ASSOCIATIONS BETWEEN DENTAL CONSONANT ARTICULATION, OROFACIAL MORPHOLOGY AND FUNCTION IN CLEFT LIP/PALATE

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CONTENTS

1. LIST OF ORIGINAL PUBLICATIONS

The thesis is based on following original articles, which are referred to in the text by their Roman numerals:

I Laitinen J, Haapanen M-L, Paaso M, Pulkkinen J, Heliövaara A, Ranta R. Occurrence of dental consonant misarticulations in different cleft types. Folia Phoniatr Logop 1998;50:92-100.

II Laitinen J, Ranta R, Pulkkinen J, Paaso M, Haapanen M-L. Changes in Finnish dental consonant articulation in cleft lip/palate children between 6 and 8 years of age. Folia Phoniatr Logop; (in press).

III Laitinen J, Ranta R, Pulkkinen J, Haapanen M-L. The association between dental arch dimensions and occurrence of Finnish dental consonant misarticulations in cleft lip/palate children. Acta Odontol Scand 1998;56:308-312.

IV Laitinen J, Ranta R, Pulkkinen J, Haapanen M-L. Associations between dental occlusion and misarticulations of Finnish dental consonants in cleft lip/palate children. Eur J Oral Sci 1999;107:109-113.

V Laitinen J, Sarmas R, Haapanen M-L, Ranta R. Speech and breathing aerodynamics, oral somatosensoric sensibility, and strength of tongue muscles correlated with articulation of the Finnish /r/-sound in subjects with and without oral clefts. Med Sci Res 1998;26:813-815.

VI Laitinen J, Hurmerinta K, Ranta R, Sarmas R, Haapanen M-L. Comparisons of speech aerodynamics and lateral craniofacial cephalometrics in cleft lip and palate patients with and without Finnish /r/ sound distortion. Folia Phoniatr Logop; (in press).

2. ABBREVIATIONS

CP   isolated cleft palate

CL(A)   cleft lip with or without cleft alveolus

UCLP   unilateral cleft lip and palate

BCLP   bilateral cleft lip and palate

NONC   non-cleft

LARE   laryngeal resistance

NASA   the smallest nasal crossectional area

NASAR   nasal resistance

VEPA   velopharyngeal orifice area

3. SUMMARY

The occurrence of articulatory problems of /r/, /s/ and /l/ sounds as well as their relations to oral and pharyngeal morphology were studied in subjects with different cleft types.

Altogether 44% of 6-year-old cleft children had studied misarticulations and the number of errors increased with the severity of the cleft. Boys outnumbered girls in the occurrence of misarticulations of all the studied sounds. Problems with the /r/ sound predominated, and one-fourth needed treatment mostly because of severe /r/ distortions. The frequency of /l/ distortions was surprisingly high.

By the age of 8 years four-fifths still misarticulated at least one of the studied sounds. There were no differences due to gender according to unchanged or changed articulation by the age of 8 years. Nearly one third of the /l/ and /s/ misarticulations but only one fifth of the /r/ errors were corrected. New misarticulations appeared similarly whether speech therapy was given or not.

Shorter and especially narrower maxillary dental arches and shallower palates as well as posterior crossbites were related to misarticulations in all the studied sounds. Mandibular dental arch dimensions, anterior crossbite alone, large maxillary overjet, or deep bite were not related to the studied misarticulations.

/R/ distortion was related to low laryngeal resistance, and anteriorly positioned hyoid bone but not to the smallest nasal cross-sectional area, nasal resistance or velopharyngeal orifice area or dentofacial morphology.

4. INTRODUCTION AND REVIEW OF THE LITERATURE

4.1. Introduction

Clefts of the lip and/or palate are the most prevalent group of congenital malformations affecting morphology and growth of the cranium and middle face. The clefting incidence is approximately 1 per 500 live births with variation in cleft type, sex, and ethnic origin. The cleft lip with or without cleft palate and the isolated cleft palate deviate both epidemiologically and etiologically. The etiology of clefting seems to be multifactorial, including hereditary and environmental factors (specific drugs, maternal smoking).

The articulation skills of cleft children are reported to be clearly inferior and mature later than those of non-cleft children (McWilliams and Musgrave, 1977; Karling et al., 1993). Improvement of articulation skills of cleft individuals continues past 8 years of age (Van Demark et al., 1979; Riski and Delong, 1984) when most non-cleft children have already achieved mature articulation. Especially errors in dental consonants /r/, /s/ and /l/ are frequent for cleft palate speakers (Philips and Harrison, 1969; McWilliams and Musgrave, 1977; Van Demark et al., 1979). Altogether, articulatory speech disorders are very common among children in general, and are more common in boys than in girls, probably due to a slower development of articulatory skills in boys.

More than half of the children with clefts are estimated to need treatment because of severe articulatory errors (Ross and Johnston, 1972). About 10% of Finnish non-cleft schoolchildren are considered to need speech therapy (Pietarinen, 1987). Van Riper (1978) maintained that since articulatory speech disorders represent 50-60% of all speech disorders they are relatively important in terms of channelling resources of speech therapy. In Finland early speech therapy rests with the community health service system, and often several speech therapy sessions over several years are needed to rehabilitate the speech especially in the case of cleft palate individual. This is costly for society, and at first, it is often hard for a child and his/her parents.

Especially /r/ disorders are reported to be fairly resistant to early speech therapy in Finland (Qvarnström et al., 1991; Luotonen, 1995). Despite speech therapy as many as one-third of young Finnish adults still have articulatory disorders, one-fifth of them misarticulating severe enough to need further treatment (Laine, 1987). It is essential to find out the conditions, which improve articulation as much as possible in order to use resources better and time treatment optimally.

4.2. Review of the literature

4.2.1. General aspects of speech and articulation in subjects with cleft palate

Motor speech functions can be divided into four events: breathing, phonation, resonance, and articulation. Besides supplying the oxygen needs for the circulatory system, breathing produces the airflow needed for the voice and sound production. Various muscles control the expiratory phase of breathing during speaking. Phonation is accomplished by controlling the airflow by moving the vocal folds in the larynx, which makes the air pressure above the larynx fluctuate. When the fluctuating air passes through the vocal tract, it resonates in the oro-nasal cavities and is heard as the voice of speech (Darley et al., 1975; Hardcastle, 1976). The larynx itself is responsible for separating voiced and unvoiced sounds (Broad, 1973), and regulating the airflow during breathing and speech (Zajac, 1995). During speech different vocal tract actions are sequenced to produce linguistically relevant sounds (Gracco, 1991). To sum up briefly, whilst voice is generated by the larynx, it is shaped by the pharynx, the mouth and the nose (Wyatt et al., 1996). Speech sound production is a rapid motor act requiring finely tuned neurological regulation of the central nervous system (Darley et al., 1975).

Articulation disorders may result from organic, neuromuscular or functional faults (Van Dyke et al., 1984) as well as from sensory abnormalities or disturbances of language development, or other developmental factors (Van Riper and Emerick, 1984). Organic disorders may be found in the speech articulators or in the articulating and resonating as well as in orofacial skeletal structures, and even in dental occlusion. The function of the tongue is the most essential compared to other articulators, since most speech sounds are

produced by altering the shape of the tongue. Neurogenic articulatory disorders result from weakness, slowness or incoordination in muscular control due to damage of the central or peripheral nervous system or both. Disabilities without any obvious organic or neurogenic cause constitute 75% of all articulatory disorders and form a group of functional disorders (McReynolds and Elbert, 1982; Van Dyke et al., 1984).

Clefts in the lip and/or palate affect the structures and growth of the orofacial area. Repetitive surgical procedures bring their own hazards by inhibiting the growth, and reducing muscular strength in the middle face (Folkins, 1985; Enemark et al., 1990; Wada et al., 1997). Since the severity of articulation deficit has been found to increase with increasing severity of clefting (Ross and Johnston, 1972; Riski and Delong, 1984), abnormal dentofacial morphology obviously is partly responsible for a higher risk for articulatory problems in cleft affected individuals. Many cleft palate children have articulatory errors associated with velopharyngeal incompetence (Haapanen and Rantala, 1992) or other conditions that result from cleft palate. While the soft palate as well as the pharyngeal wall regulates the air flow and the laryngeal voice through the oral and nasal airways, an adequate velopharyngeal sphincter provides a barrier to the nasal cavity so that the voice is shaped by the mouth and oropharynx. Excess resonance in the nasal cavity results in hypernasality. Velopharyngeal incompetence indicates a lack of separation between the oral and nasal cavities resulting, for example, from a short palate or an unusually deep nasopharynx (Wyatt et al., 1996). The production of Finnish /r/ and /l/ sounds, however, do not require high intraoral air pressures, and that is why disorders of these sounds are difficult to explain only in terms of velopharyngeal incompetence.

Dento-alveolar dysmorphology due to cleft lip and/or palate is associated with atypical cephalometric dimensions and abnormalities in vocal tract anatomy (Horowitz et al., 1976; Smahel et al., 1991; Hoenig and Schoener, 1992). Abnormalities in vocal tract probably result in abnormal functions and physiology during breathing and phonation (Ruscello et al., 1985; Scaf et al., 1991). Many cleft palate children attempt to regulate intraoral pressure by increasing the airflow rate (Warren et al., 1969a; 1985; Warren, 1986). Maxillary growth deficits due to palatal and velopharyngeal surgery may constrict the nasal floor, reduce airway size, and increase airway resistance (Warren et

al., 1969b; Smahel et al., 1991). The size of the pharynx itself has been concluded to be more important fact affecting speech than timing and the method of surgery in cleft children (Shprintzen and Goldberg, 1995). The production of the Finnish /r/ sound requires modulation of phonatory air so that the physical properties of the tremulating air stream associated with the effect of Bernoull is perceived. Thus, it is important to find out dysfunctions as well as abnormal morphology in pharyngolaryngeal region, which may be possible causes for inadequate articulation. Not all speech disorders present in cleft palate speakers are, however, directly related to the cleft (Wyatt et al., 1996). For this reason, ”unintelligible speech” requires detailed assessment to establish whether errors are predominantly cleft or non-cleft related or, as often occurs, a combination of both.

4.2.2. Articulation of the Finnish /r/, /s/ and /l/ consonants

Finnish /r/ and /s/ sounds are regarded as the most difficult sounds to produce in the Finnish language. These sounds together with the /l/ sound are dental consonants which are correctly produced by the help of the tip of the tongue with the anterior palatal alveolus. The Finnish /r/ is a voiced linguomedioalveolar tremulant, which between two vowels can be a one-tap trill, and after the /s/ sound, a fricative (Wiik, 1981). Maddieson (1984) described the Finnish /r/ as a voiced or long voiced dental trill, and Karlsson (1982) as a dental tremulant. This sound differs from that of most other languages. In Finnish there is only one sibilant, /s/ phoneme, which is an unvoiced dental sibilant (Wiik, 1981) produced by the tip of the tongue forming a narrow constriction against the medioalveolar area. The Finnish /l/ is a voiced dental lateral sound (Karlsson, 1982). Comparison of misarticulations between different languages is very difficult because production of the sounds deviate in most languages. However, the Finnish /r/ and /s/ are probably more difficult to produce than the /r/ and /s/ in Germanic languages (Arnold, 1965).

4.2.3. Prevalence of articulatory errors in /r/, /s/ and /l/ sounds in Finnish pre-school and schoolchildren

Finnish children are estimated to produce correctly all sounds of their mother language at the age of 5 years (Sarmavuori, 1982). However, articulatory problems especially in /r/ and /s/ sounds, are very common in 7 to 8 years old Finnish non-cleft children. Nearly 10% have /r/ disorders, and 30% /s/ disorders of various degrees (Sonninen and Sonninen, 1976; Qvarnström et al., 1991). Altogether /r/ and /s/ sounds make up 95% of all errors at the age of 7 years (Luotonen, 1995). Fortunately, only 1% of non-cleft schoolchildren have /l/ disorders (Qvarnström et al., 1991). Misarticulations are mainly distortions among children older than 5 years, substitutions occurring only in 1% of the schoolchildren (Qvarnström et al., 1991).

Boys are reported to have more often problems with articulation than girls (Qvarnström et al., 1991; Luotonen, 1995). Slower speech development and fine motor maturation in boys are suggested to explain the difference in articulatory abilities between gender in pre-school and the first school years (Stevenson and Richman, 1976; Silva, 1980; Beitchman et al., 1986). Boys have more /r/ disorders than girls, while /s/ disorders seem to be more common among girls (Qvarnström et al., 1991).

4.2.4. Articulatory development in children aged 6 to 8 years

Several authors have reported the frequency of articulatory speech disorders decreasing spontaneously with age (Milisen, 1971; Alstam-Malcus et al., 1976; Leske, 1981). In Finnish non-cleft children /s/ sound disorders seem spontaneously to decrease at the age of 7 years, whereas later, between 7 to 10 years of age /s/ disorders increase markedly even in subjects receiving speech therapy or special education (Qvarnström et al., 1991; 1993a). Instead /r/ disorders do not disappear and seem to be rather resistant to early speech therapy (Qvarnström et al., 1991). In the case of the non-cleft children the results of the effectiveness of early speech therapy have not altogether been obvious according

to earlier studies (Qvarnström et al., 1991; Luotonen, 1995). While articulatory speech disorders in 6-8-year old children have been stated to be associated with inaccurate tongue movements (Speirs and Maktabi, 1990), and problems in coordinating those movements (Yoss and Darley, 1974; Ferry et al., 1975; Cermak et al., 1986), tongue skills in normally developing children are known to improve markedly with advancing age up to the age of 11 years (Tingley and Allen, 1975; Watkin and Fromm, 1984; Sharkey and Folkins, 1985; Robbins and Klee, 1987; Wood and Smith, 1992; Qvarnström et al., 1994). Both efficiency in moving the tongue into articulatory positions and precision in achieving the desired articulatory effect increase with age (Fletcher, 1989).

4.2.5. Dental arch dimensions and misarticulations

Operated cleft of the palate diminishes the growth of the maxilla and upper dental arch (Ranta, 1990; Nyström and Ranta, 1992) causing crowding, malocclusions and incomplete development in the middle face. Deviant oral structures, including the dental and skeletal relationship between maxilla and mandible, are suggested to affect the precise coordination between the lips, tongue, and mandible needed for correct speech sound articulation (Lindblom and Sundberg, 1971; Powers, 1971; Starr, 1971; Van Dyke et al., 1984). In addition, variations of oral structures are suggested to affect speech by influencing the function and relation of the tongue and the soft palate (Bishara et al., 1975), as well as the position of the tongue and hyoid bone (Laine, 1987).

Subjects with noticeable articulatory problems have been found to have a tendency to have smaller oral dimensions than correctly articulating subjects (Oliver and Evans, 1986). Maxillary arch width and length dimensions at different ages have been found to be smaller in children with clefts than in subjects without clefts (Friede et al., 1993; Nyström and Ranta, 1994). Defective articulation increases (Ross and Johnston, 1972; Friede et al., 1993), and maxillary dento-alveolar dimensions decrease with the severity of the cleft (Hellquist et al., 1978; Nyström and Ranta, 1992).

4.2.6. Occlusion and misarticulations

According to the literature of both orthodontics and speech pathology, the anterior part of the dentition is important in articulation. The position of the upper and lower incisors is thought to be the most important occlusal variable influencing the production of certain sounds, especially the presence of an anterior open bite being frequently associated with distortions of the unvoiced /s/ sound (Lewis, 1971; Guay et al., 1978; Laine, 1987, 1992). Some studies on the relationships between articulatory problems and malocclusions have dealt with the occurrence of /s/ sounds produced too anteriorly (lisping) in subjects with tongue-thrust swallowing and open bite (Proffit and Norton, 1970; Lewis 1971). An open bite of more than 6 mm is found to impair the maintaining of oral pressure, which is especially vital for the speech of subjects with oral clefts (Warren, 1986). In cases of increased overjet or decreased overbite a correct /s/ sound is found to be more difficult to produce, while /r/ and /l/ misarticulations are not reported to be associated with changes in overjet or overbite (Laine et al., 1985).

Articulatory problems are reported to be more common in subjects with maxillary frontal spacing (Bankson and Byrne, 1962; Starr, 1971; Laine et al., 1987; Pahkala et al., 1991), although earlier results concerning the spacing or eruption stage of the maxillary incisors and articulation of /r/, /s/ and /l/ sounds are somewhat contradictory in both non-cleft and cleft affected subjects. Laine et al. (1985) stated that even if maxillary spacing was associated with difficulties in producing Finnish /r/, /s/, and /l/ sounds, it was less important in inter-incisal occlusion than increased overjet or decreased overbite.

Both distal molar occlusion and/or large maxillary overjet (Blyth, 1959; Subtelny et al., 1964; Laine ,1987) and mesial molar occlusion and/or mandibular overjet (Lubit, 1967; Guay et al., 1978; Ruscello et al., 1986; Laine 1987) have been reported to affect articulation. In some cases lateral cross bite has been found to predispose individuals to misarticulations of certain medio-alveolar sounds (Laine 1987). Although compensatory mechanisms are able to correct structural deviations in some individuals so that they

produce accurate speech sounds, morphology may play a role in the etiology of articulatory disorders.

5. AIMS OF THE STUDY

The purpose of the study was to elucidate misarticulations of dental (alveolar) consonants and their relationships in dental occlusion and pharyngolaryngeal function and morphology in cleft lip/palate children.

The specific aims were to

- find out the occurrence of /r/, /s/ and /l/ misarticulations at the age of 6 years in different cleft types and changes in articulation of these sounds between 6 and 8 years of age

- examine the associations between oral morphology in terms of dental arch dimensions and dental occlusion and /r/, /s/ and /l/ misarticulation

- investigate correlations between the pharyngolaryngeal morphology and function and /r/ sound distortion

6. SUBJECTS AND METHODS

6.1. Subjects

The subjects comprised 280 (115 girls and 165 boys) Finnish speaking children with clefts born between 1980-1988. The patients included 82 children with isolated cleft palate (CP), 82 with cleft lip with (34) or without (48) cleft alveolus [CL(A)], 85 unilateral (UCLP) and 31 bilateral cleft lip and palate (BCLP). All the subjects were treated at the Cleft Center, Department of Plastic Surgery, Helsinki University Central Hospital. None of them had documented persistent hearing defect or psychomotor retardation, and no known syndrome or associated anomaly possibly affecting speech. None of the subjects had had orthodontic treatment. The cleft palate was closed at the mean age of 1.4 years with one-stage closure of the cleft palate with either the Veau-Wardill-Kilner (32%) V to Y pushback procedure or (66%) the Cronin modification (Heliövaara et al., 1993). Pharyngeal flap surgery was performed in 33 children before the 6-year-old follow-up speech examination.

In the first phase of the study the patients attended regular follow-up examinations at the age of six years when speech analysis was carried out and dental casts were taken (I). The subjects with acceptable dental plaster casts comprised 263 (109 girls and 154 boys) out of the 280 (III). The occlusion was diagnosed from the dental casts of 260 of them (108 girls and 152 boys) (IV). The second phase of the study included examination of the hospital records of children with adequate speech data and without orthodontic treatment at the age of 6 and 8 years. 133 children (47 girls, 86 boys) out of 280 patients were included (II).

Speech aerodynamics, somatosensory sensibility and the strength of tongue muscles and /r/ distortion were examined and lateral cephalograms were taken in 20 (13 females, 7 males) consecutive adult patients treated surgically and orthodontically at the Cleft Center, Department of Plastic Surgery, Helsinki University Central Hospital. The mean age was 25 years. One of the patients had cleft lip and alveolus, 8 had isolated cleft palate, 8 unilateral and 3 bilateral cleft lip and palate. In all cases anomalies of dental

occlusion were corrected. Ten students of logopedics (speech therapy) served as controls for the aerodynamic measurements, as well as 10 healthy persons from the staff of the Cleft Center for the somatosensoric and muscle strength measurements (V). Eighteen (12 females, 6 males) out of these 20 subjects were included in the study of speech aerodynamics, lateral cephalometric craniofacial and pharyngeal morphology and /r/ distortion, since 2 patients (1 CP and 1 BCLP patient) were excluded due to the lack of an acceptable lateral cephalometric radiograph (VI). **Table 1** provides a summary of the subjects in the present studies (I-VI).

Table 1. Summary of the subjects in the present study.

Study	Analysis	Age	Cleft type n (male/female)				
		Mean (SD)	CP	CL(A)	UCLP	BCLP	Total
I	Speech	6.1 (0.2)	82 (37/45)	82 (49/33)	85 (55/30)	31 (24/7)	280 (165/115)
II	Speech	6.1 (0.3) 8.1 (0.4)	34 (16/18)	49 (32/17)	33 (23/10)	17 (15/2)	133 (86/47)
III	Speech Dental arches	6.1 (0.2)	79 (35/44)	77 (46/31)	80 (53/27)	27 (20/7)	263 (154/109)
IV	Speech Occlusion	6.1 (0.2)	79 (35/44)	76 (46/30)	78 (51/27)	27 (20/7)	260 (152/108)
V	/r/ sound Aerodynamics	25 (7.0)	8 (0/8)	1 (0/1)	8 (4/4)	3 (3/0)	20 (7/13)
VI	/r/ sound Aerodynamics Cephalograms	20 (7.0)	8 (0/8)	1 (0/1)	7 (4/3)	2 (2/0)	18 (6/12)

6.2. Methods

6.2.1. Speech analysis (I-VI)

Evaluation of speech at the age of 6 years was made by one of the two experienced speech pathologists of the cleft team, and the data was registered in the hospital records. The history of the speech development before the age of 6 years and the speech therapy given was also available in the hospital records. These data served as a document of the speech problem, even though the speech assessment was based on the speech condition at the age of 6 years. Misarticulations of sounds /r/, /s/ and /l/ were evaluated immediatly in spontaneous speech and words elicited by the Remes Articulation test for the Finnish language (Remes, 1975). Sounds were categorised into correct, distorted or substituted sounds. Distortions were judged according to a 3 point scale, where 0= normal production, 1= slightly distorted, speech therapy not necessary, 2= clearly distorted, unaccepted quality, speech therapy required. Substitutions and clearly distorted sounds were classified as severe misarticulations. Omissions and additions were not examined in the present study because they are extremely rare in 6-year-old children. Information of given speech therapy before the six-year-follow-up visit was collected from the hospital records and by interviewing the subjects' parents (I).

The speech analysis at the age of 8 years was carried out in a similar manner as the analysis when the child was 6 years old. However, at the age of 6 years the /r/ sounds produced with a slightly immature anterior trill were categorised as correct, whereas similar errors were categorised as slight distortions at the age of 8 years. At the age of 6 years some inconsistency in the production of /s/ and /l/ sounds was allowed. If these sounds were mainly produced normally, even though sometimes slightly too anteriorly, they were categorised as correct. The patients were divided into 2 groups. Subjects in Group 1 distorted clearly or substituted at least one studied sound at the age of 6 years, and subjects in Group 2 articulated correctly all the studied sounds at the same age. In Group 1 48% and in Group 2 14% of the subjects had received speech therapy before

the age of 6 years. Sixty-four percent of the subjects in Group 1 and none in Group 2 had received speech therapy between 6 to 8 years of age (II).

The /r/ sound of adult patients participating in studies of speech aerodynamics was tape recorded and perceptually analyzed during the clinical examination period by three speech experts. The distortion was identified by asking the patient to repeat words with a /r/ sound in the beginning and in the middle of the word (riisu, raasu, ruusu, siiri, saari, suuri, paras, parrat, pörröt). The /r/ sound was assessed as disordered if at least two of the examiners agreed upon the presence of distortion (V,VI).

6.2.2. Measurements of speech and breathing aerodynamics, oral

somatosensoric sensibility, and strength of the tongue muscles (V)

Aerodynamic parameters were measured with a pressure-flow technique called PERCI (Palatal Efficiency Rating Computed Instantaneously; Microtronics Corporation, Chapel Hill, North Caroline, USA), which measures nasal airflow and air pressure as well as oral air pressure while breathing out and speaking. The smallest nasal crossectional area and nasal resistance while breathing out, the velopharyngeal orifice area and laryngeal resistance while speaking were estimated (Warren, 1979, Smitheran and Hixon, 1981). The basic components of these aerodynamic measuring systems are flowmeters, which record volume rates of airflow, and pressure transducers, which record airway pressures within the vocal tract. The measurement of parameters depends on the placement of one or two catheters and mask. The selected flow value was 250 mls. Although pharyngeal flap surgery is stated to limit the air flow capacity (Smahel et al., 1991), the effects of velopharyngeal function and surgery were not included in the present study, because our unpublished data excluded the effect of velopharyngeal incompetence as an explanation for the frequency for the /r/, /s/ and /l/ sound misarticulations. The peak expiratory flow was measured by a Peak Flow-measurement device SPIRA.

The somatosensoric assessment was carried out as a two-point discrimination test with a Pressure Specifying Sensory Device (NK Biotechnical Engineering Co., p.O. Box 26335, Minneapolis, USA). Two points 2-7 mm from each other were tested from the medioalveolar zone of the palate, and from the tip and the sides of the tongue. The

strength of the tongue muscles was tested by modifying the fingertip pressure power measurement device included with the above mentioned device.

6.2.3. Dental arch measurements (III)

Width and length dimensions of maxillary and mandibular dental arches were measured using the method described by Moorrees (1959). The anterior palatal height was the perpendicular distance between the mid-palatal surface, and a line connecting the palatal interproximal points of maxillary first and second deciduous molars. The posterior palatal height was measured similarly, distal to the second deciduous molars (Nyström and Ranta, 1994). In this study also maxillary and mandibular intermolar arch width between the first deciduous molars (width 54,64) and width 74,84 were measured equally as width 55,65 and width 75,85. The measurements were done by two dentists of the team with a sliding digital caliper (MITUTOYO) and were read to the nearest tenth of a millimetre.

6.2.4. Analysis of occlusion and definition of spacing of the maxillary dental arch (II,IV)

Occlusal anomalies were evaluated from dental plaster casts by a senior orthodontist. Posterior crossbites were registered by the intermaxillary relationship of the permanent first molars (dd 16, 26), the second deciduous molars (dd 55, 65), and the deciduous canines (dd 53, 63). Posterior crossbite included uni- or bilateral crossbites. Unilateral crossbite included crossbites of molar and/or canine tooth. Bilateral crossbite included crossbites of molar and canine on both sides or at least one of them on both sides. Anterior crossbites were registered by the deciduous or permanent central incisors (dd 51, 61, 11, 21). An edge to edge situation was considered as crossbite as well. Anterior crossbite included crossbite of one or both central incisors. Maxillary overjet was categorised as normal (less than 6 mm) or large (6 mm or more). Overbite was categorised as normal (1/4-3/4 incisal coverage) or deep bite (more than 3/4 incisal coverage). Dental arch spacing due to changing of the maxillary incisors at the age of 6 and 8 years was defined from panoramic x-rays.

6.2.5. Lateral cephalometric measurements (VI)

Lateral cephalometric radiographs were taken with the patient´s head positioned in accordance with the Frankfort horizontal plane with her/his teeth completely occluded in the intercuspal position. Reference points and reference lines and their definitions are presented in **Fig. 1**. These points have been used to landmark the skeletal structure, pharyngeal airway diameters, and position of the hyoid bone. The cephalometric landmarks were digitised with a computer-connected digitiser (x-metrics) and 24 cephalometric linear and angular variables were calculated. All the linear dimensions were corrected for the radiographic enlargement (9%).
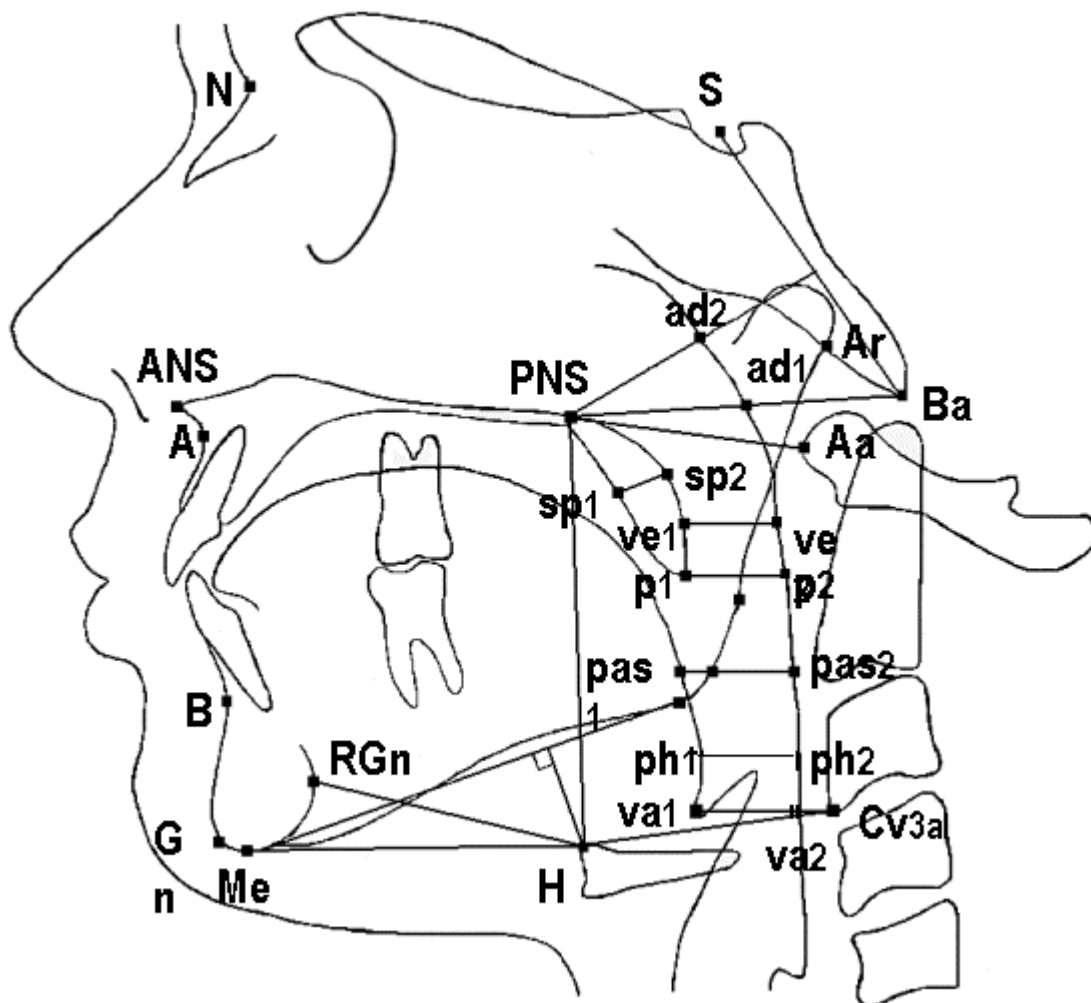
Fig 1.

Fig. 1. Reference points and reference lines used in cephalometric analysis. Abbreviated and full names, and definitions in alphabetic order.

Points: **A** = most posterior point on anterior contour of upper alveolar process; **Aa** = (atlas anterior), foremost point of atlas; **ad1** = intersection of line PNS-basion and posterior nasopharyngeal wall; **ad2** = intersection of the line from midpoint of line sella-basion to PNS and posterior nasopharyngeal wall; **ANS** = tip of anterior nasal spine; **Ar** = (articulare), intersection between external contour of cranial base and dorsal contour of mandible; **B** = most posterior point on anterior contour of lower alveolar process; **Ba** = (basion), most inferior point on clivus of occipital bone; **Cv3ai** = lowest anterior point on 3. cervical vertebra; **Gn** = (gnathion), most anterior and inferior point of bony chin; **H** = (hyoid bone), foremost and upper most point of hyoid bone; **Me** = (menton), most inferior point on mandibular symphysis; **N** = (nasion), most anterior point of nasofrontal suture; **p1** = (palate), tip of soft palate; **p2** = point on dorsal pharyngeal wall closest to p1; **pas1** = intersection between line B-gonion and anterior pharyngeal wall; **pas2** = intersection between line B -gonion and posterior pharyngeal wall; **ph1** = point of anterior pharyngeal wall above 4. vertebra, closest to posterior pharyngeal wall; **ph2** = point of posterior pharyngeal wall closest to ph1; **PNS** = posterior nasal spine; **RGn** = (retrognathion), most posterior point of mandibular symphysis; **S** = (sella), center of sella turcica; **sp1, sp2** = points for soft palate width; **va1** = (vallecula), base of epiglottis; **va2** = point of posterior pharyngeal wall closest to va1; **ve1** = (velum palati), point on soft palate closest to posterior pharyngeal wall; **ve2** = point on posterior pharyngeal wall closest to ve1.

Lines/distances/angles: **H-Cv3ai** = distance between hyoid and cervical vertebra 3 anteroinferior; **H-Gn** = distance between hyoid and gnathion; **H-ML** = perpendicular distance of hyoid point from mandibular line; **H-PNS** = distance between hyoid point and posterior nasal spine; **H-RGn** = distance between hyoid point and retrognathion; **Go-angle** = angle between the tangent to the lower border of mandible through Me and tangent to the mandibular ramus through Ar; **ML** = (mandibular line), tangent to the lower border of mandible through Me; **NL** = (nasal line),line through points ANS and PNS; **p1-p2** = distance between the tip of soft palate and posterior pharyngeal wall; **pas** = width of pharynx (pas1-pas2); **ph1-ph2** = shortest pharyngeal width above 4. cervical vertebra; **PNS -Aa** = bony length of nasopharynx; **PNS-p1** = length of soft palate; **PNS-S** = bony height of nasopharynx; **Sp1-Sp2** = width of soft palate; **va1-va2** = distance of vallecula from posterior pharyngeal wall; **ve1- ve2** = shortest distance of soft palate from posterior pharyngeal wall.

6.2.6. Statistical procedures

The data were entered into a microcomputer and analysed using NCSS 6.0 for Windows. Pearson's Chi-square or Fisher's exact statistics were calculated to test differences in occurrence of articulatory errors between genders, cleft types and different ages. These statistics were also used to examine differences in the occurrence of articulatory errors and occlusal characteristics. Dimensions of dental arches were analysed using unpaired Student's t-test and the Mann-Whitney U-test. Comparisons of /r/ sound distortion and speech and breathing aerodynamics, somatosensoric sensibility and the strength of tongue muscles were carried out by calculating the Pearson correlation, and regression analysis, ANOVA procedure as well as Student's t-test using SAS version 6 (SAS Institute Inc. 1987). Using a statistical computer program (Statview), Student`s t-test and the simple lineal regression were used for calculating the differences between subjects with or without /r/ sound distortions and their lateral cephalometric as well as speech aerodynamic variables. For all analysis, a p-value of less than 0.05 was accepted as significant.

6.2.7. Reliability of the methods

Interjudge agreement was assumed to ensure that the interpretation of the **speech** data in hospital records was identical for the team's two speech pathologists. The categorisation of the /r/, /s/ and /l/ errors to distortions and substitutions was based on a 100% consensus between the judges.

To test the intra- and interexaminer consistency in **dental arch** measurements, all 14 measurements were done twice by two authors with dental casts of BCLP-patients (n=27). Analysis of variance by Winer (1971) showed high inter- and intrajudge reliability (in width and length dimensions $r2= 0.96$ and 1.00, and in palatal height dimensions $r2= 0.82$ and 0.98).

The reliability of estimations of crossbite, overbite and overjet was tested by estimating 35 subjects **occlusions** twice (20 CP and 15 UCLP cases) with a one month interval.

Intra-judge agreement for crossbite estimations was 97.4%, 95.3% for maxillary overjet and 92.6% for overbite, respectively.

All **cephalograms** were digitised twice by the same author with a two-week interval in order to calculate the method error in landmark identification. The error of method was determined by the Dahlberg statistic using the formula: $\sqrt{\dfrac{\sum d^2}{2N}}$ where d is the difference between first and second tracing measurements and N is the number of cephalograms studied (Dahlberg, 1948). The range of error between two registrations was 0.3-1.1 mm for the linear and 0.2-1.5 degrees for the angular measurements.

7. RESULTS

7.1. Occurrence of misarticulations at the age of 6 years and changes in articulation between 6 to 8 years of age (I,II)

**At the age of 6 years** 44% of the subjects had at least one misarticulation of the sounds /r/, /s/ or /l/. Distortions were produced by 41% and substitutions by 5% of the subjects. The /r/ sound was misarticulated by 36%, the /s/ sound by 23%, and the /l/ sound by 18% of the children. One-fourth had problems with at least two sounds. Too far palatally produced sounds appeared in 9% of the subjects.

The number of the subjects with at least one misarticulation increased significantly with the severity of the cleft. The distribution of the misarticulations of /r/, /s/ or /l/ by the type of the cleft is shown in **Fig 2**. Boys outnumbered girls in misarticulating all of the studied sounds **(Fig. 3)**. Boys also misarticulated significantly more often (31%) two or more sounds than girls (12%).
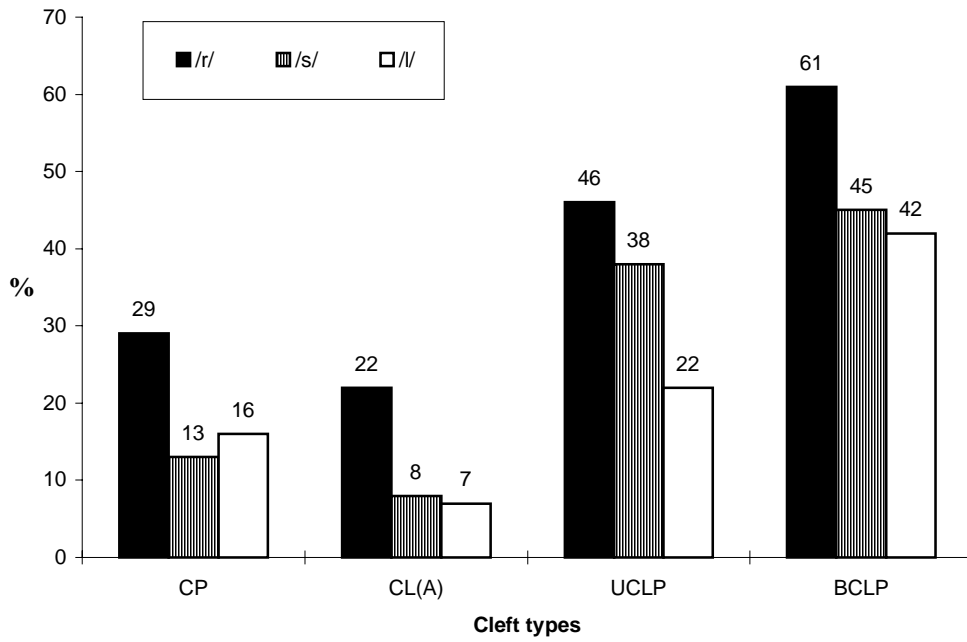
Fig. 2. The distribution of the misarticulations of /r/, /s/ or /l/ sounds by the type of the cleft in 6-year-old children.
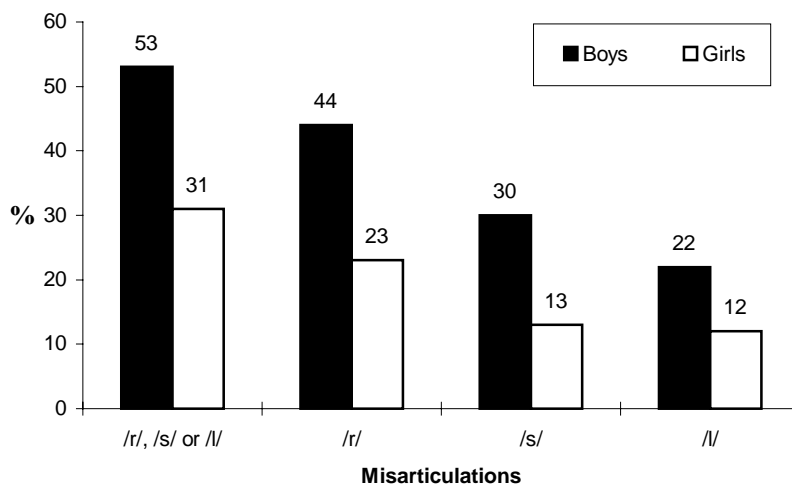
Fig. 3. Occurrence of at least one misarticulation or their combinations of /r/, /s/ or /l/ sounds and separately for at least /r/, at least /s/ or at least /l/ misarticulations between boys and girls at the age of 6 years.

Altogether, 26% of all the 6-year-old subjects required speech therapy. As many as 70% of the children who had previously received speech therapy still misarticulated at least one of the sounds, and almost half of them (43%) still needed treatment at the age of 6 years. The need for speech therapy increased with the severity of the cleft. Boys required significantly more often (34%) speech therapy than girls (14%). The most resistant to the treatment was the /r/ sound, since 64% of previously treated children still misarticulated it. Also the /s/ and /l/ sounds were rather resistant to treatment because the /s/ sound was still misarticulated by 38% and the /l/ sound distorted by 35% of treated subjects.

The genders did not differ statistically significantly according to the number of unchanged or changed articulations from 6 to **8 years of age**. Altogether 81% of subjects with misarticulations at the age of 6 years still misarticulated at least one sound at the age of 8 years. In the group of the subjects with at least one misarticulation at 6 years of age one-fifth of the patients' articulations remained unchanged, but 57% of them could eliminate at least one studied misarticulation. One, two or all three misarticulations were eliminated in 67%, 27% and 6% of the subjects, respectively, by the age of 8 years. /S/ and /l/ sounds were corrected more often than the /r/ sound. Fourteen percent of the subjects with at least one misarticulation at the age of 6 years and 16% of the subjects without any misarticulation at the age of 6 years had a new misarticulation by the age of 8 years.

At the age of 8 years new /r/, /s/ and /l/ errors were diagnosed almost equally often in those patients with misarticulations at the age of 6 years (5%, 5%, 3%, respectively), whereas in patients without misarticulations at 6 years of age the figures were 7%, 12% and 1%, respectively. Subjects with and without speech therapy before the age of 6 years produced as often new misarticulations by 8 years of age. Misarticulation of the /s/ sound appeared altogether in 12 patients, of which 9 subjects had unchanged spacing of the maxillary incisors from the age of 6 to 8 years, and only 3 had spacing at the age of 8 years but not at 6 years of age. The situation was similar for new /r/ and /l/ errors and spacing.

7.2. Dental arch dimensions, occlusion and misarticulations at the age of 6 years (III,IV)

All dimensions, and especially maxillary ones, were smaller in cleft children than in non-cleft Finnish children. Dental arch dimensions showed statistically significant differences between genders in general and in different cleft types. The boys had larger values in all dimensions in each cleft group. Maxillary widths decreased both anteriorly and posteriorly with the severity of the cleft but maxillary lengths and heights as well as lower arch dimensions did not differ so clearly. CL(A)-children had the widest and BCLP-children the narrowest dimensions. **Table 2** shows statistical comparisons of the mean values of the dental arch dimensions between subjects misarticulating one or more of the sounds /r/, /s/ or /l/ and subjects with correct /r/, /s/ and /l/ articulation genders separated and cleft types combined. In general both boys and girls with all studied articulatory errors had significantly narrower maxillary arches than subjects without these errors. In addition, girls with /r/, /s/ and /l/ errors had significantly shallower palates than girls with correct /r/, /s/ and /l/ production, and boys with the /s/ and /l/ errors, and girls with /r/ errors had also significantly shorter maxillary arches than subjects without studied errors. The biggest differences in maxillary width and palatal height dimensions were found between girls with and without /l/ errors. Only one mandibular arch dimension differed significantly in the corresponding comparisons.

Table 2. Statistical comparisons (Student's t-test) of maxillary mean values (d, mm) of the dental arch dimensions between subjects with /r/ or /s/ or /l/ misarticulation including their combinations (n1) and subjects without them (n2) separately for genders in all cleft types.

Dental arch dimensions	Boys (n=154)						Girls (n=109)					
	/r/ (n1=67, n2=87)		/s/ (n1=45, n2=109)		/l/ (n1=33, n2=121)		/r/ (n1=26, n2=83)		/s/ (n1=14, n2=95)		/l/ (n1=13, n2=96)	
	p	d	p	d	p	d	p	d	p	d	p	d
Width 53,63	0.000***	2.3	0.000***	2.9	0.004**	2.3	0.000***	4.2	0.005**	4.0	0.000***	6.5
Width 55,65	0.016*	1.4	0.000***	2.6	0.002**	2.2	0.000***	2.3	0.000***	3.1	0.000***	3.3
Maxillary arch length	ns		0.023*	1.0	0.034*	1.0	0.000***	1.2	ns		ns	
Palatal height posterior	ns		ns		ns		0.000***	2.1	0.008**	1.9	0.002**	2.2

*p<0.050, **p<0.010, ***p<0.001, ns= not significant, d= difference of the mean values (x2-x1, mm) of the dental arch dimensions between subjects without (n2) and with misarticulations (n1).

Fifty-seven percent of the subjects had anterior and/or posterior crossbite, 8% had large maxillary overjet, and 29% had deep bite. The number of subjects with crossbite increased with the severity of the cleft; 26% in CL(A)-, 34% in CP-, and 96% in both UCLP- and BCLP-groups. The occurrence of crossbites, large maxillary overjet, or deep bite did not reveal any significant sex differences. Subjects with misarticulations of at least one studied sound had significantly more dental crossbites (73%) than subjects with correct /r/, /s/ and /l/ sound production, of whom 45% had crossbites. **Table 3** shows statistical comparisons of the occurrence of at least one misarticulation of /r/, /s/ or /l/ sounds, and separately for at least /r/, at least /s/ or at least /l/ sound between subjects with and without different types of crossbites. Subjects with any of /r/ or /s/ or /l/ misarticulation or their combinations had significantly more posterior crossbites than subjects with correct /r/, /s/ and /l/ sound articulation. Subjects with at least /s/ errors had significantly more often anterior crossbite associated with posterior crossbite in one side than subjects with correct /s/ production. There were no significant differences

between subjects with misarticulations of any studied sounds and subjects with correct articulation according to the occurrence of anterior crossbite alone. No statistically significant differences were observed between subjects with or without any studied misarticulations according to the occurrence of large maxillary overjets or deep bites.

Table 3. The statistical comparisons (chi-square or Fisher's exact test) between subjects with different types of crossbites and subjects without any crossbite according to the occurrence of at least one misarticulation or their combinations of /r/, /s/ or /l/ and separately for at least /r/ or at least /s/ or at least /l/ misarticulation .

Type of crossbite	At least one misarticulation	/r/	/s/	/l/
	p	p	p	p
Anterior alone	ns	ns	ns	ns
Anterior and posterior one side	0.042*	ns	0.011*	ns
Anterior and posterior both sides	0.000***	0.000***	0.000***	0.000***
Posterior one side alone	0.002**	0.021*	0.016*	0.010**
Posterior one side with or without anterior	0.000***	0.007**	0.000***	0.019*
Posterior both sides with or without anterior	0.000***	0.000***	0.000***	0.000***

* p< 0.050, ** p< 0.010, *** p< 0.001, d.f.= 1, ns= not significant.

7.3. Correlations between speech and breathing aerodynamics, oral somatosensoric sensibility, and strength of the tongue muscles, and skeletal/pharyngeal morphology and the Finnish /r/ sound (V,VI)

Males had more frequently /r/ distortions and significantly more severe cleft types than females. In subjects with /r/ distortion laryngeal resistance was significantly lower than in subjects without /r/ distortion (p= 0.000), and significantly lower in cleft subjects without /r/ distortion than in the controls (p= 0.000). There were no significant differences in the velopharyngeal orifice area and the smallest nasal crossectional area between subjects with and without /r/ distortion. However, the smallest nasal crossectional area was significantly smaller in subjects with /r/ distortion than in the controls. Nasal resistance did not differ between cleft groups or the controls. The peak expiratory flow values, somatosensoric measurements and strength of tongue muscles did not differ between subjects with and without /r/ distortion. The sensitivity in the sides of their tongues was similar for all the subjects.

In the cephalometric comparisons the position of the hyoid bone was significantly more anterior in subjects with /r/ distortion. No significant differences in the cranial base or in the relationship of the jaws or in their relationship to the cranial base were found between the groups with and without /r/ sound distortions. The nasopharyngeal, oropharyngeal and hypopharyngeal linear measurements did not differ significantly between the groups. However, in the hypopharyngeal region all linear measurements were 12-26% wider, but in the oro- and nasopahynx it was the same or smaller in subjects with /r/ distortion than in subjects without distortion.

Comparison of the aerodynamic measurements with the craniofacial and pharyngolaryngeal measurements indicated that laryngeal resistance showed significant negative correlation to the maxillary prognathy (SNA, p= 0.020), and to the sagittal maxillo-mandibular relationship (ANB, p= 0.020). Also a positive correlation between laryngeal resistance and the distance from the posterior nasal spine to the sella-basion line on the pharyngeal wall (ad 2, p= 0.037) was observed. In other words, low laryngeal resistance was associated with a narrower nasopharyngeal region. Laryngeal resistance

also correlated positively with the anterior position of the hyoid bone (H-RGn, H-Gn, p= 0.024 and p= 0.022, respectively). Low laryngeal resistance was thus associated with more anteriorly positioned hyoid bone.

8. DISCUSSION

8.1. Subjects and methods

The treatment of cleft children in Finland is centralised in the Cleft Center in Helsinki University Central Hospital, and therefore all socio-economic groups were represented in the study groups. Non-cleft controls were not used because there are several recent methodically comparable studies on articulatory abilities of non-cleft Finnish children aged from 5 to 9 years (Qvarnström et al., 1991; Luotonen, 1995). Although the number and consistency of our material should be considered representative for examining the association between dental arch sizes, crossbites and misarticulations, too small subgroups complicated the conclusions.

In the present study quantity and quality of speech material was designed to be practically carried out in every patient in Cleft Center. Tape-recorded strictly structured speech sample collection was not used because it would have reduced the quantity of the material. The interjudge agreement between the cleft team's two speech pathologists in rating and categorising misarticulations and estimating the need of speech therapy was adequate. The criteria used to evaluate the misarticulations may, however, vary in different ages and in different language groups. Therefore, the results of this study cannot be completely compared with similar studies. Methods in evaluation the sizes of dental arches (Moorrees, 1959; Nyström and Ranta, 1994) as well as measurement of speech and breathing aerodynamics (Warren, 1979; Smitheran and Hixon, 1981) are widely used. Intra-judge agreement for estimation of occlusion was high, and the range error between two tracings of cephalometric landmarks was adequate. Only angular skeletal lateral cephalometric measurements were used so that the genders could be combined. The measurements of the sensitivity and the strength of the tongue must be taken with caution due to the limitations of the instrumentation. The method to assess tongue muscle strength was modified for the present study and not standardized. The sensitivity was possibly measured too roughly. The distance of two points should have been 1 mm instead of the 2 mm allowed by the instrumentation.

8.2. Findings

8.2.1. Articulatory abilities in cleft-children

At the age of 6 years 44% of the Finnish cleft-children have articulatory problems with /r/, /s/ or /l/ sound, while only 30% of 5-8-year-old non-cleft Finnish children have the same misarticulations (Sonninen and Sonninen, 1976; Qvarnström et al., 1991; Luotonen, 1995). Most of the present misarticulations were distortions of the sounds, whereas substitutions were rather rare. This parallels the results of Powers (1971) who reported articulatory speech disorders being mainly distortions in schoolchildren, substitutions being common among kindergarten children. According to Shelton and McReynolds (1979) distortions are the least severe articulatory disorders.

For cleft-children the /r/ sound was the most difficult to produce; altogether 36% misarticulated this sound. Also /s/ and /l/ errors were common, since as many as 23% misarticulated /s/ and 18% /l/ sound. /R/ and /s/ sounds are the most difficult ones to produce for Finnish non-cleft children, too, since together these two sounds make up 89% and 95% of all errors at the age of 5 and 7 years (Luotonen, 1995), /l/ disorders being very rare (1%) (Qvarnström et al., 1991). Earlier Finnish studies are partly at odds with regard to the frequency of /r/ or /s/ disorders in Finnish non-cleft pre-school and schoolchildren. According to Sonninen and Sonninen (1976) and Qvarnström et al. (1991) /s/ disorders are the most common (30%), /r/ disorders being rather uncommon (7-8%), whereas Luotonen (1995) reported /r/ disorders accounting 61% and /s/ disorders 28% of all errors. Luotonen's (1995) results for non-cleft children agree with ours, although the definitions and criteria used for the correctness of the /s/ sound may partly vary between the studies. The most distinguishing finding was the high frequency of /l/ distortions among cleft-children compared with non-cleft Finnish children. Although the production of correct /l/ sound seem to be clearly easier than /r/ and /s/ production for non-cleft children, the production of /l/ sound is difficult enough for cleft affected individuals.

Although articulation disorders are suggested to be psychologically based, learned phenomena, articulation defects may have both organic and functional origins (Nichols,

1981; Van Dyke et al., 1984). Accurate articulation requires precise movements of articulators involving fine motor control, and close coordination of the lips, tongue, and mandible (Lindblom and Sundberg, 1971). Dental consonants are the most difficult sounds to produce, requiring precise placement and function of both of the tip and the blade of the tongue as well as space enough to the tongue tip in the most anterior part of the palate. A deviant structure or volume of the posterior part of the oropharynx may complicate adequate placement of the tongue (Laine, 1992). In addition, since especially the production of the /r/ sound requires modulation of phonatory air, abnormalities in the vocal tract structure may affect this air stream modulation resulting in distorted /r/ or /s/ sound. Different dentofacial morphology may also explain the high frequency of /l/ distortions in cleft children, and further studies are needed to find out which structures complicate most the /l/ sound production.

The number of subjects with misarticulations increased with cleft severity, and this result is in agreement with earlier studies (Ross and Johnston, 1972; Riski and Delong, 1984). Also the need for speech therapy increased obviously with the severity of the cleft. Boys outnumbered girls in the more severe cleft types (UCLP, BCLP). Hence the correlation between the occurrence and severity of the misarticulations and the cleft type or the gender is not completely clear. However, patients with complete clefts may have maxillary collapse, and/or retrusion or protrusion of the premaxilla which present their own hazards to articulation. The fact that both the number and severity of misarticulations clearly increased with the severity of the cleft may reflect the negative effect of occlusal problems for speech development.

Boys outnumbered girls in articulatory disorders according to the present as well as earlier studies (Kenney et al., 1984; Beitchman et al., 1986; Qvarnström et al., 1991; Luotonen, 1995). Boys were also more often treated because of severe misarticulations than girls were. Early speech development as well as early progress of fine motor movements have been reported to be slower among boys (Stevenson and Richman, 1976; Silva, 1980; Kirkpatrick and Ward, 1984; Beitchman et al., 1986; Luotonen, 1995). Boys are found to have more inaccurate tongue movements and problems in coordinating those movements than girls, especially among children with articulatory speech defects (Qvarnström et al., 1993b). Disorders in speech sound production in

general are reported to reflect immaturity in fine motor control of the orofacial muscles in 6-8-year-old children (Pahkala et al., 1991). Interestingly, while non-cleft boys have more /r/ disorders (Qvarnström et al., 1991; Luotonen, 1995), but fewer /s/ disorders than non-cleft girls (Qvarnström et al., 1991), cleft-boys outnumbered cleft-girls in both /r/, /s/ and /l/ misarticulations at the age of 6 years.

Unfortunately, there is only a little information on changes in misarticulations during the maturation of speech articulation. Although children are considered to be able to produce all sounds correctly long before school age (Sarmavuori, 1982), the final control of the oral articulatory movements is thought to be achieved as late as the age of 10 to11 years (Smith and McLean-Muse, 1986). Articulatory disorders are known to decrease with age (Milisen, 1971; Alstam-Malcus et al., 1976; Leske, 1981; Qvarnström et al., 1991), but they seem to correct more often spontaneously in non-cleft schoolchildren than cleft-children, since half of the Swedish (Alstam-Malcus et al., 1976), and as many as 82% of American first grade schoolchildren correct their articulation without speech therapy up to grades 2 and 3 (Irwin et al., 1974). Half of misarticulations in Finnish non-cleft children decreased between the ages of 7 to 9, but these children had received treatment (Luotonen, 1995). Articulation of dental consonants are distinguishly difficult for cleft-children, since 81% of subjects with at least one error at the age of 6 years still misarticulated at least one sound **at the age of 8 years**.

Altogether 14% to 16% of the subjects generated a new misarticulation between the age 6 to 8 years. New misarticulations were diagnosed whether speech therapy was given or not. This may partly, however, be a consequence of the fact that some inconsistent distortions were categorised as immature but not as misarticulations at the age of 6 years, and they were expected to correct spontaneously by the age of 8 years. However, persisting dysmature articulation was considered as a misarticulation at the age of 8 years. Abnormalities in dentofacial growth may partly explain appearance of new misarticulations in cleft children.

As many as 57% of the 6-year-old patients with /r/, /s/ or /l/ misarticulations could improve their articulation to some extent and eliminate at least one of the errors by the

age of 8 years, and 16% of the subjects misarticulated less severely at least one sound at the age of 8 years. Some of these children had received speech therapy between speech examinations at 6 and 8 years of age. However, the improvement of articulation may partly be due to the spontaneous normalising of the /s/ sound. This makes questionable the timing and validity of the speech therapy given to the present children. Still, our findings of improved articulation are better than those reported in the study of American-English speaking cleft palate individuals of whom only about 20% eliminated /r/, /s/ and /l/ sound errors by 8 years of age (Van Demark et al., 1979). However, 20% of our patients with at least one misarticulation at the age of 6 years could not improve their articulatory abilities at all by the age of 8 years. Unfortunately, there are very few studies with which to compare these results, and because of language differences the results of similar studies abroad are not completely comparable. Although it was not the focus of the present study it would have been interesting to examine the consistency of the articulated sounds in various positions in the word.

Gender did not significantly influence changes in articulation of any studied sound between the age from 6 to 8 years, although boys had significantly more often severe cleft types than girls did. This finding agrees with Riski and Delong (1984) who found that the sex was not a significant factor in the development of normal articulation skills up to the age of 8 years, although age and the type of the cleft were. The boys did not catch-up in their articulatory skills in dental consonants between 6 and 8 years of age in the present study, and thus the present results do not verify the assumptions of earlier studies which presumed that during kindergarten and pre-school years the more defective articulation of both non-cleft and cleft affected boys compared to the girls simply reflects the slower maturation of the fine motor movements (Kenney et al., 1984; Beitchman et al., 1986; Luotonen, 1995). Unfortunately, in the present study it was not possible to compare the changes in articulation between cleft types due to the small number of subjects in the subgroups.

According to the present results /l/ and /s/ misarticulations were eliminated more often than /r/ errors. Similarly, among non-cleft Finnish pre-school and 7-year-old schoolchildren /s/ disorders improve spontaneously, whereas /r/ disorders seem to be notable resistant to treatment (Qvarnström et al., 1991; Luotonen, 1995). On the other

hand, with advancing age from 7 to 10 years /r/ disorders are reported to decrease, and /s/ disorders to increase markedly, although most of these subjects had received speech therapy before or at school (Qvarnström et al., 1993a). Probably the Finnish /r/ sound is more difficult to produce correctly than it is in other languages, since, for example, in American-English speaking cleft populations the degree of success for /r/ correction was similar to corrections for /s/ and /l/ between 6 to 8 years of age (Van Demark et al., 1979). Unfortunately, this study does not mention if the subjects had been treated with speech therapy. Since cleft affected subjects have articulation deficits that are apparently strongly influenced by phonological maturation, it is impossible to conclude whether the decrease in the occurrence of the studied misarticulations is due to more mature tongue movements or to the effects of speech therapy or both. Cleft children also have recurrent otitis media, which is known to affect speech development. This may also have an impact on the articulatory skills of cleft children. Unfortunately, it was not possible to control for the otitis condition in the present children. Altogether, at least the timing and intensity of speech therapy used with cleft children warrants re-evaluation so that the treatment would have related more to maturation and developmental factors.

8.2.2. Dentofacial morphology and articulation

According to present results a narrow and shorter maxillary arch as well as a shallower palate seems to explain partly the occurrence of dental consonant misarticulations. These findings are in agreement with results of earlier studies with cleft-patients (Starr, 1971; Okazaki et al., 1991), and non-cleft individuals (Oliver and Evans, 1986). Powers (1971) stated that subjects with /r/ or /l/ distortions keep their tongue posteriorly and inferiorly instead of raising it to the alveolar ridge, and Laine et al. (1987) suggested that certain sounds may be produced too far posteriorly due to a deficiency in maxillary anterior space. Wilcox et al. (1985) and Wyatt et al. (1996) concluded that subjects with reduced maxillary arches may have insufficient space for their tongues to obstruct the air steam adequately in order to produce the /s/ sound correctly. On the other hand, Bishara et al. (1975) found that subjects with isolated clefts palate with good or poor articulation did not differ systematically in their dental relations.

Our findings revealed clearly that cleft patients with posterior crossbites are at high risk for defective dental consonant articulation, while anterior crossbite was related to articulatory errors only when it was combined with posterior crossbite. Although only weak association between /s/ disorders and lateral crossbite has been earlier found (Laine, 1987), several authors have concluded that both anteriorly or posteriorly decreased intermaxillary space of the oral cavity due to occlusal anomalies prevents the precise placement and function of the tongue required for correct /s/ production (Heinz and Stevens, 1961; Wilcox et al, 1985; Howell, 1987; Laine, 1987). In distal (Class II) and mesial (Class III) molar occlusion /s/ production is found to be too anterior due to the protrusion of the tongue (Ruscello et al., 1985; Wyatt et al., 1996), although also retruded tongue posture in Class III subjects with distorted /s/ phonation has been found (Guay et al., 1978). Altogether, subjects with Class III malocclusion are reported to misarticulate more than those with incisal open bite (Laine, 1992). Probably because cleft patients' occlusion only resembles Class III occlusion due to the retruded maxilla, anterior crossbite alone did not seem to explain the articulatory errors of cleft patients.

According to the present study neither a large maxillary overjet nor a deep bite did not influence on the occurrence of misarticulations. These findings support earlier results concerning incisor relationship and articulatory defects in non-cleft adults (Oliver and Evans, 1986; Laine, 1987), although weak associations between /r/ disorders and large maxillary overjet have been reported (Laine, 1992).

The present results regarding the association between spacing of the maxillary incisors and misarticulations partly disagree with earlier studies, since several authors have found subjects with misarticulations having more often spacing of the maxillary dental arch than subjects without misarticulations (Snow, 1961; Laine et al., 1987). On the other hand, other reports have found that other developmental factors have a greater influence on correct speech sound production than the eruption stage of the incisors (Ingervall and Sarnäs, 1962; Pahkala et al., 1991). Altogether some individuals can functionally compensate for maxillary frontal spacing and control the airflow adequately to produce acoustically correct consonants (Weinberg, 1968). In this study the changing of the maxillary incisors occurred between the studied ages. The varying spacing through time due to changing may influence the appearance of new sound errors in these

subjects. However, more detailed information is needed to find out if spacing or severe malpositions of the maxillary incisors have an influence on articulation.

Since many of the present subjects with posterior crossbites had correct /r/, /s/ and /l/ articulation, and many subjects without posterior crossbites still misarticulated at least one studied consonant, a smaller oral cavity should be considered only as a possible contributing hazard to clear articulation in cleft palate patients. So, even in the presence of severe structural deviations good articulation can exist due to the highly adaptable speech mechanisms and compensatory behaviour (Starr, 1971; Hardcastle et al., 1987). Studies dealing with the developmental aspects of speech in relation to occlusion and compensatory speech responses to the presence of structural deviations are clearly lacking, partly due to methodological difficulties. Longitudinal studies to determine whether children with occlusal anomalies and articulation disorders have the same faulty sounds at a later age or whether articulatory speech disorders appear later during development of the dentition, would clarify these issues. Finally, if misarticulations of especially /s/ and /r/ sounds are so called "residual speech errors" dating from the early stages of speech development (Hardcastle et al., 1987), any other malocclusion except those existing before the age of 5 years could not possibly have any effect on speech sound production. On the other hand, it is generally recognised that both a narrow upper dental arch and posterior crossbite are sometimes seen in connection with pathological conditions causing obstruction of the nasopharyngeal airway, which may complicate articulation (Solow and Greve, 1979).

8.2.3. /R/ distortion, speech aerodynamics and pharyngeal morphology

The present results showed that cleft subjects with /r/ distortion had lower laryngeal resistance and more anterior position of the hyoid bone than subjects without /r/ distortion. Low laryngeal resistance has been found to increase the risk for different voice disorders also in earlier studies (Zajac, 1995). Velopharyngeal orifice size, the smallest nasal crossectional area or nasal resistance as well as the sensitivity of the palatal alveolus or the tongue or strength of tongue muscles were not related to /r/ distortions.

Although the cleft type per se is probably not the determinant of distorted /r/ sound articulation, the effect of the cleft type on dento-alveolar morphology and other cephalometric dimensions may be reflected both in respiration and phonation. Phonation requires precise function of the so-called physiologic larynx, i.e. tongue base, the position of the hyoid bone and the glottis (Vilkman et al., 1996), and this function may be distorted in patients with orofacial abnormalities. Dysmorphology in the vocal tract probably negatively affect the modulation of the speech air stream resulting in a distorted /r/ sound.

The present results showed no significant differences in lateral cephalometric skeletal morphology between subjects with and without /r/ sound distortion. These results parallel those of Bishara et al. (1975) who could not establish any consistent trends between dentofacial angular or linear relations and phonemes in patients with isolated cleft palate. However, some pharyngeal horizontal dimensions were slightly but not significantly bigger in our subjects with /r/ distortion. A slightly wider pharynx in subjects with /r/ distortion may alter airflow and air pressure in /r/ sound production and thus contribute to /r/ distortion. Laryngeal resistance was lower in subjects with /r/ distortion than in subjects without /r/ distortion. Although it has been previously suggested that some occlusal anomalies may affect the position of the tongue and that of the hyoid bone which may increase the risk for defective articulation (Laine, 1987), Haralabakis et al. (1993) stated that the position of the hyoid bone moves in close conjunction with the pharynx and mandibular plane even in patients with entirely different skeletal patterns. Since the position of the hyoid bone is a reflection of the relative tensions of the muscles, ligaments, and fasciae attached to it, the reason for hyoid bone moving ”in concert” with the adjacent anatomical structures is concluded to be the need to maintain the patency of the upper airway at the level of the base of the tongue (Opdebeeck et al., 1978; Haralabakis et al., 1993). Thus, it is possible that the anterior position of the hyoid bone increases the pharyngolaryngeal volume and is associated with decreased laryngeal resistance in subjects with /r/ distortion. In addition, if the hyoid bone is positioned too anteriorly, it may be difficult and perhaps impossible to place the tongue tip in the proper position for the correct production of the /r/ sound.

Even though, the smallest nasal cross-sectional area and nasal resistance correlated with each other, neither of them correlated significantly with the dentofacial or pharyngeal cephalometric measurements, except for the fact that the smallest nasal cross-sectional area decreased significantly with the more inferior position of the hyoid bone. Although anatomical abnormalities of the pharynx in cleft palate speakers can be evaluated reliable with cephalometric radiography (Hoenig and Schoener, 1992), Kluemper et al. (1995) stated that facial morphology and respiratory mode are unrelated, and that cephalometric analyses are poor indicators of nasal impairment. Nasopharyngeal depth has been reported to be shorter and thus nasopharyngeal airway to be reduced in cleft affected subjects than in non-cleft individuals (Scaf et al., 1991; Smahel et al., 1991; Wada et al., 1997), although also deviant results have been presented (Hoenig et Schoener, 1992). In individual cleft patients nasopharyngeal width may compensate for smaller nasopharyngeal depth (Smahel et al., 1991). According to present results the smallest nasal cross-sectional area and nasal resistance did not correlate with laryngeal resistance, and thus do not probably explain the /r/ distortion in cleft affected subjects.

Velopharyngeal orifice area did not correlate with lateral cephalometric skeletal morphology, hyoid measurements, pharyngolaryngeal dimensions, the smallest nasal cross-sectional area, nasal or laryngeal resistance or /r/ distortion. In our present subjects the distance from the posterior nasal spine to the pharyngeal wall (ad2) were on the average shorter than 20 mm indicating the absence of velopharyngeal incompetence (Haapanen et al., 1991). To sum up, the velopharyngeal area was not associated with any parameters that correlated with /r/ sound distortions.

The present associations between /r/ distortion and low laryngeal resistance as well as anterior position of the hyoid bone are new and suggest the need for more research to resolve treatment possibilities of orofacial structures to allow normal speech.

9. CONCLUSIONS

Altogether 44% of 6-year-old cleft children had /r/, /s/ or /l/ misarticulations and these errors increased with the severity of the cleft. The frequency of /l/ distortions was surprisingly high. Dental sound disorders were more common in boys than in girls.

As many as 81% of the subjects still misarticulated /r/, /s/ or /l/ sound at the age of 8 years. New misarticulations were diagnosed at the age of 8 years in the same way in the groups with (14%) and without (16%) misarticulations at the age of 6 years.

The decreasing size of the maxillary dental arch as well as posterior crossbites seem to be related to the increasing incidence of the studied misarticulations.

/R/ distortion is significantly correlated with low laryngeal resistance, and tends to occur with a wider pharynx, and an anteriorly positioned hyoid bone.

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