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Follow-up study of functional and morphological malocclusion trait changes from 3 to 12 years of age

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SUMMARY The aim of this study was to evaluate morphological and functional malocclusion trait changes in 3- to 12-year-old children and to determine whether such functional traits at the 3, 4, and 5 years of age correlated with malocclusion severity score at 12 years of age.

Two hundred and sixty-seven children (132 boys, 135 girls) were randomly selected for a follow-up study from a previous cohort of 560 subjects. Functional and morphological traits were clinically assessed. Five functional malocclusion traits: mouth breathing, atypical swallowing, thumb, pacifier sucking, and bottle feeding were assessed and evaluated. Intra-arch assessment involved measurements of incisor crowding, rotation of incisors, and axial inclination of the teeth. For inter-arch measurements, overbite, anterior open bite, overjet, reverse overjet, anterior crossbite, and buccal segment relationships were recorded. The weighted sum of recorded occlusal traits thus represented the total malocclusion severity score.

The median morphological malocclusion severity score was almost the same at 3 and 12 years of age, while functional malocclusion decreased. Sucking habits (finger- or dummy-sucking, bottle feeding) until 5 years of age were statistically significantly correlated with an atypical swallowing pattern from 6 to 9 years (Spearman $r = 0.178$, $P = 0.017$), which in turn was statistically significantly correlated with the morphological malocclusion severity score (Spearman $r = 0.185$, $P = 0.042$) at 12 years of age.

At an early age, the morphological severity score is related to the stage of dental development, while at a later period, malocclusion severity score is also the result of incorrect orofacial functions at an early stage of dental development.

Introduction

Today's emphasis on preventive orthodontic care necessitates rational planning of orthodontic preventive measures on a population basis among children, even in the early stage of dental development. This need highlights the importance of screening methods and epidemiological studies in order to obtain knowledge of the prevalence of malocclusion and the need for orthodontic treatment (Thilander *et al.*, 2001; Ovsenik *et al.*, 2004).

Malocclusion assessment methods differ not only according to various morphological (Baume *et al.*, 1974; Eismann, 1974, 1977; Cons *et al.*, 1986; Brook and Shaw, 1989; Espeland *et al.*, 1992; Daniels and Richmond, 2000) or functional (Summers, 1971; Lundström, 1977; Brook and Shaw, 1989; Ovsenik and Primožič, 2007) occlusal trait recordings and measurements, but also to the stage of dental development. Most malocclusion assessment methods were designed for use in the permanent dentition period (Baume *et al.*, 1974; Eismann, 1974, 1977; Cons *et al.*, 1986; Brook and Shaw, 1989; Ovsenik and Primožič, 2007), only the Occlusal Index (Summers, 1971) was designed for all developmental stages of the dentition.

With the increasing interest in the early detection and treatment of malocclusions and a corresponding emphasis on preventive procedures, it would be beneficial to collect information on patients at younger ages (Farčnik *et al.*, 1985, 1988; Trottman and Elsbach, 1996; Tschill *et al.*, 1997; Thilander *et al.*, 2001; Ovsenik *et al.*, 2004). Treatment of some malocclusions should be started in the primary and early mixed dentition stages, as it is generally believed that the status of the primary occlusion affects the development of the permanent occlusion (Farčnik *et al.*, 1985, 1988; Kurol and Berglund, 1992; Trottman and Elsbach, 1996; Ovsenik *et al.*, 2004; Kurol, 2006; Proffit, 2006).

Posterior crossbites have been reported to be one of the most prevalent malocclusions of the primary dentition in Caucasian children, and if left untreated, may lead to craniofacial asymmetry (Pirttiniemi *et al.*, 1990; Kurol and Berglund, 1992; Sonnesen *et al.*, 2001; Thilander and Lennartsson, 2002; Ovsenik *et al.*, 2004). It has also been suggested that the later these crossbite malocclusions are treated, the greater the risk of damage to the temporomandibular joint (Pirttiniemi *et al.*, 1990; Sonnesen *et al.*, 2001; Kurol, 2006).

Besides heredity, deleterious habits, impaired nasal breathing, and atypical swallowing are considered to be important factors in the aetiology of malocclusion (Melsen *et al.*, 1979; Behlfelt *et al.*, 1989; Kurol and Berglund, 1992; Larsson *et al.*, 1992; Korpar *et al.*, 1994; Øgaard *et al.*, 1994; Thilander and Lennartsson, 2002). It has, therefore, been considered important to treat incorrect orofacial functions and functional malocclusions as early as possible

(Kloehn, 1948; Farčnik *et al.*, 1986, 1988; Kurol and Berglund, 1992; Thilander and Lennartsson, 2002; Ovsenik *et al.*, 2004; Kurol, 2006).

With this background in mind of clinical problems and possible later negative consequences, it would be of interest to assess orofacial functions and functional malocclusion traits in preventive orthodontic treatment planning (Farčnik *et al.*, 1985, 1988; Kurol and Berglund, 1992).

The role of sucking habits in the aetiology of malocclusions has been investigated by Melsen *et al.* (1979), Larsson (2000), and Øgaard *et al.* (1994). These studies were cross-sectional and concentrated mostly on the effects of prolonged sucking habits, indicating that irreversible malocclusions were produced if the sucking persisted beyond 4 years of age (Lindsten *et al.*, 1996).

There have been no reported studies on the effect of incorrect orofacial functions on the development of occlusion and morphological malocclusion severity score.

Therefore, the aim of this research was to assess functional and morphological malocclusion trait changes of the orofacial region from 3 to 12 years of age and to determine how early functional malocclusion traits correlate with malocclusion severity score at 12 years of age.

Subjects and methods

The research was part of a longitudinal study (Farčnik *et al.*, 1986). A cohort of 560 children was included, from which 267 children (132 boys, 135 girls) from 3 to 12 years of age were selected at random for a follow-up study. Recordings and measurements of five functional and 10 morphological occlusal traits were registered yearly using the method of Farčnik *et al.* (1988).

Functional malocclusion traits were registered during clinical examination and the mode of breathing determined with an airflow instrument (Farčnik and Rudel, 1987) that registers the difference in airflow temperature through the mouth or nose in subjects with an incompetent lip seal, thus distinguishing mouth breathing from an incompetent lip seal (Figure 1).

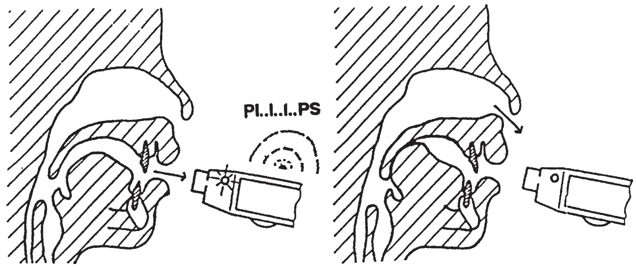

Figure 1 The breathing apparatus used to measure airflow. Airflow from the nasal cavity in an open mouth posture (right). When the airflow is through the oral vestibule (left), an audible signal/light is produced.

A modification of the method suggested by Melsen *et al.* (1979) was used to determine swallowing so that tongue-thrust and teeth-apart swallowing were registered as a single functional malocclusion trait category. The assessment of swallowing pattern was carried out while the children were swallowing small amounts of water. First, the mandibular movements and perioral muscle contractions were observed during swallowing. Then the examiners palpated the temporalis and the masseter muscles while the patient produced an 'unconscious' swallow, as this may deviate from the swallow on command.

Information on a subject's deleterious habits such as finger- or dummy-sucking and bottle feeding was recorded through parental interview. Each child was clinically examined by three independent examiners and the consensus opinion was accepted. Alginate impressions of the maxillary and mandibular arches and wax bite registrations were obtained annually for each child. All models were assessed by a single examiner (MO), calibrated in the use of the method. Intra-arch assessment involved determination of incisor crowding and rotations. For inter-arch measurements, overbite, anterior open bite, overjet, reverse overjet, anterior crossbite, and buccal segment relationships were recorded. For each set of morphological measurements, registrations were carried out using a metric ruler (Zürcher model, Dentaurum 042-751, Ispringen, Germany) accurate to 1/10 mm.

All morphological traits, recorded and measured, were weighted and scored against a scoring table (Figure 2). The weighted sum of recorded occlusal traits thus represented the total malocclusion severity score. The overall malocclusion scores according to Farčnik *et al.* (1985, 1988) were categorized in terms of mild (1–15), moderate (16–40), severe (41–65), and very severe (over 66) malocclusion. Treatment need in the present study was defined as a total malocclusion severity score over 15 (Farčnik *et al.*, 1986).

For statistical analysis, the Statistical Package for Social Sciences, Windows version 13 (SPSS Inc., Chicago, Illinois, USA) was used.

Results

For any longitudinal investigation, it is inevitable that patients drop out during the study period. For statistical correctness, it is necessary to verify that these dropouts occur at random. Figure 3 shows how the children in the study, some of whom dropped out but then returned, were transferred from the treatment need group to the no treatment need group and *vice versa*. For example, there were 110 children in the no treatment need group and 105 children needing treatment at 6 years of age. During the next year, 14 children left the study from the no treatment need group and nine from the treatment need group; the malocclusion severity score worsened in 25 children but improved in 31 subjects. Additionally, 19 children who dropped out at 6 years of age returned. Thirteen were then

I. Space analyisis

1. Anterior crowding

upper	no crowding	0
	crowding	7
lower	no crowding	0
	crowding	5

Intense crowding in the region of one tooth

3-4 mm	2
4-5 mm	4

2. Rotation of incisors

upper	0-25°	0
	> 25°	5
lower	0-25°	0
	> 25°	2

II. Morphological traits of malocclusion in the vertical plane

3. Overbite

1-2 mm	0
> 2 mm	8
>2mm with gingival trauma	20

4. Anterior open bite incl.canines

1-0 mm
0-1 mm
1-2 mm
2-3 mm
> 4 mm

III. Morphological traits of malocclusion in the antero-posterior plane

5. Overjet

1-2 mm	0
4-5 mm	2
5-6 mm	5
6-7 mm	8
7-8 mm	12
8-9 mm	16
9-10 mm	20
> 10 mm	24

6. Reverse overjet

1-0 mm	2
0-1 mm	4
1- mm	8
2-3 mm	12
3-4 mm	14
> 4 mm	16

7. Anterior crossbite incl. canines

first pair	8
next pair	5

8. Anteroposterior occlusion of posterior teeth:

Occlusion of single cusps in the case of 1-2 pairs of opposite teeth 1

Occlusion of single cusps in the case of 3 and more pairs of opposite teeth 3

IV. Morphological traits of malocclusion in the transverse plane

9. Deviation between the midlines of the upper and lower jaw

0-1 mm	0
1-2 mm	1
2-3 mm	2
> 3 mm	3

10. Transverse posterior occlusion of single cusps in the case of 1-2 premolars 1

occlusion of single cusps in the case of premolars and molars 2

crossbite per pair of opposite teeth 1

buccal or oral nonocclusion per pair of opposite teeth 4

Figure 2 The scoring table (Farčnik *et al.*, 1985, 1988, reproduced with permission).

categorized as requiring no treatment and six as requiring treatment. As a result, at 7 years of age, 115 children were in the no treatment need group and 96 in the treatment need group.

Because of multiple comparisons, it is not unusual to find few statistically significant differences, i.e. among 7- and 8-year-old children, there were more dropouts from the no treatment need group than from the treatment need group, and also there were more children with an improved morphological severity score. Overall, there was a visible shift towards an improved better occlusion, which could not be attributed to the different dropout rates in the two groups.

With the exception of 3 years of age, the morphological malocclusion severity score was almost the same throughout growth and development, median scores ranging from 11 to 15. The highest malocclusion severity score (median score 20) was found at 3 years of age, probably due to an anterior open bite resulting from deleterious sucking and feeding habits. The morphological malocclusion severity score in the need for treatment categories was present at 3 years of age in 50 per cent of the examined children and remained stable throughout growth and development (Table 1). Functional malocclusion traits were present at 3 years of age in almost all children, but showed a tendency to decrease towards the end of the mixed dentition period (from 85.4 to 37.3 per cent, Table 1).

Functional malocclusion traits had the highest value at 3 years of age and showed a tendency to diminish towards 12 years. Mouth breathing was approximately constant, regardless of age, and was present in 28 per cent of the examined children, while an atypical swallowing pattern decreased from 55 per cent in 3-year-old children to 24 per cent at 12 years of age. Deleterious sucking habits diminished completely towards the end of the primary dentition phase, at 5–6 years of age. Only thumb sucking was still present in

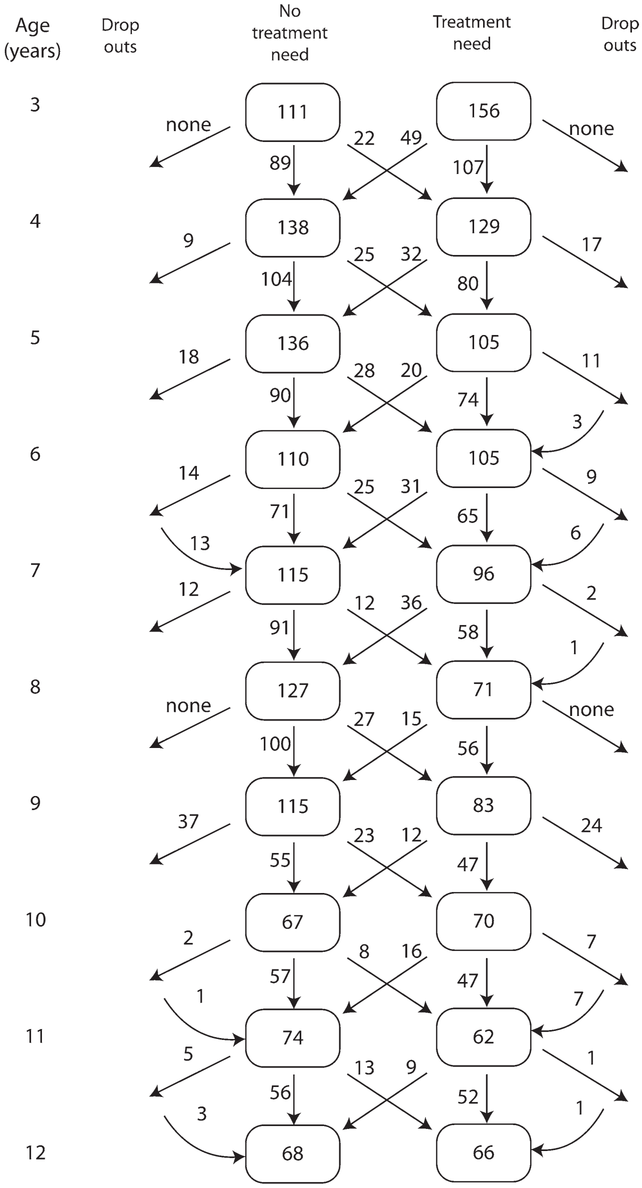

Figure 3 Classification of malocclusion scores into grades of severity classified according to treatment need.

nearly the same percentage of children at 3–8 years of age (Figure 4).

The results (Figure 5) showed that sucking behaviour (finger- or dummy-sucking, bottle feeding) that persisted at 5 years of age was statistically significant for an atypical swallowing pattern at 6–9 years of age ($r = 0.178$, $P = 0.017$).

An atypical swallowing pattern at 6–9 years was significantly correlated with morphological malocclusion severity score at 12 years of age (Figure 6).

Discussion

In order to assess malocclusion severity on a population basis among children during early dental development in preventive orthodontic treatment planning, the Eismann (1974) index was modified for the mixed and primary dentitions by Farčnik *et al.* (1985, 1988), adding numerical assessment of functional malocclusion traits. Numerical estimation of functional symptoms was clinically evaluated in Slovenia and used in a study to determine interceptive orthodontic treatment results (Korpar *et al.*, 1994). The morphological traits of malocclusion are well defined and the method was found to be easy, valid, and reliable for use in the early stages of dental development.

Table 1 Median value of morphological malocclusion score and number and percentage of children with functional malocclusion traits.

Age in years	No. of children	Median	Children with a score >15 (treatment need)	Children with functional traits
3	267	20	156 (58%)	228 (85.4%)
4	267	13	129 (48.3%)	174 (65.2%)
5	241	12	105 (43.6%)	139 (57.7%)
6	215	14	105 (48.8%)	128 (59.5%)
7	211	14	96 (45.5%)	87 (41.2%)
8	198	11	71 (35.9%)	80 (40.4%)
9	198	11	83 (41.9%)	81 (40.9%)
10	137	15	70 (51.1%)	53 (38.7%)
11	136	13	62 (45.6%)	65 (47.8%)
12	134	14	66 (49.3%)	50 (37.3%)

The prevalence of malocclusion, as well as the treatment need, should be studied longitudinally (Linder-Aronson, 1979; Farčnik *et al.*, 1986; Heikinheimo *et al.*, 1987; Trottman and Elsbach, 1996; Thilander *et al.*, 2001). The growth and development of the jaws and dentition may have an unknown effect on an individual's orthodontic treatment need, thus longitudinal studies could also clarify the question of treatment timing (Heikinheimo *et al.*, 1987).

The present longitudinal study demonstrated how functional and morphological traits of malocclusion changed during growth and development. The very small number of children with an ideal occlusion at 3 years of age was the most significant finding. The results showed that in 50 per cent of the examined children, a morphological malocclusion severity score from mild to severe was present at 3 years of age and increased towards the end of the mixed dentition period (Table 1). Such a high prevalence of malocclusion is in agreement with the study of Thilander *et al.* (2001), using other classification methods. Due to the specific approach in quantitative malocclusion assessment in an early developmental dentition stage, it was not possible to compare the findings with the results of similar investigations since most previous studies in the primary dentition were qualitative in nature and quantitative assessment of functional malocclusion traits was not taken into account (Trottman and Elsbach, 1996; Tschill *et al.*, 1997; Thilander *et al.*, 2001).

The high frequency of deleterious sucking habits at 3 years of age (83 per cent had used dummies, 9 per cent

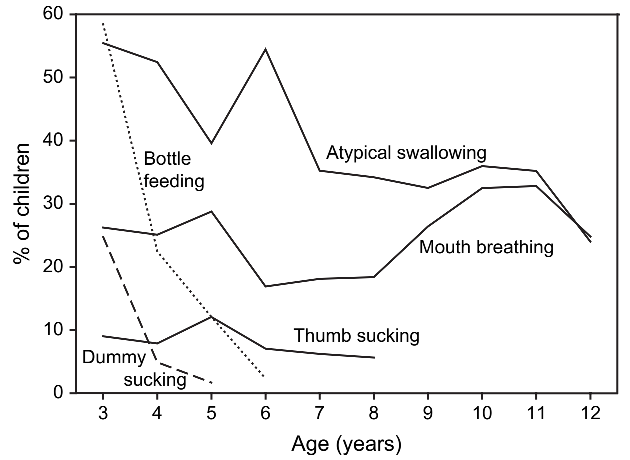

Figure 4 Number and percentage of children with functional malocclusion traits.

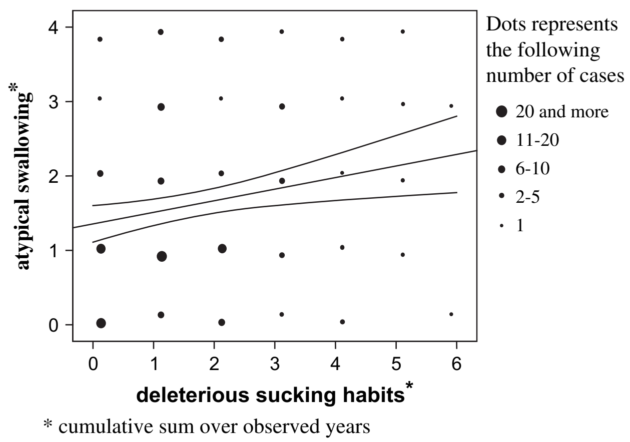

Figure 5 Correlation (Spearman's coefficient) between deleterious sucking habits (finger- or dummy-sucking, bottle feeding) from 3 to 6 years of age and atypical swallowing at 6–9 years of age.

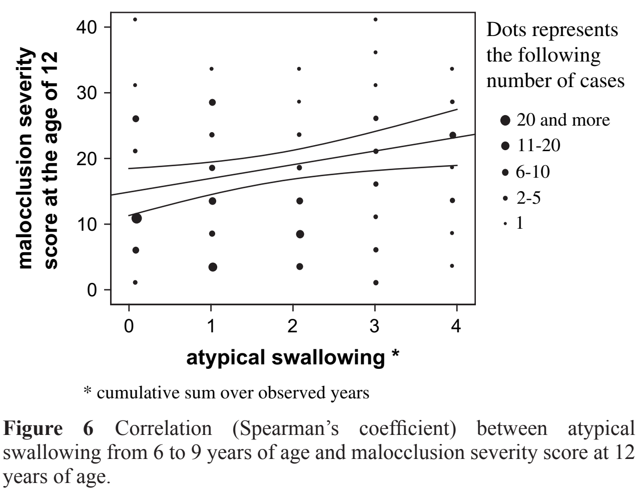

Figure 6 Correlation (Spearman's coefficient) between atypical swallowing from 6 to 9 years of age and malocclusion severity score at 12 years of age.

had sucked their thumb, but only 8 per cent had no history of non-nutritive sucking) was in agreement with the findings of others (Melsen *et al.*, 1979; Øgaard *et al.*, 1994; Larsson, 2000). However, their results were cross-sectional and concentrated mostly on the effects of prolonged sucking habits indicating irreversible malocclusions. Fifty per cent of the 3-year-old children in the present study were still bottle fed, which is in agreement with some Scandinavian studies (Modéer *et al.*, 1982; Øgaard *et al.*, 1994; Lindsten *et al.*, 1996; Larsson, 2000) that found that the use of dummies by young children has increased over the past decades, as well as the tendency to prolong the habit (Figure 4). Sucking behaviour has long been recognized to affect occlusion and dental arch characteristics and children with sucking habits are more likely to develop an anterior open bite, excessive overjet, distal occlusion, and a posterior crossbite (Warren and Bishara, 2002).

Proffit (1986) believed that the role of atypical swallowing in the aetiology of malocclusion was overestimated, while Melsen *et al.* (1979) established that previous sucking habits had no significant influence on the type of swallow, but children with sucking habits had significantly more distal, mesial occlusion and crossbites.

In this study, an atypical swallowing pattern was present in half of the examined children at 3 years of age, changed significantly after 6 years, but was still present in 25 per cent at 12 years of age (Figure 4). Melsen *et al.* (1979) reported that an atypical swallowing pattern was present in 25–30 per cent of 9 year olds, confirming the results of the present study (Figure 4).

Sucking habits, even of a short duration, must be considered to have a direct influence on the developing occlusion, as well as an indirect effect due to a change in swallowing pattern. Therefore, on the basis of previously reported data and the findings of the present study, sucking habits must be considered a factor of major influence in the aetiology of malocclusions and a causative factor for the higher malocclusion severity score at the end of the mixed dentition period.

Preventive and early treatment in orthodontics is still the subject of debate and controversy regarding cost-effectiveness in the analysis of functional and psychosocial benefits (Tschill *et al.*, 1997; Kurol, 2006; Proffit, 2006). Viazis (1995), Kurol (2006), Ngan (2006) and Proffit (2006) considered that the ideal time for treatment is in the late mixed dentition period, while others (Thilander *et al.*, 1984; Farčnik *et al.*, 1988; Korpar *et al.*, 1994; Trottman and Elsbach, 1996; Tschill *et al.*, 1997; Thilander *et al.*, 2001; Ovsenik *et al.*, 2004) concluded that early orthodontic treatment would be beneficial and desirable, especially to enhance skeletal and dental development and to correct habits, function, and malocclusion in their early stages, especially transverse discrepancies which may lead to temporomandibular joint problems or facial asymmetry (Franchi *et al.*, 2004; Kurol, 2006; Proffit, 2006).

Therefore, in preventive orthodontic treatment planning, malocclusion severity score should be based on the assessment of functional malocclusion traits, because they are caused by deleterious sucking and feeding habits in the early period of orofacial development.

Conclusions

On the basis of the results, the following conclusions can be drawn:

1. The morphological malocclusion severity score is almost the same throughout growth and development, while the functional malocclusion score significantly decreases.

2. In early dental development, the morphological severity score is related to the stage of dental development, while at a later period, the malocclusion severity score is also the result of incorrect orofacial functions at an early stage of dental development.

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References

Baume L J *et al.* 1974 A method for the measurement of occlusal characteristics. Commission on Classification and Statistics for Oral Conditions of the FDI, (COCSTOC). International Dental Journal 24: 90–97

Behlfelt K, Linder-Aronson S, McWilliam J, Neander P, Laage-Hellman J 1989 Dentition in children with enlarged tonsils compared to control children. European Journal of Orthodontics 11: 416–429

Brook P H, Shaw W C 1989 The development of an index of orthodontic treatment priority. European Journal of Orthodontics 11: 309–320

Cons N C, Jenny J, Kohout F J 1986 DAI: Dental aesthetic index. College of Dentistry, University of Iowa, Iowa City

Daniels C, Richmond S 2000 The development of the index of complexity, outcome and need (ICON). Journal of Orthodontics 27: 149–162

Eismann D 1974 A method of evaluating the efficiency of orthodontic treatment. Transactions of the European Orthodontic Society, pp. 223–232

Eismann D 1977 The morphology of the dentition as one criterion in the assessment of the need for orthodontic treatment. Transactions of the European Orthodontic Society, pp. 125–129

Espeland L V, Ivarsson K, Stenvik A 1992 A new Norwegian index of orthodontic treatment need related to orthodontic concern among 11-year-olds and their parents. Community Dentistry and Oral Epidemiology 20: 274–279

Farčnik F, Rudel D 1995 The breathing detector—a new device in functional diagnosis of malocclusion. Zobozdravstveni Vestnik 50: 244–247

Farčnik F, Korpar M, Premik M, Zorec R 1985 Numerical evaluation of malocclusion in study models of the mixed dentition. Zobozdravstveni Vestnik 40: 169–176

Farčnik F, Korpar M, Premik M, Zorec R 1986 Morphological and functional occlusal traits significant in the assessment of malocclusion to determine the severity score in deciduous dentition. Research Project for the Research Community of Slovenia No. C3-0560-329-86. URP: Stomatology Ljubljana: University Dental Clinic pp. 1–17.

Farčnik F, Korpar M, Premik M, Zorec R 1988 An attempt at numerically evaluating dysgnathias in the deciduous dentition. Stomatologie DDR 38: 386–391

Franchi L, Baccetti T, McNamara J A 2004 Postpubertal assessment of treatment timing for maxillary expansion and protraction therapy followed by fixed appliances. American Journal of Orthodontics and Dentofacial Orthopedics 126: 555–568

Heikinheimo K, Salvi K, Myllärniemi S 1987 Long term evaluation of orthodontic diagnosis made at the ages of 7 and 10 years. European Journal of Orthodontics 9: 151–159

Kloehn S J 1948 At what age should orthodontic treatment start?. Angle Orthodontist 18: 60–61

Korpar M, Farčnik F, Premik M, Zorec R 1994 Changes in the orofacial system between the 3rd and the 9th years of age. In: Farčnik F (ed). Preventive and interceptive orthodontics. Book of Proceedings, Slovenian Orthodontic Society, Rantovi dnevi, Ljubljana, pp. 41–47.

Kurol J 2006 Impacted and ankylosed teeth: why, when, and how to intervene. American Journal of Orthodontics and Dentofacial Orthopedics 120: S50–S54

Kurol J, Berglund L 1992 Longitudinal study and cost-benefit analysis of the effect of early treatment of posterior cross-bites in the primary dentition. European Journal of Orthodontics 14: 173–179

Larsson E 2000 Sucking, chewing, and feeding habits and development of crossbite: a longitudinal study of girls from birth to 3 years of age. Angle Orthodontist 71: 116–119

Larsson E, Øgaard B, Lindsten R 1992 Dummy- and finger-sucking habits in young Swedish and Norwegian children. Scandinavian Journal of Dental Research 100: 292–295

Linder-Aronson S 1979 Adenoid obstruction of the nasopharynx. In: McNamara J A (ed). Naso-respiratory function and craniofacial growth Monograph No 9, Craniofacial Growth Series, Center for Human Growth and Development, University of Michigan, Ann Arbor, pp. 121–147.

Lindsten R, Larsson E, Øgaard B 1996 Dummy sucking behaviour in 3-year old Norwegian and Swedish children. European Journal of Orthodontics 18: 205–209

Lundström A 1977 Need for treatment in cases of malocclusion. Transactions of the European Orthodontic Society, pp. 111–123

Melsen B, Stensgaard K, Pedersen J 1979 Sucking habits and their influence on swallowing pattern and prevalence of malocclusion. European Journal of Orthodontics 1: 271–280

Modéer T, Odenrick L, Lindner A 1982 Sucking habits and their relation to posterior cross-bite in 4-year-old children. Scandinavian Journal of Dental Research 90: 323–328

Ngan P 2006 Early treatment of Class III malocclusion: is it worth the burden? American Journal of Orthodontics and Dentofacial Orthopedics 129: S82–S85

Øgaard B, Larsson E, Lindsten R 1994 The effect of sucking habits, cohort, sex, intercanine arch widths, and breast or bottle feeding on posterior crossbite in Norwegian and Swedish 3-year-old children. American Journal of Orthodontics and Dentofacial Orthopedics 106: 161–166

Ovsenik M, Primožič J 2007 An evaluation of 3 occlusal indexes: Eismann index, Eismann–Farčnik index and index of orthodontic treatment need. American Journal of Orthodontics and Dentofacial Orthopedics 131: 496–503

Ovsenik M, Farčnik F, Verdenik I 2004 Comparison of intra-oral and study cast measurements in the assessment of malocclusion. European Journal of Orthodontics 26: 273–277

Pirttiniemi P, Kantomaa T, Lahtela P 1990 Relationship between craniofacial and condyle path asymmetry in unilateral cross-bite patients. European Journal of Orthodontics 12: 408–413

Proffit W R 1986 On the aetiology of malocclusion. British Journal of Orthodontics 13: 1–11

Proffit W R 2006 The timing of early treatment: an overview. American Journal of Orthodontics and Dentofacial Orthopedics 120: S47–S49

Sonnesen L, Bakke M, Solow B 2001 Bite force in pre-orthodontic children with unilateral crossbite. European Journal of Orthodontics 23: 741–749

Summers C J 1971 The occlusal index. American Journal of Orthodontics 59: 552–567

Thilander B, Lennartsson B 2002 A study of children with unilateral posterior crossbite, treated and untreated, in the deciduous dentition-occlusal and skeletal characteristics of significance in predicting the long-term outcome. Journal of Orofacial Orthopedics 63: 371–383

Thilander B, Pena L, Infante C, Parada S S, Mayorga C 2001 Prevalence of malocclusion and orthodontic treatment need in children and adolescents in Bogota, Colombia. An epidemiological study related to different stages of dental development. European Journal of Orthodontics 23: 157–176

Thilander B, Wahlund S, Lennartsson B 1984 The effect of early interceptive treatment in children with posterior cross-bite. European Journal of Orthodontics 6: 25–34

Trottman A, Elsbach H G 1996 Comparison of malocclusion in pre-school black and white children. American Journal of Orthodontics and Dentofacial Orthopedics 110: 69–72

Tschill P, Bacon W, Sonko A 1997 Malocclusion in the deciduous dentition of Caucasian children. European Journal of Orthodontics 19: 361–367

Viazis A 1995 Efficient orthodontic treatment timing. American Journal of Orthodontics and Dentofacial Orthopedics 108: 560–561

Warren J J, Bishara S E 2002 Duration of nutritive and nonnutritive sucking behaviors and their effects on the dental arches in the primary dentition. American Journal of Orthodontics and Dentofacial Orthopedics 121: 347–356