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RANGE OF SAGITTAL MOVEMENT OF THE MANDIBULAR CONDYLES AND INCLINATION OF THE CONDYLE PATH IN CHILDREN AND ADULTS

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The movements of the mandibular condyles in the sagittal plane and the inclination of the condyle path were studied with a roentgencephalometric method in children aged 7 and 10 years and in adults. In both children and adults the condyles moved, on the average, forwards and downwards from intercuspal position to postural position. The inferior movement was positively correlated with the inclination of the condyle path recorded between intercuspal and 5 mm protruded positions. The anterior movement of the condyles to maximal protrusion was the same in all the age groups, but the movement to maximal opening was somewhat smaller in 7-year old children than in 10-year old children and adults. In all the age groups the condyles were situated more anteriorly and superiorly in maximal opening than in maximal protrusion. The inferior movements of the condyles from intercuspal position to protruded positions and to maximal opening increased as did the inclination of the condyle path with age. Neither in children nor in adults was any correlation found between the inclination of the condyle path and the inclination of the incisal path. Neither was any correlation found between the inclination of the condyle path and the number of tooth contacts on the working and non-working sides.

The possibilities of inducing remodelling of the temporo-mandibular joints by orthodontic treatment during the growth period has been extensively discussed in the literature. The value of the debate is, however, limited by our present lack of knowledge of the growth and function of the joint during the growth period. Understanding of the function of the joint requires knowledge of its mechanics. As our knowledge of the change in the shape of the joint with growth is incomplete the influence, if any, of such growth changes on the mechanics of the joint is not known. At birth the articular tubercle is missing and gradually develops by appositional growth during the postnatal growth period (*Moffett*, 1968). According to *Humphreys* (1932)

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and *Scott* (1955), the tubercle is not well defined until the age of 6—7 years and it assumes its adult shape at about 12 years (*Humphreys*, 1932). Growth in height appears to continue throughout adolescence (*Angel*, 1948; *Nevakari*, 1960). According to Humphreys, the greatest growth in height occurs at 10—11 years of age.

Post-mortem studies (*Öberg, Carlsson & Fajers*, 1971) have shown that the condyle and the temporal components (fossa and tubercle) of the joint reach adult size earlier in antero-posterior direction than in medio-lateral direction. In the horizontal plane the condyle and the fossa and the tubercle are therefore more circular in children than in adults. Öberg et al. found the joint to increase in size up to the age of 20 years. During the latter part of the growth period growth occurred mainly in medio-lateral direction.

The growth in height of the tubercle, reflected as an increase in the depth of the fossa, has been studied roentgenographically by *Nevakari* (1960) who found a steady increase in the depth of the fossa from, on the average, about 6 mm at 6—8 years until somewhat more than 10 mm at 20—25 years. In skull material *Angel* (1948) measured the slope of the posterior surface of the tubercle relative to the Frankfort plane. He found an increase of the angle from 28° at 6—7 years, 37° at 15 years to 40° at 30—35 years. The depth of the fossa increased from 3.3 mm in the lowest age group to 6.7 mm in the adults, *i.e.* values differing considerably from those given by Nevakari. *Ricketts* (1950), who studied the increase in the depth of the fossa roentgenographically during the growth period, found values intermediate those given by Angel and Nevakari. Also the slope of the tubercle increased during the growth period. The angles given were, however, larger in all age classes than those reported by Angel.

The range of movement of the mandibular condyles and the inclination of the condyle path have been studied mainly in adults. In adults *Posselt & Nevstedt* (1961) found the inclination of the condyle during protrusion to be, on the average, 30° to the occlusal plane and 40° to the Frankfort plane with a considerable interindividual variation (range 60°). The condyle path in the sagittal plane is not straight but somewhat S-shaped. It is 10—12 mm long from intercuspal position to maximal protrusion and longer to maximal opening of the mouth (*Posselt*, 1968). That the condyle path is, on the average, longer to maximal opening of the mouth than to maximal protrusion is because on maximal opening of the mouth the condyle in most individuals glides anteriorly to the highest point of the tubercle (*Ricketts*, 1950; *Nevakari*, 1960; *Lundberg*, 1963, p. 51).

The few investigations published of the growth of the temporo-mandibular joint do not give a uniform picture of the changes in shape during growth and contain no information as to whether and, if so, how growth influences the mechanics of the joint. As pointed out by *Rees* (1954) recording of the slope of the posterior surface of the tubercle in skulls or in roentgenograms will not permit any clear conception of the functional inclination of the condyle path, which is dependent also on the anatomy and function of the soft parts.

Knowledge of the mechanics of the temporo-mandibular joint in children and the effect of the mechanics of the joint on contact between the teeth on contact gliding movements is thus far from complete. It has thus been discussed whether the strong attrition often seen in early mixed dentitions is due to lack of separation of the posterior teeth during gliding movements because the tubercle is not yet fully developed (*Ricketts*, 1966).

This lack of knowledge prompted the author to undertake an investigation of the mechanics of the temporo-mandibular joint in children. The purpose was to chart the sagittal movement of the mandibular condyles between intercuspal position, postural position, maximal protrusion and maximal opening of the mouth in children and in adults and to ascertain the functional, sagittal inclination of the condyle path. The purpose was also to reveal the association, if any, between the inclination of the condyle path and contact between the teeth in eccentric positions.

MATERIAL AND METHODS

The material consisted of 91 children, aged 7—11 years, and 58 adults constituting three groups (Table I).

The material included only individuals with largely normal occlusion and filling the following criteria: neutral occlusion (as judged from the intermaxillary relation at the first permanent molars and at the canines), overjet and overbite (measured *ad modum Lundström*, 1948) between 0 and 5 mm in children and between 0 and 4 mm in adults, and without crossbite. None of the persons included had had permanent teeth (except third molars) extracted. The adults therefore had complete dentitions (disregarding third molars), while in some of the children one or more temporary teeth were missing with the permanent teeth in varying stages of eruption.

The functional state of the masticatory system was judged by recording maximal opening of the mouth in group I, and in groups II and III also of maximal protrusion and maximal lateral movement of the mandible according to methods described previously (*Ingervall*, 1970). In all of the subjects the range of movement fell above the lower limit of the normal range (*Ingervall*, 1970). None of the subjects had symptoms of functional disturbances of the masticatory system.

Table I.

Number of subjects, sex, mean age and range of variation in age in the three groups examined

Group	Number of subjects	Sex	Mean age (years)	Range of variation in age (years)
I	38	20 boys	7 10/12	7 5/12— 8 4/12
		18 girls	7 10/12	7 4/12— 8 3/12
II	53	22 boys	10 9/12	10 2/12—11 3/12
		31 girls	10 8/12	10 2/12—11 2/12
III	58	26 men	23 11/12	20 0/12—29 0/12
		32 women	21 5/12	18 5/12—27 0/12

Recording of positions of mandible. Profile roentgenograms were used for recording the position of the mandible in intercuspal position, postural position, 5 mm protrusion, maximal protrusion and maximal opening.

At the roentgen examination the subjects head was fixed in a cephalostat with the Frankfort plane horizontal. Two roentgenograms were taken with the mandible in postural position, and one with the mandible in intercuspal position according to the method described previously (*Ingervall*, 1964, 1966). This was followed by roentgenograms with the mandible in 5 mm and in maximal protrusion, during which the mandible was stabilised with previously prepared indices. The recording was concluded with the taking of a roentgenogram of the maximal opening position, with the mandible stabilised with a block of wood. Between the exposures in the different positions the subjects were allowed to relax with the mandible in postural position.

The indices with the mandible in 5 mm and in maximal protrusion were prepared in impression compound (Kerr Manufacturing Co., Detroit). In order to secure 5 mm protrusion, marks were made on upper and lower premolar teeth in the same way as for measuring maximal protrusion (*Ingervall*, 1970), after which the subject protruded the mandible, guided by the examiner, and bit a piece of softened compression compound placed against the upper incisors. Maximal protrusion was obtained by the subject protruding the mandible as far as possible and biting. The position of the index for maximal protrusion was on the left posterior teeth.

For stabilisation of the mandible during maximal opening of the mouth a series of wood blocks was prepared. Consecutive blocks differed from one another by 5 mm. At roentgen examination use was made of the largest block that could be placed between the edges of the upper and lower incisors.

In order to secure distinct reference points for the roentgenographic measurements, lead pellets were fixed with impression compound in the interproximal spaces between the central incisors in the upper and lower jaws. The position of the lead pellet in the mandible coincided fairly well with the reference point, the infradentale.

Determination of mandibular position in the various positions recorded. The position of the mandible in the roentgenograms was determined by measuring the position of the condyles (the intercondylar axis) and the

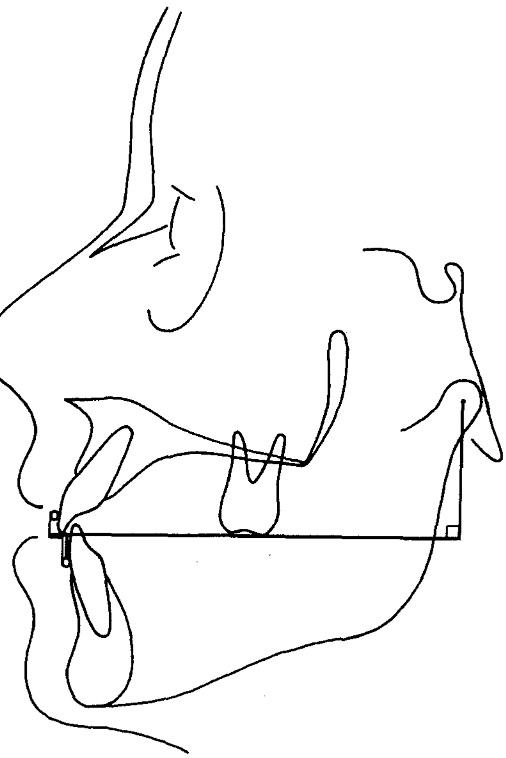

Fig. 1. Measuring points and coordinate system for measurement of the positions of infradentale and intercondylar axis.

position of the lead pellet in the mandible (the infradentale). The maxillary occlusal line (defined according to *Björk,* 1960) was used as reference line.

The occlusal line served as x-axis in a coordinate system, whose origo was situated at the point of intersection between the occlusal line and a normal to it from the lead pellet in the maxilla (Fig. 1). The coordinates for the measuring point at the infradentale and at the condyles were measured with the aid of a coordinate grid (Aristo No. 1981) (Fig. 1). The values were read to the nearest 1/10 mm.

The measuring point, infradentale, was the anterior and superior (when measuring the x- and y-coordinates, respectively) tangent to the lead pellet in the mandible. The measuring point at the condyles consisted of the projection of the intercondylar axis on the median plane. The point was determined in the following way: in one of the roentgenograms of the series the centre of the condyles was determined by measuring the distance between the anterior, posterior and superior outer contour. The point was marked by perforation of the roentgenogram with a needle. The point marked was transferred to the other roentgenograms in the series by superimposition the image of the mandible on the lead pellet at the infradentale and on the lower border of the mandible. In the event of double contours the midline between them was used for superimposition. The method has been described in detail previously (*Ingervall*, 1968a, 1968b).

To define the condyle path not only relative to the occlusal line but also to the nasion-sella line and to the nasal line, the angles between these lines were measured in the roentgenograms. The lines were defined according to *Björk* (1960). The roentgencephalometric method used involves 5.6 % linear magnification of structures in the median plane. The values given were not corrected for this enlargement.

The measurements of the mandibular positions were used for calculation of the movement of the intercondylar axis and of the infradentale between the positions studied. When determining the postural position of the mandible, the mean of the double recordings was used. The intercuspal position was used throughout as reference position by calculating the movement as the coordinate difference relative to intercuspal position. In the designation of the variables studied the following abbreviations were used: intercuspal position ICP, postural position PostP, 5 mm protruded position ProtP, maximal protruded position MPP and maximal opening position MOP. Capitals denote variables for movement of the intercondylar axis and small letters variables for movement of the infradentale.

Variables:

Var. 1	PostP, H	(−ICP, H)	
Var. 5	PostP, V	(−ICP, V)	horizontal and vertical movement of intercondylar axis to postural position,
Var. 2	ProtP, H	(−ICP, H)	
Var. 6	ProtP, V	(−ICP, V)	movement of intercondylar axis to 5 mm protruded position,
Var. 3	MPP, H	(−ICP, H)	
Var. 7	MPP, V	(−ICP, V)	movement of intercondylar axis to maximal protruded position,
Var. 4	MOP, H	(−ICP, H)	
Var. 8	MOP, V	(−ICP, V)	movement of intercondylar axis to maximal opening position,
Var. 9	(icp, H−)	postp, H	
Var. 13	postp, V	(−icp, V)	movement of infradentale to postural position,
Var. 10	(icp, H−)	protp, H	
Var. 14	protp, V	(−icp, V)	movement of infradentale to 5 mm protruded position,
Var. 11	(icp, H−)	mpp, H	
Var. 15	mpp, V	(−icp, V)	movement of infradentale to maximal protruded position,

Var. 12 mop, H (—icp, H)
Var. 16 mop, V (—icp, icp, V) movement of infradentale to maximal opening position.

Variables 2 and 6 were used for calculating the inclination of the condyle path relative to the occlusal line, the angle α (Var. 17) and variables 10 and 14 for calculating the inclination of the incisal path, angle β (Var. 18).

Supplementary recordings. Body height (Var. 19) and body weight (Var. 20) were measured with the method described previously (*Ingervall,* 1970). In roentgenograms taken with the mandible in intercuspal position overjet (Var. 21) and overbite (Var. 22) were measured *ad modum Björk* (1960).

In group I maximal opening capacity (Var. 23) and in groups II and III also maximal protrusion (Var. 24) and maximal lateral movement of the mandible (Var. 25) were measured according to methods reported previously (*Ingervall,* 1970). The total number of contacts between the teeth on the right and left working side (Var. 26) and on the right and left non-working side (Var. 27) in 3 mm lateral position of the mandible were recorded in 50 subjects in group II and in 50 in group III. The method for the registration has been described previously (*Ingervall,* 1972). It was checked by visual inspection whether there was contact between the posterior teeth at 5 mm protrusion (Var. 28).

Statistical methods. The accidental error of double determinations (error of the method), $s_{(i)}$, was calculated from the formula $s_{(i)} = \sqrt{\frac{\Sigma (x_1 - x_2)^2}{2n}}$. Deviations from the normal distribution of the variables recorded were analysed by calculation of skewness, $\sqrt{b1}$, and kurtosis, *b2* or *a* (Geary's test), according to *Pearson & Hartley* (1966). Differences between distributions were tested with Mann-Whitney's U-test. Dependence between variables was studied by calculating rank-correlation coefficients according to Spearman. The expected frequency of false significances was calculated according to *Eklund & Seeger* (1965).

Error of method. The error of the method for determining the position of the intercondylar axis and of the infradentale was calculated from double recordings of all the mandibular positions studied. In double determinations of protruded positions the same index was used on both occasions. The number of observations for double determinations varied from 26 to all the subjects. The errors were used for calculating the accidental errors of the recorded variables according to the formula $s_{(i)}$ variable $2 = \sqrt{s_{(i)}^2 \text{ ProtP, H} + s_{(i)}^2 \text{ ICP, H}}$. The errors of the variables for movement of the intercondylar axis are given in Table II.

It is clear from the table that the errors of determination of the position of the intercondylar axis in supero-inferior direction were larger throughout than those of determination in antero-posterior direction. The errors were regarded as small. For comparison it might be mentioned that the errors of a single determination of the position of the intercondylar axis with the mandible in intercuspal position was 0.16 mm in the antero-posterior direction (ICP, H) and 0.37 mm in the supero-inferior direction (ICP, V). The measuring error, as judged from double measurements of 35 randomly selected roentgenograms, was found to be 0.14 mm for the antero-posterior position of the intercondylar axis and 0.13 mm for the supero-inferior position.

The errors of the method for determining the antero-posterior positions of the infradentale varied between 0.14 mm (Var. 11; mpp, H) and 0.43 mm (Var. 12; mop, H) and for the supero-inferior positions between 0.23 mm (Var. 14; protp, V) and 0.61 mm (Var. 13; postp,V).

Table II.

Accidental errors, s(i) (in mm), of variables of the movements of the intercondylar axis

Variable	$s_{(i)}$
1. Postp,H	0.35
2. ProtP,H	0.24
3. MPP,H	0.26
4. MOP,H	0.31
5. PostP,V	0.46
6. ProtP,V	0.50
7. MPP,V	0.47
8. MOP,V	0.46

RESULTS

Movement of the intercondylar axis. Movement of the intercondylar axis from the intercuspal position to the other mandibular positions studied is accounted for in Tables III, IV and V which also give the movement of infradentale.

Table III.

Mean (M), standard error of mean (e_M), standard deviation (S.D.), range of variation, skewness ($\sqrt{b1}$) and kurtosis (a) of variables concerning movements of the intercondylar axis and the infradentale in 7-year old children (Group I, n = 38). Linear measurements in millimeters

Variable	M	e_M	S.D.	Range of variation	$\sqrt{b1}$	a
1. PostP,H	1.21	0.15	0.94	—0.3 — 4.0	0.765*	0.814
2. ProtP,H	4.58	0.15	0.90	2.6 — 7.2	0.458	0.750
3. MPP,H	9.51	0.25	1.52	4.9 —12.4	—.958**	0.771
4. MOP,H	14.03	0.36	2.19	10.3 —18.0	0.202	0.861*
5. PostP,V	0.83	0.12	0.74	—0.6 — 2.6	0.163	0.768
6. ProtP,V	1.96	0.12	0.73	0.1 — 3.1	—.418	0.788
7. MPP,V	2.10	0.16	0.99	—0.5 — 3.8	—.688*	0.803
8. MOP,V	0.09	0.28	1.74	—3.3 — 3.4	—.155	0.873*
17. α	23.05°	1.31°	8.10°	1.2°—44.1°	—.197	0.760
9. postp,H	0.79	0.15	0.94	—0.5 — 3.4	1.311**	0.762
10. protp,H	4.64	0.13	0.80	2.7 — 6.9	0.260	0.802
11. mpp,H	9.65	0.23	1.42	5.9 —12.3	—.875*	0.780
12. mop,H	17.95	0.63	3.86	12.0 —28.8	1.122**	0.761
13. postp,V	2.39	0.27	1.65	—0.7 — 5.8	0.347	0.841
14. protp,V	1.87	0.17	1.05	—0.4 — 4.0	0.163	0.803
15. mpp,V	1.64	0.20	1.24	—0.8 — 4.0	0.046	0.848
16. mop,V	44.51	3.46	0.56	38.1 —52.4	0.245	0.802
18. β	21.41°	1.67°	10.32°	—4.4°—39.8°	—.347	0.796

* = $0.01<P<0.05$ ** = $0.001<P<0.01$

Table IV.

Mean (M), standard error of mean (e_M), standard deviation (S.D.), range of variation, skewness ($\sqrt{b1}$) and kurtosis (b2) of variables concerning movements of the intercondylar axis and the infradentale in 10-year old children (Group II, n = 53). Linear measurements in millimeters

Variable	M	e_M	S.D.	Range of variation	$\sqrt{b1}$	b2
1. PostP,H	1.02	0.10	0.71	—0.1 — 3.6	1. 032**	4.845**
2. ProtP,H	4.83	0.12	0.84	3.1 — 6.6	—.014	2.239
3. MPP,H	9.82	0.25	1.85	6.4 —14.7	0.134	2.895
4. MOP,H	15.28	0.33	2.40	9.2 —20.5	—.117	3.273
5. PostP,V	0.85	0.10	0.73	—0.7 — 2.9	0.625*	3.604
6. ProtP,V	2.43	0.10	0.69	1.0 — 4.0	0.160	2.517
7. MPP,V	3.08	0.15	1.10	0.2 — 5.6	—.241	3.070
8. MOP,V	1.03	0.24	1.73	—3.6 — 3.7	—.948**	3.665
17. α	26.83°	1.03°	7.52°	11.3°—45.8°	0.483	3.051
9. postp,H	0.31	0.12	0.86	—1.9 — 2.0	—.206	3.160
10. protp,H	4.85	0.11	0.79	3.1 — 6.5	0.064	2.634
11. mpp,H	10.13	0.23	1.66	6.7 —13.9	—.175	2.797
12. mop,H	22.58	0.76	5.51	12.0 —37.2	0.464	2.939
13. postp,V	2.85	0.22	1.63	—0.1 — 6.9	0.660*	3.060
14. protp,V	2.65	0.19	1.40	0.3 — 5.6	0.106	1.969*
15. mpp,V	1.78	0.25	1.79	—2.4 — 8.2	1.102**	5.753**
16. mop,V	48.57	0.58	4.21	37.1 —61.9	—.008	4.696*
18. β	27.34°	1.85°	13.50°	0.4°—48.4°	—.235	2.019*

* = $0.01<P<0.05$
** = $0.001<P<0.01$

In all the groups the condyles moved on the average forwards and downwards from intercuspal position to postural position. The anterior movement in the children (groups I and II) was, on the average, somewhat larger than the inferior movement, while in the adults the anterior and inferior movements were of the same order of magnitude.

The range of variation of the variables 2 and 10 shows that it was not possible to standardise the position of the mandible exactly in 5 mm protrusion. The range of variation, like the mean, was, however, of the same order in all the groups.

The magnitude of the anterior movement of the intercondylar axis to maximal protrusion agreed well in the three groups and was, on the average, 9—10 mm. The condyles moved on the average 14—15 mm anteriorly on maximal opening. The average movement was the same in groups II and III, while the range of variation increased somewhat with age.

Table V.

Mean (M), standard error of mean (e_M), standard deviation (S.D.), range of variation, skewness ($\sqrt{b1}$) and kurtosis (b2) of variables concerning movements of the intercondylar axis and the infradentale in adults (Group III, n = 58). Linear measurements in millimeters

Variable	M	e_M	S.D.	Range of variation	$\sqrt{b1}$	b2
1. PostP,H	0.44	0.05	0.39	—0.2 — 1.6	0.838**	3.889
2. ProtP,H	4.79	0.11	0.81	3.4 — 6.5	—.339	3.584
3. MPP,H	9.18	0.22	1.70	4.9 —12.3	—.245	2.525
4. MOP,H	15.20	0.45	3.43	6.6 —20.8	—.730*	2.878
5. PostP,V	0.52	0.06	0.44	—0.3 — 1.8	0.371	3.009
6. ProtP,V	3.53	0.11	0.85	1.3 — 5.4	0.004	2.841
7. MPP,V	4.83	0.15	1.13	2.5 — 7.4	0.173	2.536
8. MOP,V	3.67	0.24	1.83	—0.5 — 6.9	—.204	2.408
17. α	36.33°	1.13°	8.58°	17.2°—59.7°	0.195	2.720
9. postp,H	—.33	0.07	0.56	—2.5 — 0.6	—1.301**	5.448**
10. protp,H	4.94	0.08	0.63	3.6 — 6.1	—.051	2.318
11. mpp,H	10.49	0.23	1.75	6.9 —14.1	—.173	2.607
12. mop,H	26.21	0.80	6.11	16.1 —40.4	0.341	2.589
13. postp,V	2.23	0.17	1.32	0.3 — 5.9	0.712*	2.981
14. protp,V	3.26	0.16	1.25	0.4 — 6.3	0.353	2.879
15. mpp,V	1.74	0.16	1.25	—0.8 — 5.6	0.359	3.223
16. mop,V	48.74	0.62	4.69	38.4 —59.2	—.095	2.314
18. β	32.58°	1.29°	9.78°	4.9°—56.9°	—.115	3.247

* = $0.01<P<0.05$
** = $0.001<P<0.01$

The inferior movement of the condyles to 5 mm protrusion, maximal protrusion and to maximal opening, like the condyle path inclination, increased with age. In all the groups the condyles occupied a more superior position in maximal opening than in maximal protrusion. In the 7-year old children (group I) the condyles were at the same vertical level in maximal opening as in intercuspal position.

The distribution of some of the variables deviated from normality. The deviations were, however, as a rule, small and were seen mostly among variables for the movement of the mandible to postural position.

Sex differences. In the 7-year old children no statistically significant differences in movement of the intercondylar axis were found with sex. In the 10-year old children the variables 6 and 7 (ProtP, V and MPP, V) were, on the average, probably significantly ($0.01<P<0.05$) higher in the girls than in the boys. The mean inferior movement of the intercondylar axis from

Table VI.
Significant differences between means of variables of movements of intercondylar axis on comparison between groups

Variable	Difference		
	Group I — Group II	Group II — Group III	Group I — Group III
1. PostP,H		0.59***	0.78***
2. ProtP,H			
3. MPP,H			
4. MOP,H	—1.23*		— 1.17*
5. Post,P,V		0.33**	0.31*
6. ProtP,V	—0.47**	—1.10***	— 1.57***
7. MPP,V	—0.99***	—1.75***	— 2.74***
8. MOP,V	—0.94**	—2.64***	— 3.58***
17. α	—3.78*	—9.51***	—13.28***

* = 0.01<P<0.05
** = 0.001<P<0.01
*** = P<0.001

Expected frequency of false significances at 5 % level at most 8 %, at 1 % level at most 2 % and at 0.1 % level at most 0.3 %

intercuspal position to 5 mm protrusion was 2.6 mm in the girls and 2.2 mm in the boys, the corresponding values for movement to maximal protrusion being 3.4 mm and 2.6 mm, respectively. No significant difference was found with sex, however, in the inclination of the condyle path. In the adult group significant differences were found (0.001<P<0.01) for two of the variables (Var. 7, MPP, V and Var. 8, MOP, V), which were, on the average, larger for the males than for the females. The mean inferior movement of the intercondylar axis to maximal protrusion (Var. 7) was 5.3 mm for men and 4.5 mm for women and to maximal opening (Var. 8) 4.4 mm for men and 3.1 mm for women.

Age differences. Most of the variables for movement of the intercondylar axis varied with age. The differences are given in Table VI.

It is clear from the table that statistically significant differences were found between the groups for variables 6—8 and 17. The inferior movement of the intercondylar axis from intercuspal position to 5 mm protrusion, maximal protrusion and maximal opening increased with age. This was also the case for the inclination of the condyle path.

The anterior movement of the condyles to maximal opening was somewhat smaller in 7-year old children than in 10-year old children and adults. Thus, the antero-posterior movement of the condyles increases somewhat during development from 7-years of age.

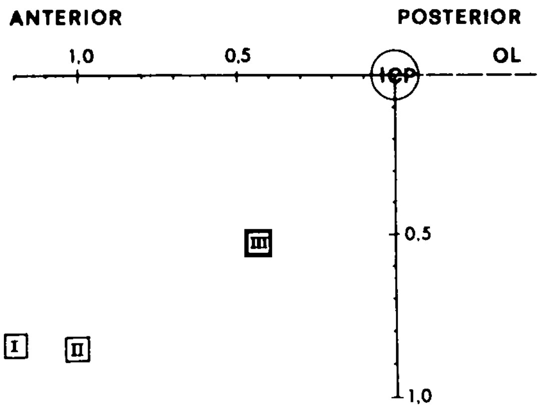

Fig. 2. Average position of intercondylar axis in postural position in groups I, II and III. The position of the intercondylar axis in intercuspal position (ICP) was chosen as the common starting point. OL=line parallel to occlusal line. Measurements i millimeters.

The anterior and inferior movement of the condyles to postural position was larger in the children than in the adults, while no difference was found between the two groups of children. The anterior (Var. 9) movement of infradentale to postural position, on the other hand, was significantly ($0.01 < P < 0.05$) larger in 7-year old children than in 10-year old children and in both 7- and 10-year old children this movement was highly significantly ($P < 0.001$) larger than in adults. It is clear from Tables III—V that in children the infradentale was, on the average, more anteriorly situated when the mandible was in intercuspal position than when it was in postural position, while the relationship was the opposite in adults. The differences in position of the intercondylar axis in the mandibular positions studied in the three groups are given in Figs. 2 and 3.

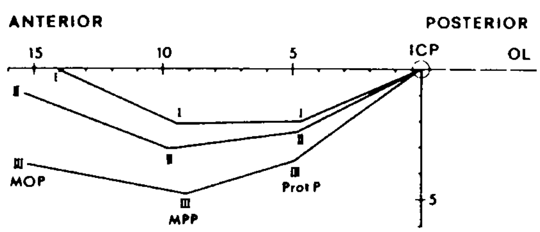

Fig. 3. Average position of intercondylar axis in 5 mm protrusion (ProtP), in maximal protrusion (MPP) and in maximal opening (MOP) in groups I, II and III. The position of the intercondylar axis in intercuspal position (ICP) was chosen as the common starting point. OL=line parallel to occlusal line. Measurements in millimeters.

Table VII.
Average inclination of condyle path in different age groups

	Inclination of condyle path relative to		
Age	maxillary occlusal line	nasion-sella line	nasal line
7-year old boys	21.90°	42.58°	36.90°
7-year old girls	24.33°	45.64°	40.36°
10-year old boys	24.45°	42.75°	37.09°
10-year old girls	28.52°	47.36°	40.74°
Men	38.20°	52.66°	46.54°
Women	34.82°	50.40°	42.63°

The increasing inclination of the condyle path with age is apparent from Table VII, which also gives the average inclination of the condyle path in relation to the nasion-sella line and the nasal line.

Relation between movements of the intercondylar axis. The coefficients of correlation between movements of the intercondylar axis (Table VIII) show that the anterior and inferior movements from intercuspal position to postural position (Var. 1 and 5) were positively correlated in all the groups. The inferior movement (Var. 5) was positively correlated also with the inclination of the condyle path (Var. 17), and in groups I and III also with the vertical movement of the condyles to maximal protrusion (Var. 7) and in group I with the vertical movement to maximal opening (Var. 8). These positive correlations suggest that the magnitude of the inferior movement of the condyles to postural position depends on the height of the tubercles.

The anterior and inferior movements of the condyles to maximal opening (Var. 4 and 8) were negatively correlated in all the groups because during extreme opening the condyles glide anteriorly to the highest point of the tubercles.

The inferior movement of the condyles to maximal protrusion (Var. 7) was positively correlated with the inferior movement to maximal opening (Var. 8) in all the groups and to the inclination of the condyle path (Var. 17). In adults (group III) there was a positive correlation between the inferior movement of the condyles to maximal opening (Var. 8) and the inclination of the condyle path (Var. 17).

Relation between movements of the intercondylar axis and other variables. The coefficients of correlation between the movements of the intercondylar axis and those of infradentale are given in Table IX. As expected, a relatively

Table VIII.

Significant rank-correlation coefficients between movements of intercondylar axis and inclination of condyle path for group I, group II (italics) and group III **(bold print)**

Variable	1. PostP,H	3. MPP,H	4. MOP,H	5. PostP,V	7 MPP,V	8 MOP,V
4 MOP,H	 __0.48__***	0.45** __0.46__***				
5. Postp,V	0.52** _0.48_*** __0.26__*					
7. MPP,V	 _0.31_*			0.54*** __0.46__***		
8. MOP,V		—.33*	—.73*** _—.37_** __—.35__**	0.47**	0.52** _0.52_*** __0.66__***	
17. α		 __—.31__*	 _0.34_*	0.65*** _0.40_** __0.51__***	0.70*** _0.54_*** __0.77__***	 __0.71__***

* = 0.01<P<0.05
** = 0.001<P<0.01
*** = P<0.001

close relation was found between the movements of the condyles and of infradentale. This was particularly the case for the correlations with the anterior movements of the condyles. It was of interest to note that the inclination of the condyle path was not significantly correlated with the inclination of the incisal path in any of the groups.

It is clear from Table X that in the 7-year old children (group I) none of the movements of the condyles were significantly correlated with body height. In the 10-year old children (group II) there were weak positive correlations between body height and the anterior movements of the condyles to postural position and to maximal opening (Var. 1 and 4) and negative correlations with the inferior movements to the same positions (Var. 5 and 8). In the adults (group III) the inferior movements of the condyles to maximal protrusion and to maximal opening (Var. 7 and 8) were positively correlated with body height. A significant correlation with body weight was found only for the anterior movement of the condyles to maximal opening (Var. 4) in the groups of children. The relatively few significant correlations with body height and body weight were weak.

Table IX.

Significant rank-correlation coefficients between movements of intercondylar axis and inclination of condyle path (α) and movements of infradentale and inclination of incisal path (β) for group I ,group II (italics) and group III **(bold print)**

Variable	1. PostP,H	3. MPP,H	4. MOP,H	5. PostP,V	7. MPP,V	8. MOP,V	17. α
9. postp,H	0.79***			0.50**			
	*0.72****	*0.43***		*0.50****			
	0.30*						
11. mpp,H		0.91***	0.51**				
	*0.36**	*0.80****	*0.39***				*0.30**
		0.85**	**0.47****		**0.33***		
12. mop,H			0.43**				0.49**
			0.57*			**—.34***	
13. postp,V	0.52**			0.69***			0.43**
	*0.34**						
	0.40*			**0.34***			
15. mpp,V	0.43**						
		*0.38**			*—.41***		*—.34**
					—.31*		**—.29***
16. mop,V			0.56***			—.46**	
		*0.49****	*0.37***				
	0.36*	**0.37***	**0.78****				
18. β							
		*0.29**					
				0.32*			

* = 0.01<P<0.05
** = 0.001<P<0.01
*** = P<0.001

The overjet and overbite showed, with but few exceptions, no significant correlations with the variables for the movements of the intercondylar axis.

Maximal opening capacity, maximal protrusion and maximal lateral movement of the mandible (Var, 23, 24 and 25) showed moderate to strong correlations with the anterior movements of the condyles to maximal protrusion and maximal opening (Var. 3 and 4) but only occasional significant correlations with the inferior movements of the condyles. The range of movement of the mandible thus appears to be at most weakly related to the height of the tubercles and the inclination of the condyle path.

Only few significant correlation coefficients were found between movements of the condyles and the number of tooth contacts in eccentric positions.

Table X.

Significant rank-correlation coefficients for movements of intercondylar axis and inclination of condyle path (α) with variables 19—23 and Var. 28 for group I and with variables 19—28 for group II (italics) and group III **(bold print)**

Variable	1. PostP,H	3. MPP,H	4. MOP,H	5. PostP,V	7. MPP,V	8. MOP,V	17. α
19. Height	_0.29*_		_0.34*_	_—.29*_	__0.32*__	_—.28*_ __0.35**__	
20. Weight			0.36* _0.34*_				
21. Overjet		_0.33*_					
22. Overbite				__0.32*__			
23. Maximal opening	__0.35*__	_0.42**_ __0.36**__	0.58*** _0.30*_ __0.79***__				0.40*
24. Maximal protrusion		_0.70***_ __0.71***__	_0.43**_ __0.35**__		__0.33*__		
25. Maximal lateral movement		_0.49***_ __0.57***__	_0.33*_ __0.37**__				
26. Working-side contact	_0.39*_		_0.30*_	_0.39*_			
27. Non-working-side contact						__—.41**__	
28. Contact on protrusion				__—.35*__	__—.30*__		

* = 0.01 < P < 0.05
** = 0.001 < P < 0.01
*** = P < 0.001

In the adult group no correlation was found with the number of tooth contacts on the working side (Var. 26) and in the 10-year old children none with the number of tooth contacts on the non-working side (Var. 27). In the adults, on the other hand, a significant negative correlation was demonstrated between the non-working side contacts (Var. 27) and the inferior movement of the condyles to maximal opening (Var. 8). Significant correlations between the *movements* of the condyles and the occurrence of contact between posterior teeth on protrusion (Var. 28) was found only in the adult group. In none of the groups was tooth contact in the eccentric positions found to be significantly correlated with the inclination of the condyle path.

DISCUSSION

The method used for recording the movements of the mandibular condyles has also been employed in a previous investigation (*Ingervall*, 1968a). In both investigations the method proved to have a good degree of precision. With the relatively simple method the movements of the condyles can be recorded with at least as good a precision as with more complicated methods used by other authors (*Nevakari*, 1956, p. 54; *Lundberg*, 1963, p. 23).

For recording the movements of the condyles between the positions studied the roentgenograms are superimposed upon one another with the lead pellet in the mandible and the lower border of the mandible as references. In the event of double contours of the lower border of the mandible, which may occur among other things owing to asymmetric movement of the mandible, the midline between the double contours is used for superimposition. The procedure compensates difference in movement of the right and the left condyle by the fact that the recording point for the condyles is projected into the median plane as the mean of the movement of the condyle on both sides. That this is so has been shown experimentally by *Posselt* (1957) and theoretically by *van Aken* (1963).

The expected frequency of false significances in the tests of the correlation coefficients in Tables VIII, IX and X was calculated according to *Eklund* and *Seeger* (1965). The results of these calculations reveal that of the probably significant ($0.01<P<0.05$) correlation coefficients, at most 21 % were false significances, among the significant ($0.001<P<0.01$) at most 7 % were false, and among the highly significant correlations ($P<0.001$), at most 1 %. This means that a significance level of 5 % is less suitable in the present testsituation because it implies a considerable risk of false significances, which should be observed in the evaluation of the correlation coefficients. But when using the significance levels of 1 % and 0.1 %, especially the 0.1 % level, the risk of false significances is reduced to acceptable level.

The movement of the condyles from postural position to intercuspal position is, on the average, backwards and upwards. The antero-posterior movement of the condyles between the two mandibular positions differs from *Lundberg's* (1963, p. 50) results. He found only a vertical movement of the condyles between these positions. Other authors, such as *Ricketts* (1950), *Posselt* (1952), *Nevakari* (1956, p. 100) and *Sarnäs* (1959) have, however, as in the present investigation, found both an antero-posterior and a supero-inferior movement of the condyles between postural position and intercuspal position. In children as well as in adults the antero-posterior and supero-inferior movements between postural position and intercuspal position were positively correlated. The supero-inferior movement was positively correlated also with *inter alia* the condyle path inclination. These correlations suggest that movements of the condyle between the two mandibular positions are dependent on the anatomy of the tubercle.

The anterior movement of the condyles from intercuspal position to maximal protrusion was, on the average, the same in all age groups, while the movement to maximal opening was somewhat smaller in 7-year old children than in 10-year old children and adults. The investigation showed that already at 7 years the antero-posterior range of movement of the mandibular condyles is about 90 % of the adult range of movement. No difference was found between children and adults in the relation between the positions of the condyles in maximal protrusion and in maximal opening. In all the age groups the condyles were, on the average, more anterior and superior in maximal opening position than in maximal protrusion.

As for the inferior movement of the condyles from intercuspal position to protruded positions and to maximal opening, clear differences were found with age. The inferior movement of the condyles increased with advancing age. As shown by *Lundberg* (1963, p. 51) the translation of the condyle follows the contour of the tubercle. The increasing inferior movement may therefore be regarded as an expression of the increase in the height of the tubercle and in depth of the fossa during growth, as reported by *Angel* (1948), *Ricketts* (1950) and *Nevakari* (1960) and others. No strict comparison with the results reported by these authors is, however, possible because of methodological differences and, second, because the authors in question studied the anatomic growth changes, while in the present investigation the growth changes were studied from a functional point of view. The increase in the supero-inferior movement of the condyles between intercuspal position and maximal protrusion position from 7 years of age to adult age was smaller than the increase in the height of the tubercle during the same time on comparison with the values reported by Angel and by Nevakari, but larger than those given by Ricketts.

The value found for the mean inclination of the condyle path in the adults was somewhat higher than the corresponding value given by *Posselt & Nevstedt* (1961). These authors, however, recorded the inclination of the condyle path with an intraoral wax index and articulator which, according to

Agerberg & Carlsson (1969), tends to give lower values than roentgenography. On comparison with the values found in adults for the inclination of the condyle path registered extraorally with the face-bow method by *Posselt & Skytting* (1960) there is good agreement with those recorded in the adult group in the present investigation.

Differences with sex were found only for a few variables. The inferior movements of the condyles to protruded positions were larger in 10-year old girls than in boys of corresponding age. The difference can probably be explained by the generally earlier physical development of girls than of boys at this age. This difference with sex has also been observed by *Nevakari* (1960) in the increase of the depth of the fossa during the period of growth up to 15 years of age. The sex difference in the adult group in the inferior movements of the condyles to maximal protrusion and to maximal opening is more difficult to explain because in other adult series no difference with sex has been demonstrable in the anatomy or mechanics of the joints (*Isaacson*, 1959; *Lindblom*, 1960, p. 252; *Nevakari*, 1960; *Öberg et al.*, 1971).

Neither in infants nor in adults could any relation be demonstrated between the inclination of the condyle path and the inclination of the incisal path. The condyle path and the inferior movement of the condyles to maximal protrusion was not significantly correlated with the overjet or overbite in any of the groups either. Neither in other investigations (*Nevakari*, 1958; *Lindblom*, 1960, p. 226) has any relation been demonstrated between these variables. It would therefore appear as if the inferior translation of the condyles on protrusion is independent of the relation of the incisors.

As pointed out by *Isaacson* (1959), the inclination of the condyle path on protrusion and the inclination of the path of the non-working side condyle on lateral gliding are not quite equivalent. A close correlation between the inclination of these paths may, however, be assumed. The investigation revealed no correlation between the inclination of the condyle path on protrusion and the number of tooth contacts in lateral positions. Tooth contacts on lateral gliding in the material studied has been accounted for elsewhere (*Ingervall*, 1972). Only one correlation was found between the inferior movements of the condyles and the number of non-working side contacts (in the adult group with the inferior movement of the condyles to maximal opening). Neither was any correlation found between the inferior movements of the condyles and the occurrence of contact between posterior teeth on protrusion in children, while in adults a weak correlation could be demonstrated with the inferior movement of the condyles to maximal protrusion. Both in 10-year old children and in adults, on the other hand, the number of non-working side contacts was weakly negatively correlated with the inclination the incisal path (group II, $r_s = -0.28$; group III, $r_s = -0.29$), and in all the groups the occurrence of contact between posterior teeth on protrusion was negatively correlated with the inclination of the incisal path (group I, $r_s = -0.76$; group II, $r_s = -0.65$; group III, $r_s = -0.43$), *i.e.* the greater the inclination of the incisal path the more separation of posterior teeth on protrusion. The contacts between the teeth in eccentric positions therefore appear to be dependent more on the morphology of the dentition than on the height of the tubercles.

As pointed out in the introduction, our knowledge of growth changes in the temporo-mandibular joints and of the function of the joints during the growth period is far from complete. In the present investigation the mechanics of the joints was studied in children of two ages. The investigation showed that growth changes markedly influence the mechanics of the joint during the growth period. Further investigations of the temporo-mandibular joints in children are desirable. Especially the growth changes of the joints should be examined histologically.

REFERENCES

Agerberg, G. & G. E. Carlsson, 1969: Intraoral och röntgenologisk bestämning av kondylbanelutningen på betandade individer. Sverig. Tandläk.-Förb. Tidn., *61:* 95—104.

Aken, J. van, 1963: Geometrical errors in lateral skull x-ray projections. Nederl. T. Tandheelk., *70:* 18—30.

Angel, J. L., 1948: Factors in temporomandibular joint form. Amer. J. Anat., *83:* 223—246.

Björk, A., 1960: The relationship of the jaws to the cranium. In Lundström, A. (ed.), Introduction to orthodontics. McGraw-Hill Book Company, New-York.

Eklund, G. & P. Seeger, 1965: Massignifikansanalys. Statistiskt Tidskrift, *5:* 355—365.

Humphreys, H., 1932: Age changes in the temporomandibular joint and their importance in orthodontics. Int. J. Orthodontics, *18:* 809—815.

Ingervall, B., 1964: Retruded contact position of mandible. A comparison between children and adults. Odont. Revy, *15:* 130—149.

—»— 1966: Relation between retruded contact, intercuspal, and rest positions of mandible in children with Angle class II, division 1 malocclusion. Odont. Revy, *17:* 28—39.

—»— 1968a: Relation between retruded contact, intercuspal, and rest positions of mandible in children with Angle class II, division 2 malocclusion. Odont. Revy, *19:* 293—311.

—»— 1968b: Studies of mandibular positions in children. Odont. Revy, *19*, suppl. 15, p. 13.

—»— 1970: Range of movement of mandible in children. Scand. J. dent. Res., *78:* 311—322.

—»— 1971: Tooth contacts on the functional and non-functional side in children and young adults. Arch. oral Biol., *17:* 191—200.

Isaacson, D., 1959: A clinical study of the condyle path. J. prosth. Dent., *9:* 927—935.

Lindblom, G., 1960: On the anatomy and function of the temporomandibular joint. Acta odont. scand., *18*, suppl. 28.

Lundberg, M., 1963: Free movements in the temporomandibular joint. A cineradiographic study. Acta radiol. (Stockh.), suppl. 220.

Lundström, A., 1948: Tooth size and occlusion in twins. S. Karger, Basel, p. 52.
Moffett, B. C., 1968: The temporomandibular joints. In Sharry ,J. J. (ed.), Complete denture prosthodontics (2nd ed.). McGraw-Hill Book Company New-York.
Nevakari, K., 1956: An analysis of the mandibular movement from rest to occlusal position. Acta odont. scand., *14*, suppl. 19.
—»— 1958: Alaleuan toiminnallinen protruusioliike. Röntgenologiskefalometrinen tutkimus alaleuan liikeestä keskipurennan ja kärkipurennan välillä. (The functional protruding movement of the mandible). Suom. Hammaslääk. Toim., *54:* 94—120.
—»— 1960: »Elapsio praearticularis» of the temporomandibular joint. A pantomographic study of the so-called physiological subluxation. Acta odont. scand., *18:* 123—170.
Pearson, E. S. & H. O. Hartley, 1966: Biometrica tables for statisticans (3rd ed.), Cambridge University Press, p. 67.
Posselt, U., 1952: Studies in the mobility of the human mandible. Acta odont. scand., *10*, suppl. 10, p. 107.
—»— 1957: Terminal hinge movement of mandible. J. prosth. Dent., *7:* 787—797.
—»— 1968: Physiology of occlusion and rehabilitation (2nd ed.). Blackwell Scientific Publications, Oxford, p. 55.
Posselt, U. & B. Skytting, 1960: Registration of the condyle path inclination: variations using the Gysi technique. J. prosth. Dent., *10:* 243—247.
Posselt, U. & P. Nevstedt, 1961: Registration of the condyle path inclination by intraoral wax records-its practical value. J. prosth. Dent., *11:* 43—47.
Rees, L. A., 1954: The structure and function of the mandibular joint. Brit. dent. J., *96:* 125—133.
Ricketts, R. M., 1950: Variations of the temporomandibular joint as revealed by cephalometric laminagraphy. Amer. J. Orthodont., *36:* 877—898.
—»— 1966: Clinical implications of the temporomandibular joint. Amer. J. Orthodont., *52:* 416—439.
Sarnäs, K.-V., 1959: Inter- and intra-family variations in the facial profile. Odont. Revy, *10*, suppl. 4, p. 41.
Scott, J. H., 1955: Growth changes in the glenoid fossa. Dent. Practit. dent. Rec., *6:* 117—120.
Öberg, T., G. E. Carlsson & C.-M. Fajers, 1971: The temporomandibular joint. A morphologic study on a human autopsy material. Acta odont. scand. *29:* 349—384.

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