Change in the width of the mandibular body from 6 to 23 years of age: an implant study

Haluk Işeri* and Beni Solow**

Departments of Orthodontics, Universities of *Ankara, Turkey and **Copenhagen, Denmark

SUMMARY After the ossification of the mandibular symphysis, shortly after birth, changes in mandibular width would be expected to occur only by surface apposition or resorption on the buccal surfaces of the left and right mandibular halves. However, evidence for an opening hinge movement of the two mandibular halves around a vertical axis located in the region of the mandibular symphysis was recently found in longitudinal studies of 29 subjects with *unilateral* implant markers in the mandible. These subjects were followed from 8.5 to 15.5 years of age (Korn and Baumrind, 1990; Baumrind and Korn, 1992). The aim of the present investigation was to examine whether the presence of such an age-related increase in mandibular body width could be confirmed in a sample with *bilateral* implant markers in the mandible. The sample comprised 10 subjects (3F, 7M) from the files of another longitudinal study with implant markers (Björk, 1968). A total of 122 pairs of annual lateral and postero-anterior (p-a) cephalometric records were available, covering longitudinal observation periods ranging from 8 to 16 years within an age interval of between 6 and 23 years. The width between a right and left side mandibular implant marker was measured with digital callipers on all p-a radiographs. Each measurement was corrected mathematically for various sources of radiographic enlargement.

A small, but statistically significant increase in the distance between the right and left implant markers, i.e. in the bilateral width of the mandibular body, was observed in all subjects. The total increase in width in each subject ranged from 0.7 to 1.7 mm for the various periods of observation ($P \leq 0.01$). For the 12-year period from 6 to 18 years, the average total increase was 1.6 mm ($P \leq 0.001$, SD = 0.42), i.e. 0.13 mm/year. After this age there was no systematic trend. The mechanism for this increase in width is unknown. It is suggested that during postnatal growth, an increasing load from the masticatory occlusal forces might influence endosteal bone remodelling in the mandibular body, thus producing or allowing a gradual permanent outward bending of the right and left mandibular halves.

Introduction

During facial growth, the positions of all facial bones change by displacement, while at the same time their surfaces undergo extensive appositional and resorptional surface modelling. The studies of Björk (1963), and Björk and Skieller (1983), have demonstrated the translatory and rotational growth displacements of the mandible in the sagittal and vertical directions, and the accompanying extensive surface modelling. Regarding the transversal growth of the mandible, it is well-known that permanent and total fusion between the right and left mandibular halves occurs early in postnatal life. After that time, postnatal changes in skeletal mandibular width would be expected to occur only by surface apposition or resorption. However, Korn and Baumrind (1990), and Baumrind and Korn (1992), in longitudinal radiographic studies of 29 patients provided with unilateral implants in the mandible and followed from 8.5 to 15.5 years of age, found statistically significant increases in the calculated distances from the implants to a mathematically constructed median sagittal plane of the head. These findings were interpreted to suggest that the two

mandibular halves had separated by an opening hinge movement around a vertical axis located in the region of the mandibular symphysis.

It was the aim of the present study to examine whether such a separation of the two mandibular halves during the postnatal period of growth could be confirmed in a sample with bilateral implants in the mandible. Such a sample would permit precise direct measurement of the width between bilateral implant markers in the mandibular body.

Subjects and methods

The sample was obtained from the archives of the Björk implant studies (1968). The criteria for the selection of subjects from the files was the presence of bilateral tantalum (Ta) implant markers inserted in the mandibular body below the region of the mandibular premolars (Figure 1), and anteriorly and bilaterally in the maxilla (Björk and Skieller, 1974). Subjects with craniofacial anomalies and those treated by orthognathic surgery were excluded. The final sample comprised longitudinal cephalometric radiographic records of 10 subjects (3F, 7M, Table 1). A total of 122 pairs of annual lateral and postero-anterior (p-a) cephalometric radiographs were available, covering longitudinal observation periods ranging from 8 to 16 years within the age interval 6–23 years. The sample represented various types of malocclusions, and records during periods of orthodontic treatment and retention were included.

Radiographic procedures

The films had been taken in a Lumex type B cephalometer (Björk, 1968). The lateral radiographs were recorded with fixed focus to mid-sagittal plane and mid-sagittal plane to film distances of 180 and 10 cm, respectively. For the p-a films, the subjects were positioned in the cephalometer facing the film with the Frankfort plane horizontal. The focus to ear rod plane and ear rod plane to film distances were 180 and 15 cm, respectively. Intensifying screens and a grid were used to reduce exposure dose and scattered radiation on the films.

Figure 1   Segment of p-a cephalometric film from a subject with bilateral anterior and posterior implants in the maxilla, as well as anterior and bilateral posterior implants in the mandible.

Age grouping

In the implant sample of Björk (1968), each subject was followed with annual observations. However, between subjects, the fixed annual date of observation varied randomly in relation to the subject's birthday. This design of the data collection is in contrast to most studies of human growth, but is in agreement with many clinical studies. It preserves more information than conventional growth studies in which the observations are made on the subjects' birthdays, but the statistical processing is somewhat more complicated (Solow, 1969). In the present study, the statistical analyses were based on the series of increments between the annual measurements of the distance between the bilateral groups of implant markers in the mandibular body. Each increment was characterized by its class mid-point age. Age groups (Table 2) were defined by means of these mid-point ages. The first age group, '7 years', thus comprised increments with mid-point ages in the interval 6.50–7.49 years. In four instances of missing films, the corresponding 2- or 3-year intervals were deleted from the calculation of average increments. Age increments were calculated for a total of 109 individual 1-year periods.

Table 1 Survey of the sample, and individual changes in width (Wt) of the mandibular body (ipl–ipr, mm).

Sex	ID	Observation period (age in years)		No. of time points	Length of period (years)	No. of 1-year periods	Total change (mm)	P
		Individual curves	Average curves					
1. F	1906	6.67–20.67	6.67–20.67	15	14	14	1.05	≤0.01
2. F	1908*	6.17–22.25	6.17–20.25	16	16	14	0.68	≤0.01
3. F	1909*	6.17–22.17	6.17–20.17	16	16	14	1.19	≤0.001
4. M	2088	12.08–22.17	12.08–22.17	11	10	10	0.67	≤0.01
5. M	2671	8.50–18.50	8.50–18.50	11	10	10	0.83	≤0.01
6. M	2881	8.25–22.33	8.25–22.33	15	14	14	1.66	≤0.001
7. M	5196	8.92–16.00	8.92–16.00	8	7	7	1.61	≤0.001
8. M	5483	11.42–22.58	11.42–22.58	12	11	11	0.74	≤0.01
9. M	6897	14.50–22.50	14.50–22.50	9	8	8	0.88	≤0.01
10. M	8313**	10.50–20.50	10.50–17.50	9	10	7	0.76	≤0.01
Total					122		109	

*Radiograph missing at 21 years of age.
**Radiographs missing at 18 and 19 years of age.

Table 2 Annual observation periods.

Age group		Mid-points of observation periods		
	n	Mean	Min.	Max.
7	3	6.84	6.67	7.17
8	3	7.85	7.67	8.21
9	5	8.86	8.67	9.21
10	6	9.79	9.50	10.17
11	7	10.83	10.50	11.17
12	8	11.84	11.50	12.17
13	9	12.82	12.50	13.21
14	9	13.81	13.50	14.21
15	10	14.83	14.54	15.17
16	10	15.85	15.54	16.25
17	9	16.89	16.58	17.25
18	8	17.87	17.58	18.17
19	7	18.85	18.58	19.21
20	7	19.84	19.58	20.21
21	4	20.81	20.58	21.00
22	4	21.85	21.63	22.00

Reference points

In all subjects, bilateral anterior and posterior implant markers in the maxilla as well as anterior and bilateral posterior implants in the mandible had been inserted. The bilateral posterior implants in the mandible comprised two implants inserted in each side of the mandibular body below the region of the mandibular premolars. Based on these bilateral mandibular implants, one left (ipl) and one right (ipr) mandibular implant point were defined on each p-a film, throughout each series of films (Figure 2a). All implant points on the p-a films could also be identified on the lateral films. A maxillary anterior implant point and the mid-point between the right and left mandibular implant points were marked on the lateral films (Figure 2b). All points were marked directly on each film with a soft, finely pointed carbon tip pencil (Schwan Stabilo 8008). The width between the left and right implant points on the p-a films (Wm) was measured with digital callipers with a resolution of 0.01 mm.

Correction for radiographic enlargement

Corrections for variations in linear enlargement were necessary before calculation of the growth data. Although all films had been taken in a cephalometer, the radiographic enlargement of the implant distance in each series of films showed within-subject variation due to small differences in head posture on the different films and due to the continued forward growth of the mandible which carried the implant markers
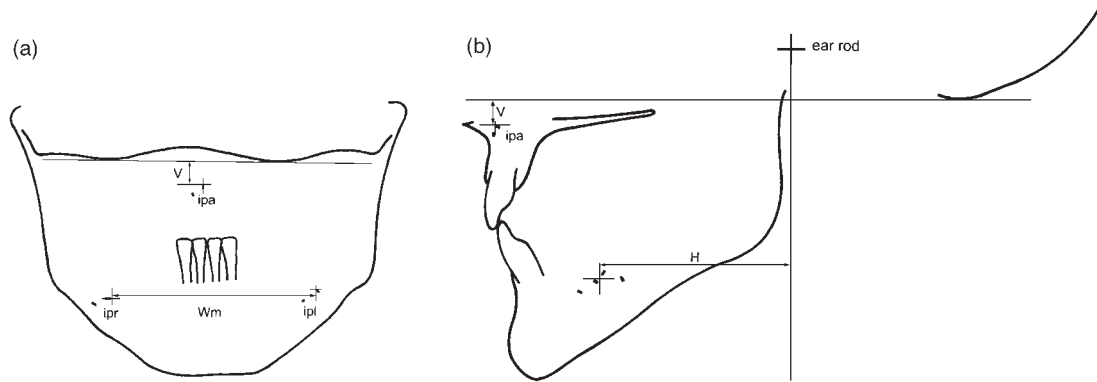
(a)   (b)

Figure 2 Correction for radiographic enlargement of the width measured between the mandibular implants: 1. The width (Wm) between the left (ipl) and right (ipr) implant points was measured on the p-a film (Figure 2a). 2. The course of a central X-ray beam on the p-a film was identified on the lateral film (Figure 2b) by the following procedure: (A) On the p-a film the signed vertical distance, V, from the anterior maxillary implant point (ipa) to a tangent to the most inferior points on the lower border of the occipital bone was measured. (B) On the lateral film, a tangent was drawn from the most inferior point on the lower border of the occipital bone to a point, V mm below or above the anterior maxillary implant point. This line represents the path of the X-rays on the p-a film. 3. On the lateral film the distance, H, from the mid-point between the two mandibular implant points to the centre of the ear rods was measured parallel to the traced X-ray beam. 4. The true width between the left and right mandibular implant points (Wt) was then calculated by correcting the measured width (Wm) for radiographic enlargement by the formula: $Wt = Wm \times [fe + H/(ffl/fmsp)]/ffpa$, where Wt = true width; Wm = measured width; fe = focus-ear rod distance on the p-a film =180 cm; H = distance from the mid-point between the left and right mandibular implant points to the ear rod; ffl = focus film distance on the lateral film = 190 cm; fmsp = focus mid-sagittal plane distance on the lateral film = 180 cm; ffpa = focus film distance on the p-a film = 195 cm. Insertion of the data for the Lumex cephalometer resulted in: $Wt = Wm \times (180 + H/1.0556)/195$.

closer to the film. Moreover, between-subject variations in radiographic enlargement of the implant distance were caused by differences in the distances from the implants to the film plane due to the variability in craniofacial morphology and minor variations in the site of insertion of the implant markers. These variations in radiographic enlargement were corrected mathematically by combining the information from the lateral and p-a films with information about the fixed geometry of the cephalometer as described in Figure 2.

Growth data

Since the sample was mixed longitudinal in nature, with each series of films covering different but overlapping periods of growth, a special technique was used to obtain annual growth data. Average annual increments in width were calculated from those subjects that were included in each of the sixteen 1-year age groups (Table 1). The average distance curve was obtained by setting the curve point at the lower class limit of the first age group, 6.5 years, to zero and plotting the cumulated average annual increments in the upper class limits of the age groups (Table 2). The average velocity curve was determined by plotting the average increments in the class midpoints of the age groups.

Statistical analysis

The statistical analyses were carried out using the Minitab and SAS statistical program packages (SAS Institute Inc., 1982; Ryan et al., 1989). The statistical significance of average changes was assessed by t-tests, and the statistical significance of the change in mandibular body width of the individual subjects was assessed by linear regression analyses. The total average increase in mandibular width was determined by summation of the annual average increments, and the variance for the total change was assessed according to the rules for linear functions of stochastic variables (Hald, 1952).

Method error

For assessment of the error of the method, all marks were removed from the first and last pair of films in each series, and the films were marked again after a period of several months. The calculation of the true width between the implant points on each p-a film was repeated and the total change in width from first to last film was calculated again. There was no significant difference in the average change in width calculated at the two occasions. The method error, $s(i)$, of the assessment of change in width was 0.13 mm (Dahlberg, 1940) and the coefficient of reliability was 0.91 (Houston, 1983).

Results

The average data for the annual and the cumulated annual increments in the mandibular body width, measured between the bilateral mandibular implant points and corrected for radiographic enlargement, are given in Table 3.

The average distance curve from 6 to 23 years of age is shown in Figure 3. From 6 to 18 years, there was a gradual increase, but after 18 years of age there was no systematic trend. The ±2 SE confidence limits for the mean of each annual increment are indicated in the figure. The total average increase was 1.6 mm ($P \leq 0.001$) for the age intervals 7–18 years. This corresponds

Table 3 Average changes in width (Wt) of the mandibular body (ipl–ipr, mm).

| Age group			Mean increment (mm)					
Class mid-points	Class limits	N	Annual	Cumulated	SD	SE	Min.	Max.
	6.5	Starting point set to:		0.00				
7		3	0.34		0.06	0.03	0.28	0.39
	7.5			0.34				
8		3	0.19		0.11	0.06	0.07	0.29
	8.5			0.53				
9		5	0.12		0.14	0.06	–0.11	0.25
	9.5			0.65				
10		6	0.12		0.20	0.08	–0.14	0.44
	10.5			0.78				
11		7	0.22		0.04	0.01	0.14	0.25
	11.5			0.99				
12		8	0.08		0.15	0.05	–0.14	0.29
	12.5			1.07				
13		9	0.07		0.11	0.04	–0.16	0.22
	13.5			1.14				
14		9	0.15		0.13	0.04	0.00	0.40
	14.5			1.29				
15		10	0.11		0.13	0.04	–0.02	0.38
	15.5			1.40				
16		10	0.07		0.16	0.05	–0.17	0.34
	16.5			1.47				
17		9	0.06		0.16	0.05	–0.17	0.34
	17.5			1.54				
18		8	0.07		0.09	0.03	–0.04	0.23
	18.5			1.61				
19		7	0.01		0.06	0.02	–0.09	0.09
	19.5			1.61				
20		7	0.00		0.16	0.06	–0.17	0.28
	20.5			1.62				
21		4	–0.04		0.11	0.06	–0.20	0.06
	21.5			1.58				
22		4	0.07		0.10	0.05	–0.08	0.14
	22.5			1.65				
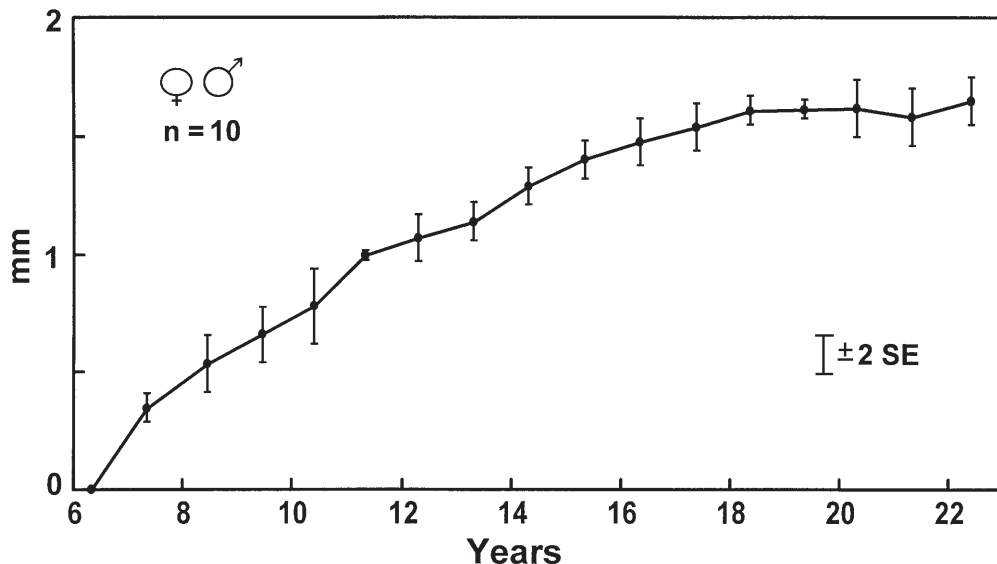
Figure 3 Average change in mandibular body width, corrected for radiographic enlargement. The curve illustrates the gradual increase in the average distance between right and left mandibular body implants. From 6 to 18 years there was a gradual increase in width. After this age, the average width remained constant. The vertical bars in the upper class limits indicate ±2 SE for the average annual increment.

to an average annual increase of 0.13 mm ($P \leq 0.001$). The standard deviation for the total increase was 0.42 mm, and the 5 per cent confidence interval 0.8–2.4 mm.

The average velocity curve (Figure 4) decreased gradually from 6 to 10 years of age. The curve peaked at 11 and 14 years and showed a post-pubertal decrease in velocity until the age of 18.

The individual curves for the 10 subjects (Figure 5) all showed a statistically significant increase in width between the right and left mandibular implant points ranging from 0.7 to 1.7 mm for the various periods of observation (Table 1, $P \leq 0.01$, $P \leq 0.001$). The true width at the initial observation (Wt1) is indicated for each case in Figure 5.

Discussion

Detection of small annual changes on sequential p-a radiographs requires high-precision techniques. A major source of random error in cephalometric investigations is usually the identification of the landmarks. This source of error was markedly reduced in the archive material used in the present study, due to the availability of previously inserted sets of metallic markers ('implants') in both sides of the mandibular body (Björk, 1968). When properly inserted in the endosteal bone, such markers remain permanently stationary.

Another important source of random error is the variability in the radiographic enlargement of transverse skeletal dimensions projected onto p-a films. The first problem is the position of the head in the cephalometer. The subject is positioned facing the film and the head is placed in the cephalometer with the Frankfort plane horizontal. Although in the present archive material, the positioning of the head had been performed by the same operator on all occasions throughout the period of study, some degree of up- and down-tilting was inevitable between films in a series. Therefore, depending upon the differences in the distance from the mandibular implants to the film, the enlargement and, accordingly, the projected width between the implant points, could vary from film to film in a series.
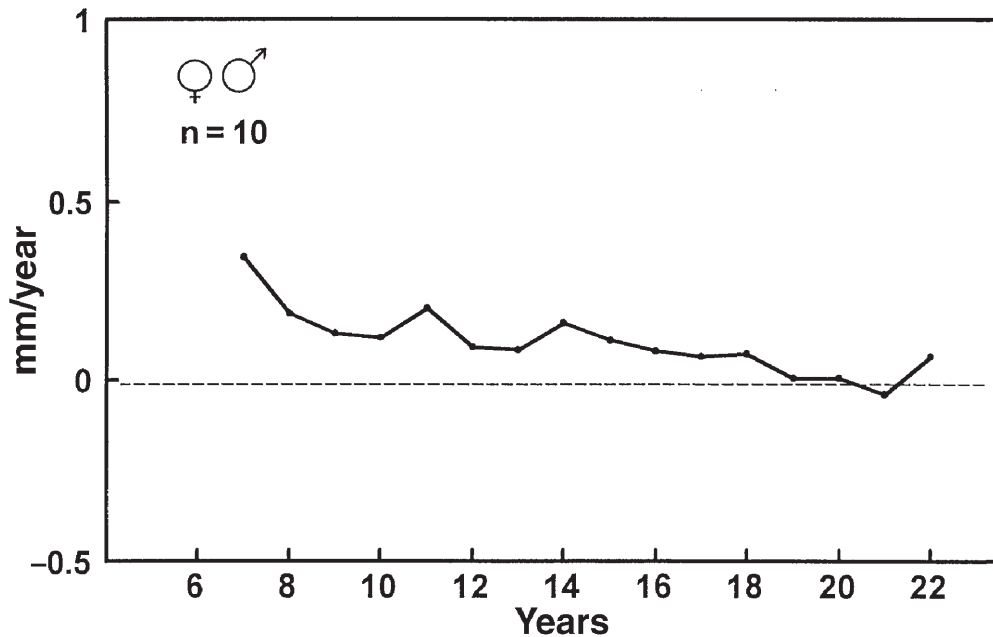
Figure 4 Average rate of change in the width of the mandibular body, corrected for radiographic enlargement.

A second problem was created by the sagittal growth of the mandible. The film cassette is mounted at a fixed distance (15 cm) from the plane of the ear rods. The growth of the mandibular condyles carries the mandibular body and the implant markers closer to the film and, therefore, the projected distance between the right and left implant points on the p-a films will be reduced.

Moreover, in addition to these intra-individual changes in radiographic enlargement in a longitudinal series of films, the variability in craniofacial morphology of the different subjects and minor variations in the site of insertion of the implants, results in between-subject variations in radiographic enlargement of the implant distance on the p-a films.

Since lateral and p-a cephalometric radiographs were available at each age stage, the 3-D radiographic projection geometry could be reconstructed. It was possible, therefore, to mathematically correct each annual measurement of

mandibular width for the radiographic enlargement, thus eliminating these sources of variability.

After correction for enlargement, a gradual increase in the distance between the right and left side mandibular implants was found in all subjects. The total increase in the individual subjects ranged from 0.7 to 1.7 mm for the various periods of observation and the total average increase in mandibular width for the whole group was 1.6 mm (SD = 0.42 mm). In Baumrind and Korn's study (1992) the average linear increase in the mandibular width was found to be 1.84 mm (0.92 mm one side) with a SD of 2.22 mm. The findings of the present study thus confirm those of Korn and Baumrind (1990), and Baumrind and Korn (1992), that an increase in width between the two mandibular halves does, indeed, occur postnatally. On the other hand, the variability of the increase in width of the mandible was markedly smaller in the present study ($P \leq 0.001$), probably due to the fact that in the previous studies only
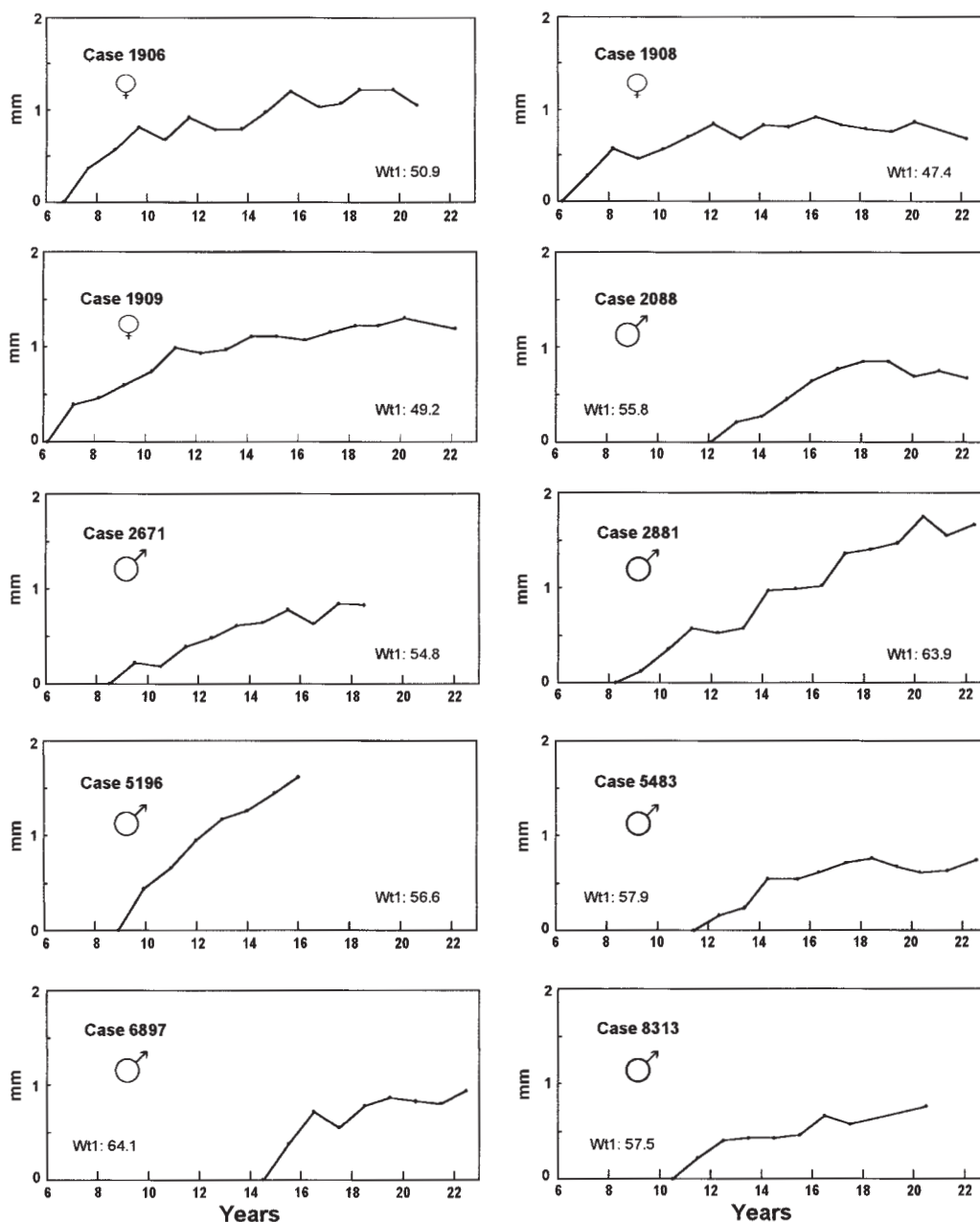
Figure 5 Individual changes in mandibular body width, corrected for radiographic enlargement. Wt1 is the true distance between the mandibular implants at the first time point. The total increase in mandibular body width was statistically significant in all subjects (Table 1).

unilateral implants were available, so that the width had to be calculated by projection onto a constructed median sagittal plane of the head, a method that is probably quite sensitive to the precision of the positioning in the cephalometer. Furthermore, the 3-D correction for radiographic enlargement in the present study would also have contributed to reduction of the component

of random error in the width measurements. The average distance curve was, therefore, remarkably smooth despite the small number of observations in each age group.

The data for males and females were pooled in the calculation of average data, due to the small number of subjects. The average curve increased gradually until 18 years of age, after which the course remained horizontal. The same shape was observed for almost all of the individual distance curves. This shape of the curves is remarkably similar to that of distance curves for variables that reflect the growth of the skeleto-muscular system and skeletal craniofacial growth (Tanner, 1962; Iseri and Solow, 1990). These observations lead to the conclusion that the increase in width between the two mandibular halves is, in some way, probably related to the general development of the skeleto-muscular system of the subjects.

The mechanism that allows the distance between the two mandibular halves to increase is unknown. It is well-known that the mandibular symphysis ossifies shortly after birth, so there is no synchondrosis, suture, or joint that allows an opening hinge movement of the jaws. The implants are below the surface of the bone and remain stable, unaffected by apposition on the bone surface. Usually, several implant markers had been inserted at each implant location. Such implants retained their mutual positional relationship throughout the period of observation. It is not likely that they could move identically through the bone. Moreover, the similar course of all the individual curves makes it unlikely that factors of a random nature could be responsible for the observed changes.

Baumrind and Korn (1992) concluded that 'accommodational changes in the region of the symphysis' was the most likely explanation for the changes observed in their study. Since the symphyseal region ossifies shortly after birth, the question of the detailed nature of such changes remains. Several experimental and simulation studies have demonstrated an outward elastic bending of the mandible under load from masticatory occlusal forces (Hylander, 1977; Weijs and Jongh, 1977; Hylander *et al.*, 1987, Korioth and Hannam, 1994). It seems possible, therefore, that the cause of the outward bending of the two mandibular halves could be related to the increasing long-term intermittent load from masticatory occlusal forces during post-natal growth. The only possible mechanism for such a change seems to be a restructuring of the cancellous and compact bone in the symphyseal region, occurring in connection with the continuous turnover of osteons (Frost 1990a,b).

A permanent increase in width, apparently related to bending of the mandibular body as demonstrated by Korn and Baumrind (1990), Baumrind and Korn (1992), and in the present study, has not previously been reported. To obtain deeper insight into the mechanism responsible for these changes, it is suggested that biomechanical investigations that simulate the transverse strain in the mandibular body caused by masticatory occlusal forces and other functional loads, and also studies of the bone turnover in the human mandible should be carried out.

Address for correspondence

Professor Beni Solow
Department of Orthodontics
School of Dentistry
Nørre Allé 20
DK-2200 Copenhagen N
Denmark

References

Baumrind S, Korn E L 1992 Postnatal width changes in the internal structures of the human mandible: a longitudinal three-dimensional cephalometric study using implants. European Journal of Orthodontics 14: 417–426

Björk A 1963 Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. Journal of Dental Research 42: 400–411

Björk A 1968 The use of metallic implants in the study of facial growth in children: method and application. American Journal of Physical Anthropology 29: 243–254

Björk A, Skieller V 1974 Growth in width of the maxilla studied by the implant method. Scandinavian Journal of Plastic and Reconstructive Surgery 8: 26–33

Björk A, Skieller V 1983 Normal and abnormal growth of the mandible: a synthesis of longitudinal cephalometric implant studies over a period of 25 years. European Journal of Orthodontics 5: 1–46

Dahlberg G 1940 Statistical methods for medical and biological students. Interscience Publications, New York

Frost H M 1990a Skeletal structural adaptations to mechanical usage (SATMU): 1. Redefining Wolff's law: the bone remodeling problem. Anatomical Record 226: 403–413

Frost H M 1990b Skeletal structural adaptations to mechanical usage (SATMU): 2. Redefining Wolff's law: the bone modeling problem. Anatomical Record 226: 414–422

Hald A 1952 Statistical theory with engineering applications. Wiley & Sons, New York

Houston W B J 1983 The analysis of errors in orthodontic measurements. American Journal of Orthodontics 83: 382–390

Hylander W L 1977 *In vivo* bone strain in the mandible of *Galago crassicaudatus*. American Journal of Physical Anthropology 46: 309–326

Hylander W L, Johnson K R, Crompton A W 1987 Loading patterns and jaw movements during mastication in *Macaca fascicularis*: a bone strain, electromyographic, and cineradiographic analysis. American Journal of Physical Anthropology 72: 287–314

Iseri H, Solow B 1990 Growth displacement of the maxilla in girls studied by the implant method. European Journal of Orthodontics 12: 389–398

Korioth T W P, Hannam A G 1994 Mandibular forces during simulated tooth clenching. Journal of Orofacial Pain 8: 178–189

Korn E L, Baumrind S 1990 Transverse development of the human jaws between the ages of 8.5 and 15.5 years, studied longitudinally with use of implants. Journal of Dental Research 69: 1298–1306

Ryan B F, Joiner B L, Ryan T A Jr 1989 Minitab reference manual. Kent, Boston

SAS Institute Inc. 1982 SAS User's Guide: Basics. SAS Institute Inc., Cary

Solow B 1969 Automatic processing of growth data. Angle Orthodontist 39: 186–197

Tanner J M 1962 Growth at adolescence, 2nd edn. Blackwell Scientific Publications, Oxford

Weijs W A, Jongh H J 1977 Strain in mandibular alveolar bone during mastication in he rabbit. Archives of Oral Biology 22: 667–675