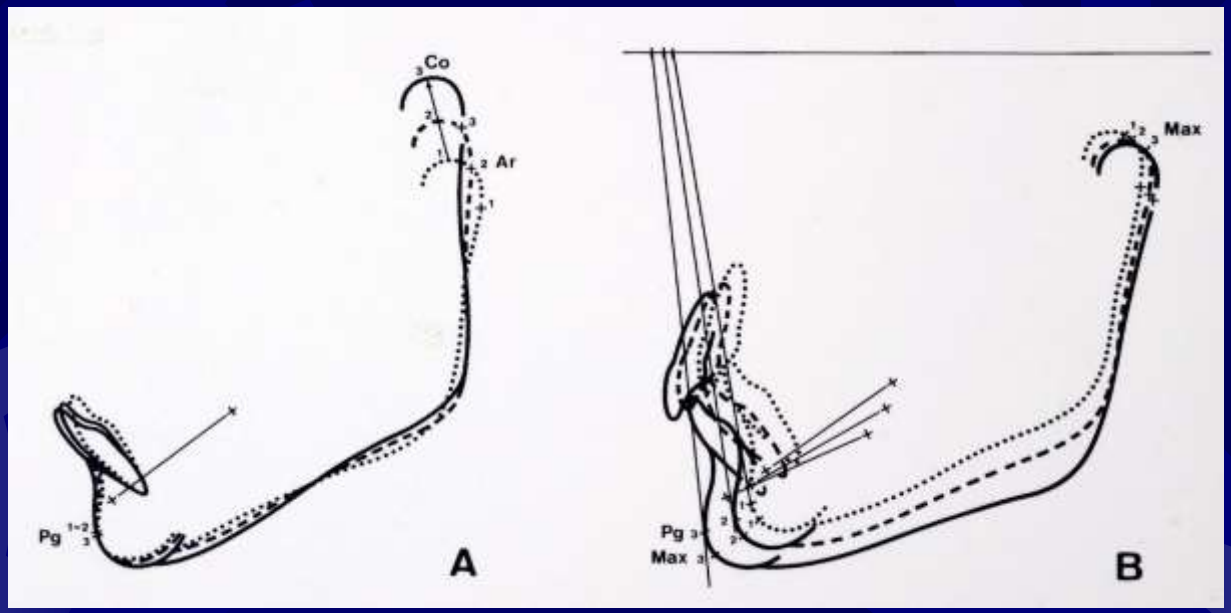
- Changes in the growth of the various facial dimensions discussed above are based on the linear distance between two cephalometric landmarks. For the anterior cranial base (S–N) this does not present a problem, but for an angular bone such as the mandible, the linear dimension Co–Gn or its surrogate Ar–Gn has considerable potential for error.
- When Björk superimposed mandibular profiles on implants he found growth of the mandible was confined to the head of the condyle, but the direction of growth was highly variable.
- From Björk (1963), *Journal of Dental Research* **42**, 400– 411.

Condylar growth rate



- Bjork also measured condylar growth rate in 45 boys from the age of 5–22 years, and found clear differences between the average growth rates for the juvenile (prepubertal) and pubertal periods.
- Annual mean growth during the juvenile period was fairly even at about 3 mm; during the pubertal period condylar growth accelerated to an average of about 5 mm/annum, although marked by wide individual variation.
- From Björk (1963), *Journal of Dental Research* **42**, 400– 411.

Mandibular growth rotation

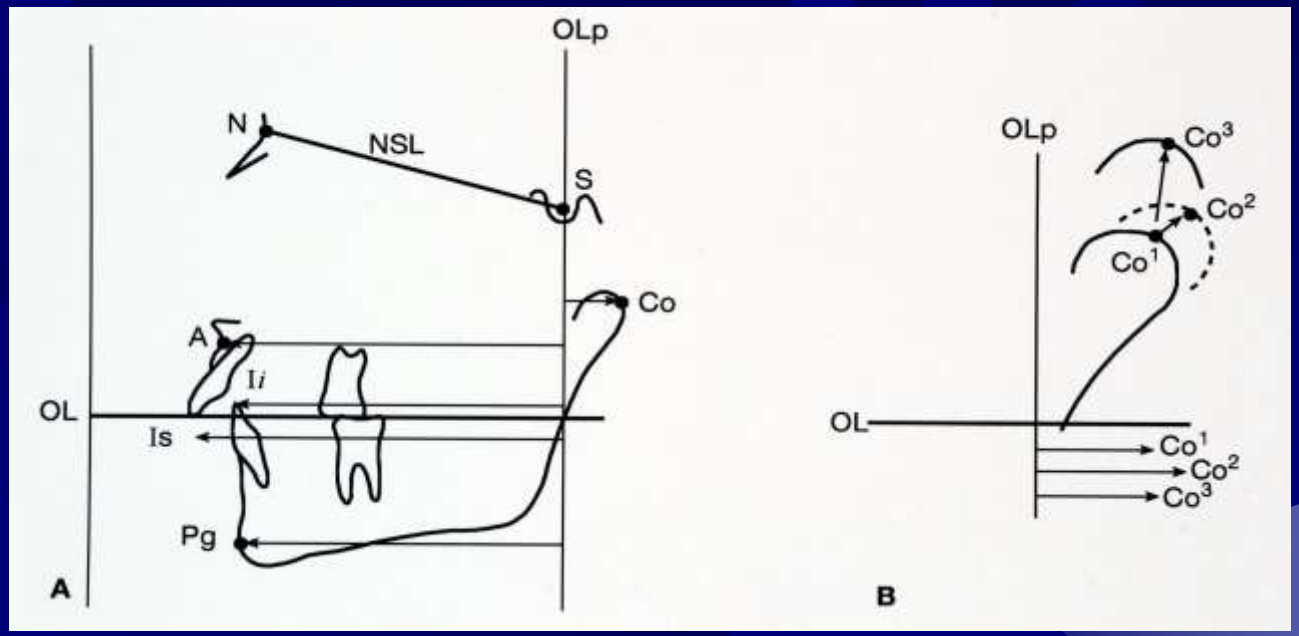


- No studies of mandibular growth published subsequent to Björk's 1963 paper have taken variation in condylar growth direction, and/or mandibular growth rotation into account.
- To address this problem, Hägg and Attström quantified differences between standard cephalometric methods for estimating mandibular length, and (A) a 'scientific method' based on changes in condylion on cephalograms orientated on implants.
- From Hägg.and Attström (1992). *American Journal of Orthodontics and Dentofacial Orthopedics* **102**, 146–152.

Conventional measurements of mandibular length are not valid

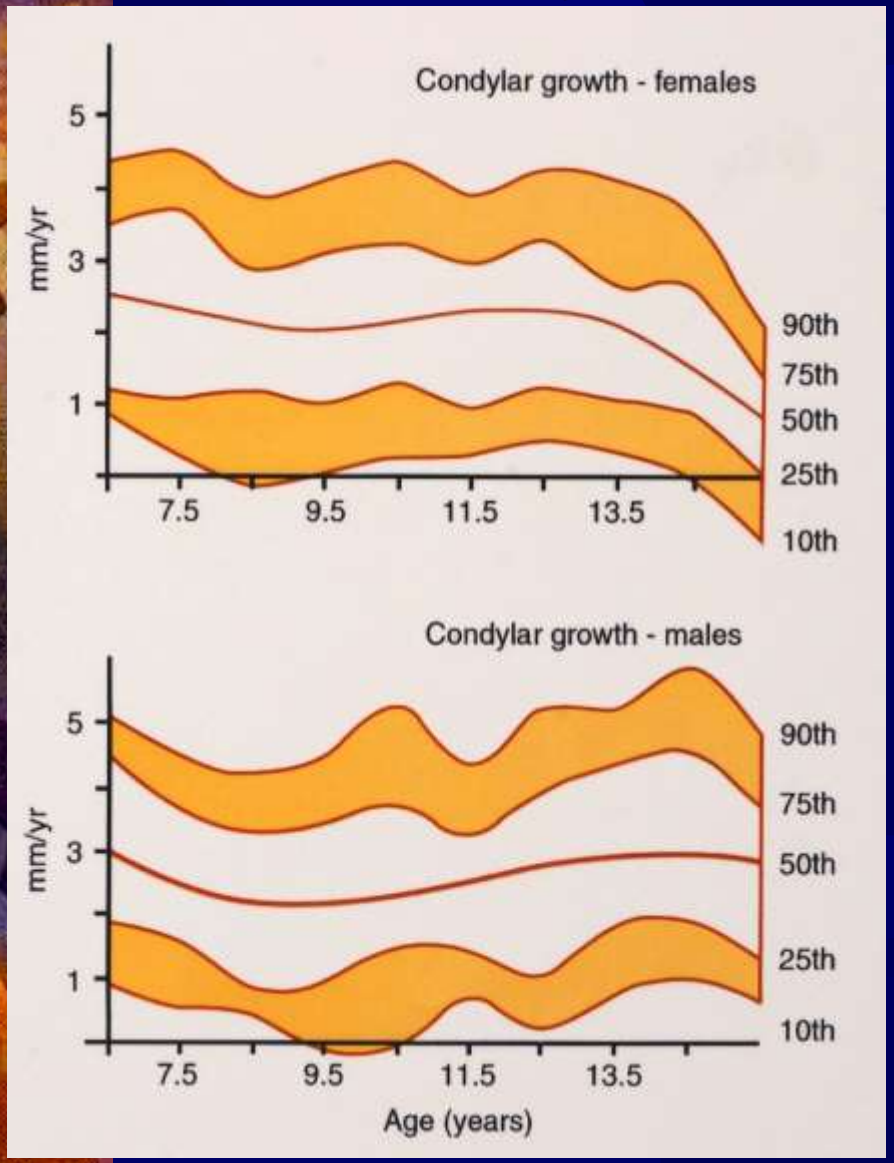
- Hägg and Attström found that (1) the amount of growth estimated by the distance Co–Pog was on average 3.3 mm less than the scientific method, and (2) that the distance Ar–Pog was on average 3.9 mm less than the scientific method. By any criteria these are significant differences.
- Mandibular growth curves based on standard cephalometric methods, and clinical investigations of the effects of treatment on mandibular growth which consistently underestimate the growth of the condyle, are therefore not valid.

Pancherz analysis



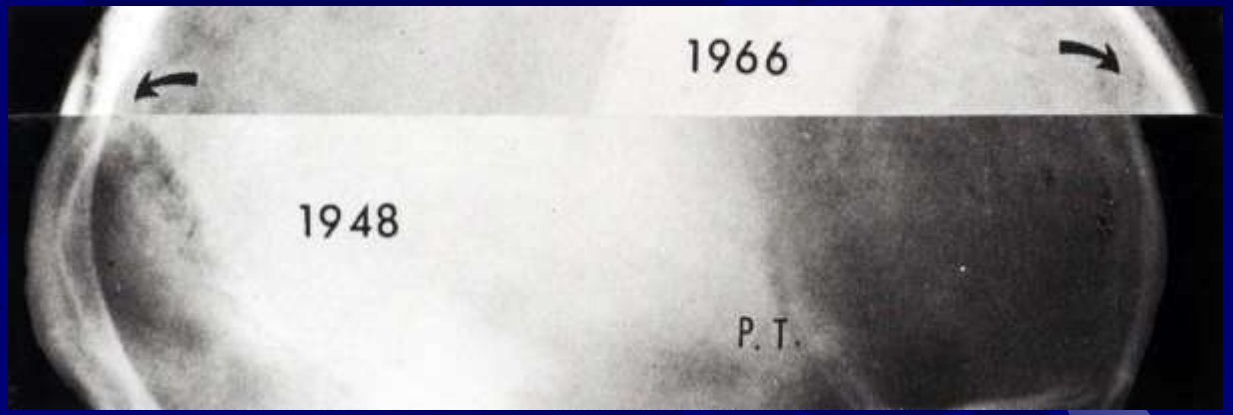
- The Pancherz analysis that has been used for (A) measuring mandibular length (Pg/OLp plus Co/OLp) will also underestimate the contribution of condylar growth (Co/OLp), compared to (B) a direct measurement from Co^1 to Co^2 or Co^3.
- The difference will be less significant the more horizontal the growth pattern of the condyles. However, Björk's research suggests that most will grow in the direction suggested by Co^3, leading to significant differences between direct and indirect measurements.
- Redrawn from Pancherz (1982). *American Journal of Orthodontics* **82**, 104–113.

Condylar growth velocity curves



- This has been addressed by sex-specific growth charts for the condyle (Buschang *et al*. 1999). The data was derived from a mixed–longitudinal sample of 113 male and 108 female French-Canadian children.
- The curves are based on the movement of condylion on serial mandibular tracings superimposed on Björk's structures, and percentiles used to describe individual variation.
- For a male patient on the 90th percentile, for example, condylar growth will average 5mm/year; on the 25th as little as 1–2 mm.
- Redrawn from Buschang *et al*.(1999). *European Journal of Orthodontics* **21**, 167–173.

Growth of the ageing craniofacial skeleton

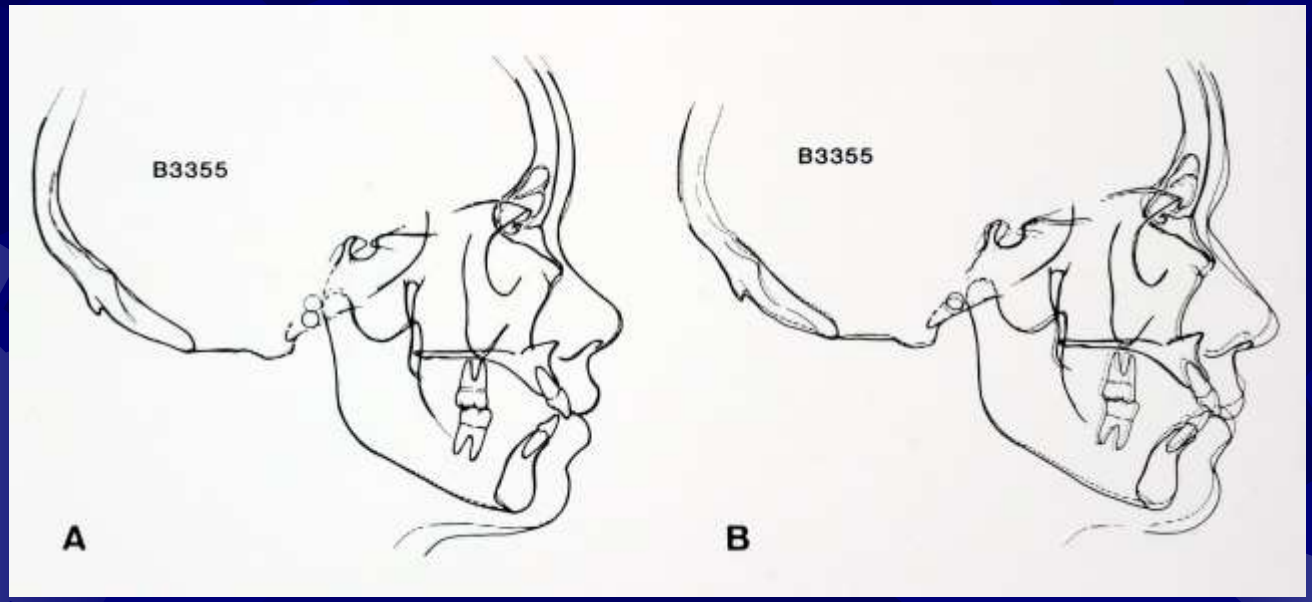


- Growth of the face and head does not cease on physical maturity. Small, measurable increases in both cranial and facial dimensions occur in hard and soft tissue landmarks beyond the age of 20 years.
- The effects of ageing on the skeleton were originally made by anthropologists using craniometric measurements through soft tissues. Cephalometry enabled skull dimensions to be measured more accurately.
- Israel (1968) using subjects from the Fels Research Institute found the skull increased in thickness in both sexes by about 6% after the age of 24. The figure shows an increase in thickness and diameter over an 18 year period.
- From Israel (1968). *Archives of Oral Biology* **13**, 133–137.

Periosteal bone growth at maturity

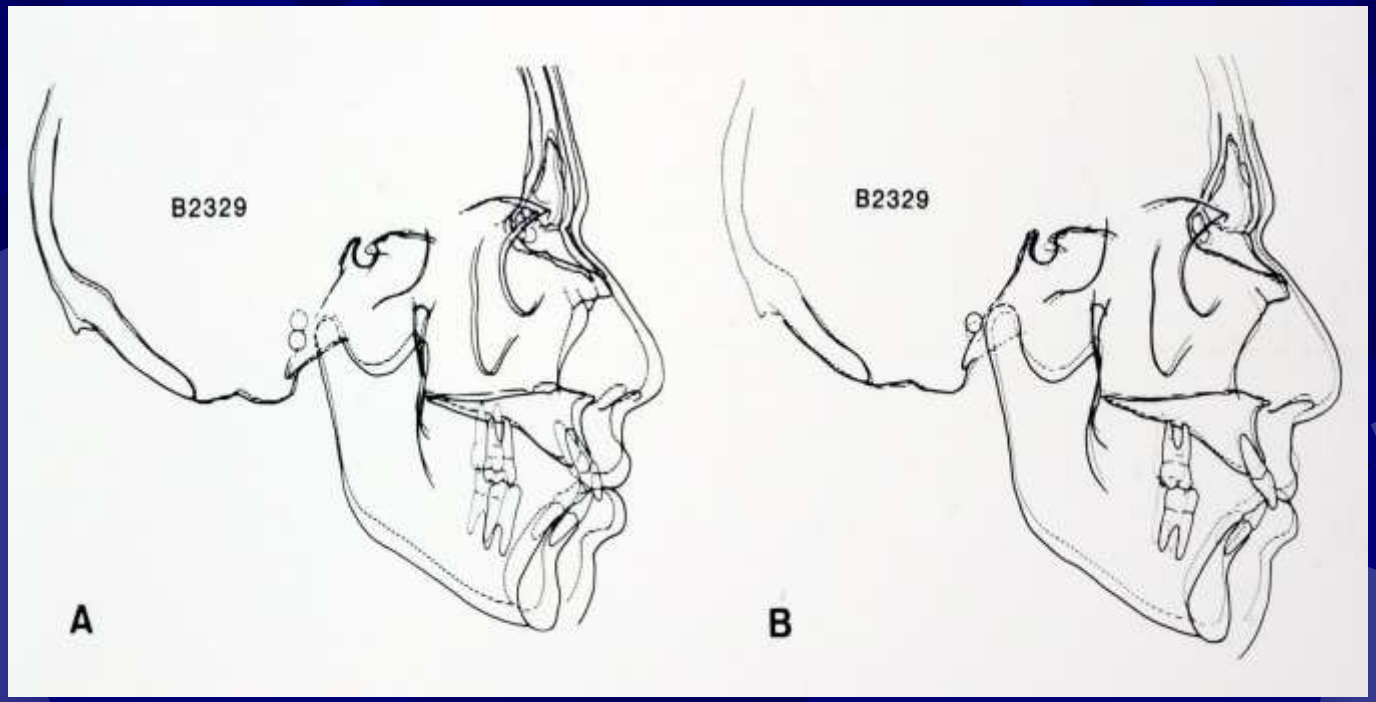
- Israel found a 5–7% increase in mandibular size, and contrary to teaching of long-standing, neither age or dental status had any effect on the gonial (mandibular) angle. Longitudinal radiographic studies of the mandible do not support the view popularized by textbooks that the gonial angle increases with age or edentulism.
- Contrary to the generally accepted assumption that periosteal deposition of new bone ceases at or shortly after skeletal maturity (about age 20), histological studies of sections through the human rib and femur have shown that increases in the transverse dimensions of these bones continues well past the age of 40 years.
- Conclusive evidence that periosteal bone deposition can continue after attaining skeletal maturity was provided by Epker and Frost (1966), who analyzed over 400 mineralized cross-sections of ribs from ninety-two metabolically normal individuals, whose bones had been labelled *in vivo* with tetracycline on one or more occasions.
- Epker BN, Frost HM (1966). Periosteal appositional bone growth from age two to age seventy in man. A tetracycline evaluation. *Anatomical Record* **154**, 573–577.

Growth in the ageing facial skeleton



- Behrents (1985) in a well-known investigation recalled some of the participants in the original Bolton Study; of these 113 were selected for in-depth analysis. Serial headfilm tracings indicated that growth had occurred at older ages than previously thought.
- (A). Female subject at 17 (dotted line) and 21 years (solid line). B. Superimposition at 21 (dotted) and 57 years (solid line). However, it was not possible to pinpoint exactly when the changes had occurred.
- From Behrents (1985), *Growth in the Aging Craniofacial Skeleton.* Monograph 17 Craniofacial Growth Series, Center for Human Growth and Development, University of Michigan, Ann Arbor.

Growth in the ageing facial skeleton



- (A). Male subject at 17 (dotted) and 20 years (solid line). Changes in both osseous and soft tissue landmarks are marked. (B). Superimposition at 20 (dotted) and 55 years (solid line) showing further growth adjustments. From Behrents (1985), *Growth in the Aging Craniofacial Skeleton*.
- Soft tissue glabella moved forwards and downwards with time and soft tissue nasion showed similar adjustments. The nose continued to enlarge and the upper lip lengthened; soft tissue pogonion and menton followed a progressive forward and downward movement.

Summary

- Prior to cephalometric radiography most clinicians believed the dogma of the Angle School; malocclusion of the teeth and jaws was the consequence of inadequate bone growth which could be corrected by orthodontic treatment. In other words, orthodontic appliances could stimulate the growth of bone.
- Following the investigations of Broadbent and Brodie, this was replaced by a new dogma. First, facial growth occurred in an orderly, gradual and consistent manner. Second, orthodontic treatment was limited to dentoalveolar remodelling and tooth movement alone. Some clinicians still believe this.
- Small but detectable spurts in facial growth, and the pubertal growth spurt in height have been well documented, although the timing may be asynchronous.

- Volumes of facial growth standards should now be regarded as historical documents. Facial growth curves are useful if one wishes to know the average growth for a given population sample, but like growth curves for height they reveal little about the dynamics of pubertal growth or the growth of an individual. And after all, as clinicians, that is what we are interested in.

- The Kings College London manual being the most recent, has addressed some of the inadequacies of the Michigan and Bolton standards. However, none are substitutes for contemporaneous controls in clinical investigations of treatment outcome.

- Measurements of mandibular growth based on linear measurements which do not take into account variability in the amount and direction of condylar growth, or mandibular growth rotation are not valid. Editors and referees of academic dental journals please take note.