Changes in masticatory mandibular movements in growing individuals: a six-year follow-up

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Papargyriou G, Kjellberg H, Kiliaridis S. Changes in masticatory mandibular movements in growing individuals: a six-year follow-up. Acta Odontol Scand 2000;58:129–134. Oslo. ISSN 0001-6357.

The pattern of mandibular movement during chewing is influenced by several central and peripheral factors. The aim of the present study was to determine whether changes in masticatory function, characterized by mandibular velocity and displacement, occurred during individuals' normal growth. Forty-seven children, 9–15 years of age, were followed over a 6-year period. All had an Angle Class I occlusion with no obvious orthodontic problems. Oral motor function with respect to mandibular displacement, duration, and velocity was monitored 3-dimensionally with an opto-electronic method. The chewing cycle was divided into an opening, closing, and occlusal phase. Total body height was measured. During the follow-up period, all masticatory variables except the 3-dimensional opening distance showed significant changes. The total chewing cycle duration, the opening and occlusal time of the chewing cycle, and the 3-dimensional closing distance increased during the growth period, while the closing time of the chewing cycle, the 2-dimensional lateral and vertical distances and both the opening and closing velocity decreased. The children who grew proportionally most in height during the 6-year period, i.e. the youngest children in the group studied, showed a significantly larger decrease in the opening velocity. From this study it becomes evident that the variables of the chewing cycle undergo a continuous process of change during growth. This is possibly a reflection of anatomical changes, maturation of the central nervous system, and altered functional demands. ☐ *Chewing cycle; children; longitudinal study; oral motor function*

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Mastication is one of the most important functions of the stomatognathic system and the first stage of digestion. The development of mastication is probably an extension and modification of suckling (1, 2). The contemporary view is that the rhythmic cycle of mandibular movement is generated by a neuronal population in the brain stem (the central pattern generator) (3–10). This regular centrally generated pattern is influenced both by cerebra-cortical input and by peripheral feedback from receptors in muscles, joints and intraoral structures, causing the great variability in the pattern of mastication (7, 9).

The masticatory pattern is influenced by local factors, such as the presence and consistency of the bolus in the mouth (11, 12), its shape, size, and taste (13–15), as well as the state of dentition (16), type of occlusion (17–20), and muscles (12, 20).

General factors, such as maturation of the central nervous system and peripheral feedback from the oral region (7, 21, 22), the process of learning during childhood (23) growth and development (22, 24, 25), and aging (26) might contribute to the forming of the individual's masticatory pattern. During muscle growth, there is a change in the distribution of masticatory muscle fibers towards an increased percentage of type II (fast fibers) in adulthood (27, 28). The changes in the distribution of the muscle fibers reflect alterations in the motor nerve stimulation. This alteration may be a result of the altered individual functional status (29, 30), and it could be related to central developmental and maturational changes.

Most of the above-mentioned studies on general factors influencing the masticatory pattern have relied primarily on cross-sectional experimental designs, even though the large inter-individual variations in masticatory patterns suggest the need for longitudinal studies. Thus, the aim of this study is to evaluate the masticatory mandibular displacement and velocity longitudinally in healthy growing individuals.

Subjects and methods

Sixty healthy individuals (30 boys and 30 girls) were investigated. Before they entered the study, a clinical examination was performed in order to establish the jaw relation and to ensure that there were no signs or symptoms of TMD.

The individuals who participated in the study were children (9–10 years of age) in the stage of late mixed dentition with at least the second deciduous molars still in occlusion and adolescents (13–15 years of age) with the premolars erupted and in occlusion (Fig. 1). All had Angle Class I occlusion with a harmonious profile, examined clinically, indicating a normal skeletal pattern. They were

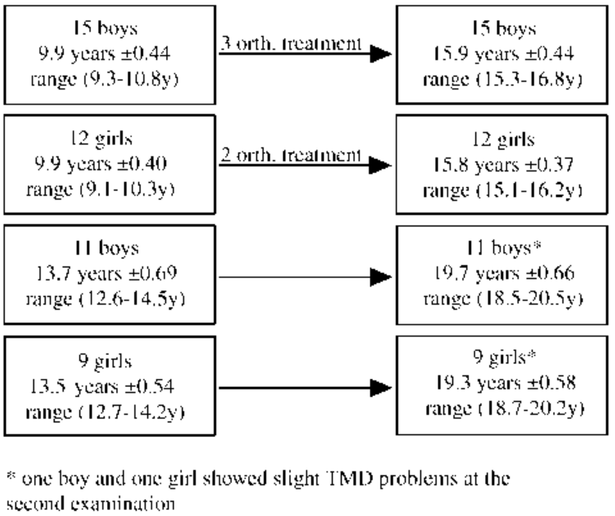

Fig. 1. Age and gender distribution of the subjects participating in the follow-up study. The number of subjects who underwent orthodontic treatment during the follow-up period are presented above the arrows.

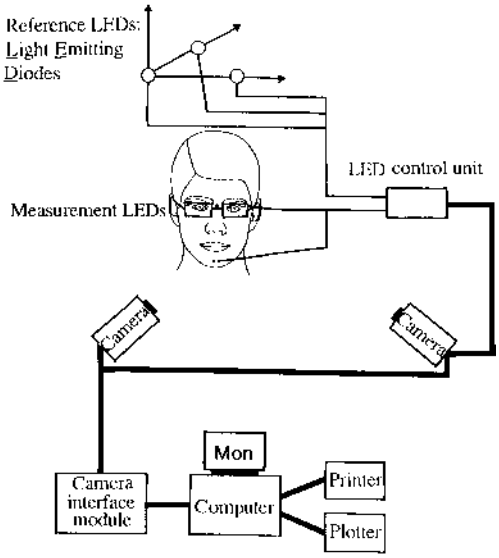

Fig. 2. The components of the Selspot movement analysis system. The system consists of light emitting diodes (LEDs) attached to the mandible and to spectacles, a position-sensitive detector located in 2 cameras and a computer with a camera interface. The computer controls the infrared light emitted from the diodes. A monitor function displays the camera on-line on the screen. By using two cameras, placed perpendicularly to each other, the 3-dimensional coordinates of a movement can be calculated.

selected consecutively from the patients visiting the Department of Orthodontics, Institute of Odontology, Göteborg University, for one of the regular check-ups for occlusal development. Subjects' rights have been protected, and the children and their parents gave their informed consent before entering the study.

Six years later, a total of 47 individuals (26 boys and 21 girls) were re-examined. The remaining 13 individuals could not be reached for re-examination.

During the 6-year period, 5 of the re-examined children underwent orthodontic treatment (between 1.2 and 2.1 years) because of crowding or deep bite. No orthodontic appliance was used on any of the children during the examinations. By the time of the second examination the permanent teeth had erupted in all subjects. Two children showed mild signs and/or symptoms of temporo-mandibular disorders (Fig. 1). The height of all individuals was measured for evaluation of growth between the first and second examinations.

Oral motor function with regard to mandibular displacement and velocity was monitored using an opto-electronic method (Selspot, Partille, Sweden). The reliability of this method for measuring 3-dimensional quantitative data has been proved in previous studies (14, 26, 31).

The system consists of 3 basic units: light emitting diodes (LEDs), 2 cameras, and a computer with a camera interface. Three light-emitting diodes (LEDs) were attached to spectacle frames worn by the subjects; thus creating a reference plane for measuring the LED attached to the subjects' chins (Fig. 2). The system allows accurate analysis of the movements of the mandible in 3 dimensions (3-D). The computer program compensated for head movements. This movement analysis system has been described in detail in previous reports (14, 26, 32, 33). To record a masticatory sequence, the test subject was requested to sit upright in a dental chair and chew peanuts (~1.5 g). Two masticatory sequences from the start to swallowing, omitting the first incomplete masticatory cycle in each sequence, were recorded and analyzed, for a mean of 38 analyzed cycles per subject. Subjects were allowed to change the bolus from side to side at random.

For the computer analysis, a masticatory cycle was divided into 3 separate phases: mandibular opening, mandibular closing, and an occlusal level phase. The occlusal level phase was defined as an arbitrary position of the mandible, from maximum intercuspation to a level 0.5 mm inferior to that position (Fig. 3). A quantitative analysis was performed of the following variables: 1. Time variables: the total duration of a masticatory cycle (TCD) as well as the subdivision of it, the opening phase (OP), the closing phase (CP), and the occlusal level phase (OLP). 2. Distance variables: the mean spatial mandibular displacement in the OP and CP phases, the maximal linear vertical and lateral distances and linear vertical opening amplitude. 3. Velocity variables: the mean velocity measured 3-dimensionally in the OP and CP divisions.

Error of the method

The technical and spatial errors of the method have been studied previously (14, 31) and were found to be less than 1% of the recorded variables: the magnitude of

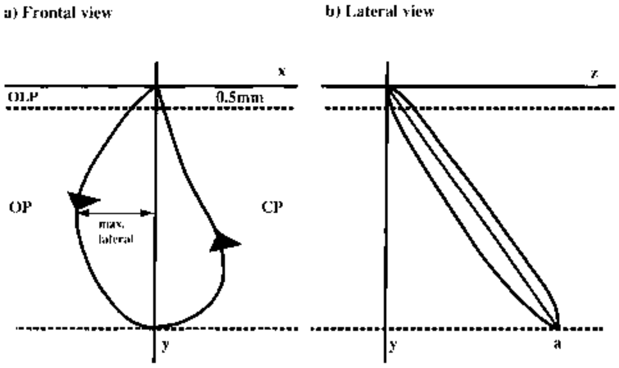

Fig. 3. Computerized measurements of the different phases of the chewing envelopes. x = mesio-lateral dimensions, y = vertical dimensions, z = antero-posterior dimensions. (a) Frontal view: OLP = occlusal level phase; OP = opening phase; CP = closing phase. (b) Lateral view: a = amplitude = $(y^2 + z^2)^{1/2}$. All measurements, except the amplitude and maximal lateral measurements, were based on 3-dimensional recordings.

mandibular displacement, mandibular velocity, and masticatory cycle duration.

Factorial analysis (ANOVA) was applied to test if the recordings from 10 individuals were influenced by the time of the day at which they were performed (morning, noon (before lunch), and late afternoon) or if the recordings taken 2 days (48 h) apart differed. Neither the time of the day nor the time between two adjacent days was a significant factor influencing the masticatory mandibular displacement and velocity.

Statistical methods

Both age groups were merged before the statistical calculations. A paired *t*-test was applied for testing changes in the recorded values between the first and second examinations. Multiple-regression analysis was used to test the influence of growth (expressed by differences in body height), gender and orthodontic treatment (independent variables) on the recorded values of the chewing cycle (dependent variables). The levels of significance chosen were $P < 0.05$.

Results

During the first examination the mean height of the individuals participating in the study was 151 cm (129–180 cm). The growth change in height during the follow-up period was on average 22 cm (0–41 cm).

The orthodontic treatment showed no significant influence on the masticatory variables recorded (Table 2). Almost all the masticatory variables tested changed during the 6-year follow-up period (Table 1).

Masticatory cycle duration

The total duration of the masticatory cycle (TCD) increased by 7.7% during growth. The time for the opening phase increased by 24% and more in the children who grew most during the follow-up (Table 2). The closing time decreased by 8.4%. The duration of the occlusal level phase increased by 21.8%.

Magnitude of masticatory mandibular displacement

The 3-D-closing distance increased by 22.4% though the 2-D amplitude decreased by 14.2%. The maximal linear lateral distance decreased by 17.4%, and this decrease was significantly higher in boys (Table 2). The maximal vertical movements decreased by 15.5%.

Table 1. The mean and standard deviations of the masticatory parameters (time in sec, distance in mm and velocity in mm/sec) from the initial and final recordings of 47 growing individuals. A paired *t*-test was applied for testing the 6-year differences between the initial and final recordings

	Initial recording		Final recording		6-year difference		
Parameters	Mean	SD	Mean	SD	Mean	SD	p
Time variables (in sec)							
cycle duration	0.69	0.08	0.74	0.13	0.05	0.14	0.011
time opening	0.20	0.04	0.25	0.06	0.05	0.06	0.000
time closing	0.35	0.07	0.32	0.09	−0.03	0.09	0.033
time occlusal	0.14	0.04	0.17	0.03	0.03	0.03	0.000
Distance variables (in mm)							
Amplitude	14.02	3.04	12.02	3.00	−2.00	3.37	0.000
Distance open	14.81	3.19	15.68	3.44	0.86	3.54	n.s.
Distance closing	14.10	3.14	17.27	4.39	3.17	3.99	0.000
Max position lateral	7.44	2.18	6.14	1.44	−1.30	2.02	0.000
Max pos. vertical	12.24	2.60	10.35	2.46	−1.90	2.76	0.000
Velocity variables (in mm/sec)							
Velocity opening	89.96	19.99	65.87	15.85	−24.09	16.09	0.000
Velocity closing	60.95	13.23	56.49	9.84	−4.47	13.18	0.025

Table 2. The influence of body height, gender and orthodontic treatment on the changes of the masticatory parameters during the follow up period. Multiple regression analysis of data from the differences during the follow-up period

Dependent variable Y	b_1 gender	b_2 body height	b_3 ort.treatment	R^2%
Time variables (in sec)				
Cycle duration	n.s.	n.s.	n.s.	9.8
Time opening	n.s.	0.002*	n.s.	32.9
Time closing	n.s.	n.s.	n.s.	19.7
Time occlusal	n.s.	n.s.	n.s.	28.7
Distance variables (in mm)				
Amplitude	n.s.	n.s.	n.s.	16.4
Distance open	n.s.	n.s.	n.s.	12.5
Distance closing	n.s.	n.s.	n.s.	12.1
Max position lateral	1.23*	n.s.	n.s.	35.2
Max pos. vertical	n.s.	n.s.	n.s.	20.5
Velocity variables (in mm/sec)				
Velocity opening	n.s.	−0.73***	n.s.	59.3
Velocity closing	n.s.	n.s.	n.s.	8.6

Dependent variables: Y = the differences between the last and the first recording of the masticatory parameters. Independent variables: X = gender body height and ort. treatment. b = coefficient of regression, R^2 = coefficient of determination, * = probability values.

$Y = a + b_1$body height $+ b_2$age $+ b_3$ort.treatment. In the multiple regression analysis concerning the independent value "gender" and "orthodontic treatment", 1 stands for males and 2 for females, and 1 stands for orthodontic treatment and 2 for no treatment, respectively. $*P < 0.05$, $**P < 0.01$, $***P < 0.001$. n.s., not significant.

Mandibular velocity

In the opening phase the mandibular velocity decreased by 26.7%. The children who grew proportionally most in height during the 6-year period showed a significantly higher decrease in the opening velocity (Table 2). This was the case for the youngest children in the group studied. In the closing phase the mandibular velocity decreased by 7.3%.

Discussion

Changes in the masticatory mandibular displacement and velocity of the chewing cycle were observed during the individual's growth period.

Different techniques have been used in studying mandibular motion, and all of them include errors and compromises. One problem is the increased perception of chewing to a more conscious level among the subjects participating in such investigations. The electronic equipment we used in this investigation (Selspot Company, Partille, Sweden) is highly accurate and interferes to a minimum extent with natural chewing. However, it could be discussed if the chewing pattern might be influenced either by the fact that the subjects were getting used to the equipment or by hunger or tiredness due to different recording times during the day. Our findings are based on re-examination of individuals who had undergone a regular occlusal check-up 6 years previously. The equipment and methods used on the first occasion and at follow-up were the same. Unfortunately, the individuals were not re-examined systematically during the same period of the day, and this might have contributed to increase the variation of the measurements. However, according to our observations of how the chewing movements varied during different hours of the day and during adjacent days, these factors seem to be of minor importance. The chewing pattern seems to be stable, which might be interpreted as evidence of a fairly stable underlying control structure as long as other extrinsic or peripheral factors, such as the consistency and size of the bolus, are unchanged. In the present study, the type of test food was standardized to minimize the variation due to consistency and taste (11, 14).

The sagittal molar relations did not change during the follow-up period except for "normal growth changes", i.e. a slightly larger mesial drift of lower molars during tooth shedding of the deciduous molars. None of the children had orthodontic treatment during any of the examinations. At the final examination the 5 children who underwent orthodontic treatment during the follow-up period had been out of retention for at least 6 months.

The maximal movement range, i.e. the 2-D amplitude, the maximal vertical and lateral movements, showed a significant decrease. This is in line with the findings from Wickwire et al. (24), who showed that a wide lateral excursion during opening decreased with age and by the age of 10–12 years the children showed a more vertical pattern, similar to that for adults. They partly explained their findings with the lack of anterior guidance from anterior teeth in the young children. Another plausible explanation might be the skeletal enlargement during growth, that is, when the geometrical proportions between the jaws change, the opening of the jaws does not need to be so large for the same size of bolus (25). Although skeletal enlargement was not measured in the present study, we know from previous studies that the jaws grow between 2 and 5mm/year in the period around puberty and that the jaw growth follows the growth in body height. In the present study the first examination took place before or during the pubertal growth spurt period in most of the children. Therefore we might expect that the changes in jaw growth change correspondingly.

In spite of the smaller movement envelope found, the 3-D closing distance increases. The pattern is also seen for younger children, 4–10 years of age (24). One might have expected that the path of movement would have decreased, firstly because of the geometrical changes and secondly due to maturation, in that developmental changes mostly result in better coordination and exploitation of the locomotion (22). A possible explanation of our finding may be related to the more complex occlusal surface of the permanent dentition due to the presence of larger and steeper cusps compared to the deciduous dentition (34).

The time of the occlusal level phase as well as the total duration of the masticatory cycle increased significantly during the 6-year period. In the mixed dentition, the chewing time may be affected by the eruption of the permanent dentition, the reduced occlusal contacts from missing deciduous teeth, as well as the painful stimuli from periodontal receptors due to deciduous teeth mobility. The increasing number of occlusal contacts during growth after the eruption of permanent teeth and the consequent increase in the occlusal surface area might demand a longer time in occlusion to achieve a better interdigitation. However, our findings conflict to some extent with those of Wickwire et al. (24), who found an increase of the occlusal time during the mixed dentition period and a decrease in the permanent dentition.

No prolongation of the duration of the chewing cycles with age could be detected either in growing individuals or in adults in previous cross-sectional studies comparing different age groups (16, 25, 35). The discrepancy in the findings between our longitudinal and previous cross-sectional studies could be explained by the great inter-individual variation in the masticatory pattern in cross-sectional studies, which may lead to erroneous results.

During the 6-year period the individuals studied underwent a considerable number of changes with regard to their body stature, muscle growth, maturation, and dentition. The possible impact of the development of the dentition on the characteristics of the masticatory movement and velocity has been discussed above. Similarly, the masticatory muscular growth (36) and the increasing bite force during growth (37) could be expected to influence the characteristics of the masticatory cycle. However, this seems not to be the case, at least not for the time duration of the chewing cycle. No statistically significant differences could be detected in the duration of the chewing cycle between individuals suffering from myotonic dystrophy and a healthy control group, though the former had a weaker bite force (38) and thinner masticatory muscles (39).

In a recent study, an increase in synchrony among jaw elevators, a decrease in coactivation between antagonistic muscles and a decrease in EMG burst duration were found during maturation in very small children (1–4 years old), resulting in an altered chewing pattern (22).

In animal experiments, it was suggested that the contraction patterns in the masseter muscle develop and become more refined during growth and that this might result in an altered chewing pattern (40). In another study it was suggested that the changes in the contraction pattern were related not only to changes in the anatomy of the muscle but possibly also to neurological maturation (41).

On the basis of the findings of this study, we may conclude that the variables of the chewing cycle undergo a continuous process of change during growth. This is possibly a reflection of neurological changes and maturation of the central nervous system, as well as of altered functional demands.

Acknowledgements.—This study was supported by grants from the Swedish Dental Society and the Royal Society of Arts and Sciences in Göteborg: the Albert Wallin Foundation.

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Received for publication 14 January 2000
Accepted 18 April 2000