From the Cleft Center, Department of Plastic Surgery
Helsinki University Central Hospital
University of Helsinki
Helsinki, Finland

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

Joonas Pulkkinen

Academic dissertation

to be publicly discussed with the assent of the Faculty of Medicine of the University of Helsinki for public examination in Auditorium XII of the University Main Building, on 19 April, 2002, at 12 noon.

HELSINKI 2002

Supervised by

Docent Reijo Ranta, DDS, PhD
and
Docent Marja-Leena Haapanen, MD, PhD
Cleft Center, Department of Plastic Surgery,
Helsinki University Central Hospital, University of Helsinki

Reviewed by

Docent Eeva Sala, MD, PhD
Department of Ear, Nose, Throat Clinic
Turku University Central Hospital, University of Turku
and
Professor Juha Varrela, DDS, PhD
Department of Oral Development and Orthodontics
Institute of Dentistry, University of Turku

Opponent

Professor Lassi Alvesalo
Department of Oral Development and Orthodontics
Institute of Dentistry, University of Oulu

ISBN 952-91-4451-2 (nid.)
ISBN 952-10-0422-3 (PDF)

Yliopistopaino, Helsinki 2002

CONTENTS

1. LIST OF ORIGINAL PUBLICATIONS

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

I Pulkkinen J, Ranta R, Haapanen M-L, Heliövaara A, Laitinen J. Associations between lateral cephalometric dimensions and misarticulations of Finnish dental consonants in cleft lip/palate children. Folia Phoniatr Logop, in press.

II 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. Also published in the academic dissertation ”Associations between dental consonant articulation, orofacial morphology and function in cleft lip/palate” by Jaana Laitinen. Yliopistopaino Helsinki 1999.

III Pulkkinen J, Ranta R, Heliövaara A, Haapanen M-L. Craniofacial characteristics and velopharyngeal function in cleft lip / palate children with and without adenoidectomy. Eur Arch Otorhinolaryngol 2002;259:100-104.

IV Pulkkinen J, Haapanen M-L, Paaso M, Laitinen J, Ranta R. Velopharyngeal function from the age of three to eight years in cleft palate patients. Folia Phoniatr Logop 2001;53:93-98.

V Pulkkinen J, Haapanen M-L, Laitinen J, Paaso M, Ranta R. Association between velopharyngeal function and dental-consonant misarticulations in children with cleft lip/palate. Br J Plast Surg 2001;54:290-293.

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
NAE	nasal air emission
HNA	hypernasality
WPC	weakness of pressure consonants
COMP	compensatory articulations
VPF	velopharyngeal function
VPC	velopharyngeal competence
VPI	velopharyngeal incompetence, insufficiency
VPP	velopharyngoplasty

3. ABSTRACT

The associations of craniofacial morphology, dentoalveolar misarticulations of /r/, /s/ and /l/ sound and velopharyngeal function were studied in children with different cleft types. Speech was analysed at the age of 3, 6 and 8 years. Velopharyngeal function was assessed perceptually and velopharyngeal insufficiency confirmed by instrumental examinations with nasalance measurements and/or the x- ray or videofluorographic examinations. Occlusal anomalies were evaluated from plaster casts and cephalometric morphology from standardized lateral roentgen cephalograms taken at 6 years of age.

Some significant associations between cephalometric measurements and misarticulations were observed. Children with /r/ distortion had upward rotation of the mandible, maxillary protrusion and a higher position of the hyoid bone in the isolated cleft palate group. In the bilateral cleft lip and palate group, the mandible had downward rotation, mandibular retrusion and narrower nasopharyngeal port. The /s/ and /l/ sounds were less associated with craniofacial morphology. The cranial base, the anteroposterior relationship of the maxilla and the mandible did not show any association with dentoalveolar misarticulations.

Posterior crossbites were significantly associated with any misarticulations of /r/ or /s/ or /l/ or their combinations, whereas anterior crossbite alone, large maxillary overjet, or deep bite were not. Forty-three per cent of the subjects misarticulated at least one of the studied sounds, and they had crossbites significantly more often (73%) than subjects with correct /r/, /s/ and /l/ production (45%).

The size and shape of the cranial base, interrelationship of the maxilla and mandible and their relationship to the cranial base, the bony nasopharynx (triangle S-Ba-Pm) and the length of the velum did not differ between children with competent and incompetent velopharyngeal function or velopharyngoplasty. The sagittal depth of the nasopharyngeal airway was significantly wider in children with than without velopharyngoplasty. Any previous adenoidectomy decreased the thickness of the posterior pharyngeal wall and increased nasal airway size but did not exclusively result in velopharyngeal insufficiency. With advancing age and growth improvement of the velopharyngeal function was apparent. The patients who required velopharyngeal flap before the age of eight years did not differ significantly from those who did not require the flap operation at the age groups of 3, 6 and 8 years with respect to the presence of nasal air emission, hypernasality, weakness of pressure consonants or compensatory articulation. Velopharyngeal function was good at the age of 8 years both in children treated conservatively or requiring velopharyngoplasty. The isolated cleft palate children (34.3%) significantly required more often a velopharyngeal flap than the unilateral cleft lip and palate children (13.3%) but they developed similar velopharyngeal function.

In the occurrences of misarticulation of /r/, /s/ and /l/ or their combinations there were no significant differences between subjects with competent, marginal competent or obvious incompetent velopharyngeal function. Subjects with previous velopharyngoplasty did not differ from those without previous velopharyngoplasty in the frequency of misarticulations. Thus, dental consonant misarticulations occur independently of velopharyngeal function.

4. INTRODUCTION

Clefts of the lip and/or palate are the most common group of congenital malformations affecting morphology and growth of the middle face. The incidence is about two cleft lip and/or palate children per 1000 newborns in Finland. The etiology and pathogenesis of oral clefts are still unknown. Both genetic and environmental factors probably play a role in the occurrence of oral clefts.

The cleft anomaly affects also other facial structures than those directly within the cleft region. The maxilla tends to be small and retruded, and the growth of the mandible may also be deficient (Dahl 1970). Orofacial morphology of cleft palate patients changes with age because of surgical interventions and growth. These changes also affect speech and voice production. Therefore the treatment of cleft lip and palate needs multidisciplinary team work. Cleft lip palate patients have speech difficulties due to impaired velopharyngeal function. The patients suffer from nasal voice resonance and various types of articulatory disorders, which may severely impair the intelligibility of their speech and cause social problems (McWilliams et al. 1990, Haapanen 1992).

The occurrence of dental consonant articulatory errors are higher among cleft patients than in noncleft patients (Van Demark et al. 1979, Qvarnström et al. 1991, Laitinen et al. 1998a). Variable factors may cause dental sound misarticulations. Speech aerodynamics may be distorted in cleft patients (Mayo et al. 1998). Dentoalveolar dysmorphology results in atypical cephalometric dimensions and may be associated with abnormalities in vocal tract anatomy. Dentoalveolar dysmorphology results in atypical cephalometric dimensions and may be associated with abnormalities in vocal tract anatomy (Smahel et al. 1991). Oral structural dysmorphology may affect negatively on the dental and skeletal relationships between maxilla and mandible. These changes may prevent proper coordination of the lips, tongue and mandible and hence result in misarticulations (Bishara et al. 1975, Van Dyke et al. 1984, Qvarnström et al. 1994). Wide cephalometric dimensions of the nasopharynx may cause hypernasal resonance of speech (Haapanen et al. 1991). Orofacial dysmorphology may also disturb normal physiology and functions during breathing and phonation (Warren et al. 1992, Mayo et al. 1998). The pattern of speech development may also depend on cofactors such as the method of primary palatoplasty used, previous velopharyngoplasty, existing hard palate fistula as well as social, psychomotor and psychodynamic factors.

Incompetent velopharyngeal function (VPI) is a common problem in cleft children. VPI may results in nasal air emissions, weakness of plosives and compensatory articulations (McWilliams and Musgrave 1971, Haapanen 1992). The length, function and posture of the soft palate; the activity of the posterior and lateral pharyngeal walls; deviated or deficient neuromuscular or cognitive development; the depth and the width of the nasopharynx and cervical spinal abnormalities and adenoidectomy that cause increased pharyngeal depth may contribute to persisting VPI after primary palatal repair (Osborne et al. 1971). Persistent VPI is treated, depending on its etiology and severity, by speech rehabilitation, surgically or their combinations. Indications for surgery are recommended to be based on perceptual assessments and confirmed by instrumental examinations (Hirschberg et al. 1995).

This study was carried out to investigate the associations between craniofacial morphology, dental consonant misarticulations of /r/, /s/ and /l/ sounds and velopharyngeal function.

5. REVIEW OF THE LITERATURE

5.1. Aspects of speech in cleft and non-cleft subjects

Fine neurological regulation of rapid motor acts are needed for normal speech articulation (Darley et al. 1975). Voice is generated by the larynx and shaped into articulation in the pharynx as well as the mouth and the nose (Wyat et al. 1996). The airflow for phonation, i.e. voice production, is generated by the expiratory phase of breathing. The larynx is responsible for the regulation of the airflow during both breathing and speech (Zajac 1995). The airflow is controlled for speech by the movements of vocal folds in the larynx resulting in changes of the air pressure above the larynx. The fluctuating air passing through the vocal tract it resonates in the oro-nasal cavities (Darley et al. 1975, Hardcastle 1976). Different vocal tract actions result in production of linguistically relevant sounds (Gracco 1991). The production of voiced and voiceless sounds is dependent on laryngeal functioning (Broad 1973).

Linguists and phoneticians have categorised speech sounds depending on the place and manner of the articulation. In Finnish there are sounds that are produced by the tip of the tongue closely contacting the anterior palatal alveolus (/r/, /l/, /s/, /t/, /d/, /n/). Because the place of their articulation is in the dental zone, these sounds are termed dentoalveolars or dentals (Sovijärvi 1963). The dentals /r/ and /s/ are regarded as the most difficult sounds to produce in Finnish. The Finnish /r/ is described as a voiced linguomedioalveolar tremulant, a voiced or long voiced dental trill or a dental tremulant (Wiik 1981, Karlsson 1982, Maddieson 1984). Between two vowels /r/ may be articulated as a one-tap trill and after the /s/ sound as a fricative (Wiik 1981). It is hard to compare Finnish sounds with other languages, particularly the /r/ sounds, because of the articulatory differences. The Finnish /r/ sound differs much from its English counterpart, which is a semivowel and not at all a trill and therefore not so difficult to produce as the Finnish one. The Finnish /r/ and /s/ may be more difficult to produce than those of Germanic languages (Arnold 1965).

Children are generally expected to produce correctly most of the speech sounds of their mother tongue by the age of 4-5 years. However, Finnish children commonly incorrectly produce /r/ and /s/ sounds even at the age of 7-8 years. Up to 30 % of the Finnish children produce incorrectly some of the dental sounds (Sonninen and Sonninen 1976, Qvarnström et al. 1991). According to Luotonen (1995) the /r/ and /s/ sounds make up 95 % of all errors at the age of 7 years. Non-cleft children, however, rarely incorrectly produce the /l/ sound (Qvarnström et al. 1991). At the age of 5 years only 1% of the children substitute a difficult sound by various difficult to articulate sounds (e.g. /t/ for /s/). Misarticulations are mainly distortions of the targeted sound (Qvarnström et al. 1991).

5.1.1. Factors affecting speech development in children

Gender is often reported to be associated with speech development. Boys outnumber girls in articulation disorders in preschool years and at the first school years (Qvarnström et al. 1991, Luotonen 1995). Boys are found to have more /r/ sound disorders than girls, who, on the other hand, have more often /s/ sound disorders (Qvarnström et al. 1991). The articulatory difficulties of the boys are attributed to their slower speech development and fine motor maturation (Stevenson and Richman 1976, Silva 1980, Beitchman et al. 1986). Articulatory errors tend to decrease with age (Leske 1981, Qvarnström et al. 1994). However, some misarticulations, such as the /r/ sound in Finnish children, seem to be quite therapy resistant (Qvarnström et al. 1991).

Articulatory errors originate from many different organic or functional disorders, such as structural defects of the articulating organs, resonance cavities, orofacial skeletal dysmorphologies or dental occlusion problems, neuromuscular dysfunctions, sensory abnormalities, delayed or deviated language development or other developmental factors (Van Dyke et al. 1984, Van Riper and Emerick 1984).

Weakness, slowness and incoordination of articulatory muscles may be of neurogenic, either central or peripheral origin. Even though many different defects may result in disordered speech sound production, as much as 75 % of all articulatory disorders are suggested to be of functional etiology (McReynolds and Elbert 1982, Van Dyke et al. 1984). The tongue has been regarded as the most important articulator, since most speech sounds are produced by altering the shape of the tongue. Articulatory speech disorders in 6-8 year old children have been attributed to inaccurate tongue movements (Speirs and Maktabi, 1990), or coordination of articulatory movements (Yoss and Darley 1974, Ferry et al. 1975, Cermak et al. 1986). Fortunately tongue skills, the efficiency in moving the tongue into correct and precise articulatory positions seem to improve with advancing age up to the age of 11 years (Watkins and Fromm 1984, Sharkey and Folkins 1985, Robbins and Klee 1987, Fletcher 1989, Wood and Smith 1992, Qvarnström et al. 1994).

The production of the Finnish /r/ sound is based on the modulation of the phonatory air. The creation of the tremulating air may be hindered by dysmorphologic or dysfunctional articulators and abnormal pharyngolaryngeal morphology. The orofacial structures and growth are affected by clefts of the lip, alveolus or palate. Abnormal dentofacial morphology is attributed to higher risk of articulatory problems in cleft children. The severity of the cleft is interrelated with the severity of articulatory problems (Ross and Johnston 1972, Riski and Delong 1984, Laitinen et al. 1998a,b). Cleft palate boys seem to have more dental consonant errors than girls (Laitinen et al. 1998a). The growth and muscular strength and function of the middle face may also be negatively affected by surgical procedures (Folkins 1985, Enemark et al. 1990, Wada et al. 1997).

Persistent palatal fistulas affect negatively on speech, particularly on the production of pressure consonants articulated anterior to the fistula (Rohrich et al. 1996, Pinborough-Zimmerman et al. 1998). Palatal or velopharyngeal surgery may cause maxillary growth deficits and result in constrictions of the nasal floor and reduction of airway size thus increasing airway resistance (Warren et al. 1969, Smahel et al. 1991). Atypical cephalometric dimensions associated with dento-alveolar morphology due to cleft lip and/or palate may result in vocal tract anomalies (Smahel et al. 1991, Hoenig and Schoener 1992), and hence explain abnormal breathing and phonation (Ruscello et al. 1985, Scaf et al. 1991). Intraoral pressure necessary for speech may be achieved by abnormally increasing the airflow rate in cleft affected patients (Warren et al. 1985, Warren 1986). The size of the pharynx has been regarded tobe more important for normal speech production than timing or the method of palatal surgeryin cleft palate children (Shprintzen and Goldberg 1995).

5.1.2. Dental arches and malocclusions in articulatory errors

Smaller oral dimensions have been found in patients with misarticulations than in children with normal speech (Oliver and Evans 1986). Cleft children tend to have smaller maxillary arch widths and lengths than the non-cleft subjects (Nyström and Ranta, 1990, Friede et al. 1993, Nyström and Ranta, 1994). Dental consonant misarticulations may be associated with narrow and short maxillary arches and shallow palates in cleft palate patients (Starr 1971, Okazaki et al. 1991, Laitinen et al. 1998a,b) as well as in non-cleft patients (Oliver and Evans 1986). Maxillary dento-alveolar dimensions tend to decrease and articulatory errors increase with the severity of the cleft (Ross and Johnston 1972, Friede et al. 1993, Hellquist et al. 1978). Malocclusion, crowding and incomplete middle face development occur with diminishing growth of the maxilla and upper dental arch cleft patients who have been operated on (Nyström et al.1992).

Studies examining correlation between speech articulation and occlusion have mainly focused on the position of upper and lower incisors. The distortions of the unvoiced sibilant /s/- has been explained by an open bite (Lewis 1971, Guay et al. 1978, Laine et al. 1987, Laine 1992). The /s/ sound is also found to be associated with the tongue being placed too anteriorly. Lisping has been found in patients with open bite associated with tongue-thrust (Proffit and Norton 1970, Lewis 1971).

The abnormally low oral pressure affects speech negatively. The maintenance of oral air pressure is particularly important for cleft patients. It is decreased by an open bite resulting in the impairment of speech in cleft subjects (Warren 1986). Obviously the type of the overjet or overbite affects articulation quite specifically. Laine et al. (1985) noticed no effect of changes in overjet or overbite on /r/ or /l/ sound, but an increased overjet or decreased overbite was associated with difficulties in the production of /s/. Distal molar occlusion with or without maxillary overjet has been found in association with misarticulations (Blyth 1959, Subtelny et al. 1964, Laine et al. 1987). Mesial molar occlusion with or without mandibular overjet has been regarded to affect articulation (Lubit 1967, Guay et al. 1978, Ruscello et al. 1985, Laine 1987).

Some studies attribute articulatory problems to maxillary frontal spacing (Bankson and Byrne 1962, Starr 1971, Laine et al. 1987, Pahkala et al. 1991). However, maxillary spacing has been found to be of less importance in inter-incisal occlusion than in increased overjet or decreased overbite with respect to the occurrence of articulatory difficulties in the case of dentoalveolars such as /r/, /l/ and /s/.

5.1.3. Craniofacial morphology and speech disorders

Associations between dental consonant articulation and craniofacial cephalometrics in different cleft types have not been sufficiently studied. Cephalometric morphology does not seem to be associated with misarticulations in cleft lip and palate children (Bishara et al. 1975). In noncleft children, weak associations between /r/ sound disorders and large maxillary overjet have been reported (Subtelny et al. 1964). Reduced overjet and overbite in Class III subjects create smaller speech movements of the mandible reducing the space needed for the tongue movements used in proper articulation (Howell 1987). Due to the protrusion of the tongue /s/ production is found to be too anterior in Class III cases (Wyatt et al. 1996). Noncleft subjects with Class III occlusion and anterior crossbite resulting from a protruded mandible are reported to have a higher risk of having articulatory speech disorders than those with incisal openbite (Laine 1992). As the studies focusing on craniofacial cephalometrics and speech articulation are no quite comparable because of the heterogeneity of the study population and methods. Hence the results of the previous studies are somewhat contradictory. It is obvious that further studies focusing on the relationship between cephalometric dimensions and speech articulation are needed.

5.2. Velopharyngeal function and morphology

5.2.1. Terminology

The terminology concerning inadequate velopharyngeal valving mechanism is variable. The terms incompetence, inadequacy, insufficiency and dysfunction have been used interchangeable referring either to impaired motion, tissue deficiency or their combinations (Folkins 1985, Loney and Bloom 1987, Folkins 1988, Trost-Cardamone 1989). The term velopharyngeal incompetence has been used referring to an inability to produce full closure of the velopharynx while speaking due to structural defects or neuromotor dysfunction or in association with the perceived speech characteristics of cleft palate speech (Folkins 1985, 1988, Searl and Carpenter 1999), or probably just contrasting the terms competence-incompetence. Valving dysfunction due to impaired motion is termed `incompetence`, tissue deficiency `insufficiency` and mixture a of both `inadequacy` by Conley et al. (1997).

VPI affects both voice resonance and articulation. The typical signs of incompetent velopharynx during speech are hypernasality, audible nasal air emissions, weakness of pressure consonants and compensatory articulation. Hypernasality affects the resonance or voiced sounds such as vowels and vocalic consonants (Trost 1981). In Finnish the vowels, e.g. /a/, /i/, /e/ and sonorant consonants, e.g. (/l/) and (/r/) may be distorted by hypernasal resonance. Audible air emissions, a hissing or snorting noise may disturb the production of pressure consonants. Pressure consonants, voiceless plosives or fricatives, (in Finnish /k/, /p/, /t/ or /s/) may also be substituted by laryngeal glottal stop sounds compensatorily in association with velopharyngeal insufficiency. Substitutions of glottal stops for oral pressure consonants are termed compensatory articulation or misarticulation (Trost 1981, Bzoch 1989).

5.2.2. Assessment of velopharyngeal function

Normal deglution and speech requires appropriate velopharyngeal mechanism. The velopharyngeal valve separates the nasal and oral cavities from each other during swallowing and articulation. It is a complex mechanism including the soft palate, posterior pharyngeal wall and also often the lateral pharyngeal walls. Velopharyngeal valving dysfunction is due to motor incompetence, tissue deficiency or a combination of both. Velopharyngeal function is described in terms of perceptual analysis of the speech or by instrumental parameters or by combining perceptual and instrumental information (Warren 1979, Henningsson and Isberg 1986, Dántonio et al. 1998, Sphrintzen and Golding-Kushner 1989, Van Demark et al.1989, Henningsson and Isberg 1991, Conley et al. 1997).

The perceptual analysis of speech has been carried out by various methods. Various perceptual signs of VPI have been assessed using e.g. psychological scales like presence/absence scale (Ericsson and Yström 1989), category scales (Fox et al. 1988), equal appearing rating scales

(Henningsson and Isberg 1986, 1991), paired comparisons (Flecther 1976, Haapanen 1991a, Keuning et al. 1999) or direct magnitude estimation (Redenbaugh and Reich 1985). To add to the reliability of perceptual analysis intra- and interjudge agreement level has been assessed (Sphrintzen et al. 1979, Hardin et al. 1986, Henningsson and Isberg 1987, Kummer et al. 1989, Hardin et al. 1992). Some studies has used training sessions to increase the interjudge agreement level (Trost 1981). In many studies intra- and interjudge agreement has varied from 73 to 100% (Trost 1981, Van Demark and Hardin 1985).

It has been recommended that instrumental methods be used in addition to perceptual speech analysis particularly for assessing the need for palatal surgery to correct speech. The relative proportions of the sound pressure level within a specified frequency band emitted from the mouth and nose during speech has been measured with a nasometer (Fletcher 1989) and expressed as in percent "nasalance" score. The validity of the nasalance measurement has been tested against perceptual judgements by contrasting the degree of perceived hypernasality and the nasalance score (Fletcher 1976, Haapanen 1991a,b). The sensitivity and the specificity of the nasalance measurement in assessing hypernasality has varied from 0.89-0.95 and 0.87-0.93, respectively (Dalston et al. 1991, Hardin et al. 1992). Pressure and flow measurements are used as well for velopharyngeal function analysis (Warren and Dubois 1964).

Instrumental devices has been developed to find objective structural correlates for perceptual analysis of speech. Flexible nasal endoscopy, and multiview video fluoroscopy are the most frequently used methods to assess the type of velopharyngeal closure pattern, the movement of the soft palate, posterior pharyngeal wall and the Passavant´s ridge and lateral pharyngeal walls (Henningsson and Isberg 1991, Haapanen and Ertama 1994, Conley et al. 1997). The between the soft palate and the posterior pharyngeal wall, the length of the extended soft palate at the maximal velopharyngeal closure and the angular lift of the soft palate as compared to the hard palate can be measured reliably by lateral video fluoroscopy (Birch et al. 1999). Also cephalometric radiographs have been used in assessing velopharyngeal function, speech physiology or articulation (Haapanen 1991a, Satoh et al. 1999, Dántonio et al. 2000, Stellzig-Eisenhauer 2001, Laitinen et al. 2001). The most recent studies consider MRI for assessment of velopharyngeal function (Akguner 1999, Ozgur et al. 2000).
The differential diagnosis for velopharyngeal functional or organic insufficiency requires adequate speech material for analysis. Many studies have focused on the speech material relevant for velopharyngeal assessment (Van Demark et al. 1979, Haapanen 1991a,Haapanen al.1991, Vallino-Napoli and Montgomery 1997, Watterson et al. 1998).

5.2.3. Factors affecting velopharyngeal function

An open cleft results almost invariably in speech signs characteristic to VPI. Much scientific effort have been expended to find optimal surgical methods and timetable for primary palatal repair (Greene 1960, Evans and Renfrew 1974, Krause et al. 1976, Seyfer and Simon 1989, Van Demark et at. 1989, Haapanen and Rantala 1992). There has also been much debate optimal method for secondary surgery to correct speech after primary palatal repair (Lindholm 1971, Shulz et al. 1973, Sphrintzen et al. 1979, Bronsted et al. 1984, Trier 1985, Epker and Wu 1990, Haapanen and Iivonen 1992, Witsell et al. 1994, Muhler and Erler 1997). It is generally accepted that the cleft palate should be operated primarily so early that a child may develop normal speech articulation. Therefore one-stage closure performed at about the age of one year is widely recommended. A velopharygneal flap as a method of secondary surgery has generally proven reliable in eliminating VPI.

Cleft severity has been found to correlate with speech (Krause et al. 1976, Van Demark and Hardin 1985, Jakobsson 1990, Haapanen 1992). The dimensions of sagittal nasopharynx, in particular depth affects, the occurrence of hypernasality (Haapanen et al. 1991). The adenoid pad does not seem to be necessary for normal velopharyngeal function, but cleft palate patients have been regarded as being exposed to a risk for VPI after adenoidectomy. Patients with structural and functional velopharyngeal valving deficiencies or defects such as short palate, repaired cleft, submucuous cleft palate, deep nasopharynx, deafness, mental retardation, cerebral palsy, dystonias, facial paralysis and minor fine motor co-ordination problems are at risk of developing velopharygneal insufficiency after adenoidectomy (Conley et al. 1997).
VPI may result in compensatory articulation (Trost 1981), which cannot be eliminated only by surgery. Instead a combination of both surgery and speech rehabilitation may be required. The most common type of compensatory articulation in production of pressure consonants, such as /p/, /t/, /k/ and /s/ is the activity of glottis instead of the velum. Speech therapy is required to eliminate faulty articulatory maneuvers. The stability of the corrected articulation is however dependent on velopharyngeal competence achieved by secondary surgery (McWilliams et al. 1990, pp. 375-400).

5.3. Associations between velopharyngeal function and dental consonant misarticulation

Hypernasality, nasal air emissions, weakness of plosives and glottal compensations are typical speech deviations associated with velopharyngeal dysfunctions of variable origin (Haapanen 1992). Children also probably demonstrate misarticulations that are not specific to velopharyngeal insufficiency. Nearly forty years ago some researchers were interested in the relationship between velopharyngeal closure or function and articulation (McWilliams et al. 1990, pp. 267-305). No clear correlation has been found between the velopharyngeal gap size and the speech characteristics reflecting VPI (Kummer et al. 1992). Powers et al. (1990) have questioned whether all articulatory problems among cleft palate children are explainable solely on the basis of present or past structural deficits. However, studies of cleft palate patients focusing on speech outcome, proficiency or intelligibility do not differentiated between VPI dependent or independent misarticulations. This may have biased the results of studies focusing on designing treatment procedures for cleft individuals. There are not, as far as the author knows, studies on the relationship of velopharyngeal insufficiency and the common dentoalveolar misarticulations /r/, /s/ and /l/. This knowledge would however be very important for assessing the optimal protocol for cleft palate treatment.

6. AIMS OF THE STUDY

The purpose of the study was to elucidate the associations between craniofacial morphology, misarticulations of dental consonants and velopharyngeal function in cleft lip/palate children.

The specific aims were to

- determine whether lateral cephalometric morphology and dental occlusion are related to dental misarticualtions in different cleft types

- examine the associations between craniofacial morphology, adenoidectomy and velopharyngeal function

- examine the changes of velopharyngeal function during the growth period of 3-8 years of age

- examine the relationship between velopharyngeal function and articulation of the Finnish dental consonants /r/, /s/ and /l/

7. SUBJECTS AND METHODS

7.1. Subjects

The subjects comprised 278 (115 girls and 163 boys) Finnish speaking children with clefts who were born between 1980-1988. The patients included 82 children with cleft lip with (34) or without (48) cleft alveolus [CL(A)], 81 with isolated cleft palate (CP), 84 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 which could affect their speech. None of the subjects had had orthodontic treatment. The cleft palate were closed at the mean age of 1.4 years (s.d.=0.38 years; range 0.7-2.1 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 speech follow-up examination.

The patients attended regular follow-up examinations at the age of six years when speech analysis was carried out and lateral cephalometric roentgenograms and dental casts were taken. The association between lateral cephalometric variables and the misarticulations of Finnish dental consonants /r/, /s/ and /l/ was studied in 134 boys (I). The association of dental occlusion and Finnish dental consonants /r/, /s/ and /l/ was studied in 260 children (108 girls, 152 boys) (II). The association between craniofacial morphology, velopharyngeal function and adenoidectomy was investigated in 96 boys (III). The changes of velopharyngeal function between the ages of 3, 6 and 8 years was studied in 65 children (30 girls, 35 boys) (IV). The association between velopharyngeal function and misarticulation of the dental consonants /r/, /s/ and /l/ was studied in 278 children (115 girls, 163 boys) (V). Table 1. provides a summary of subjects in the present studies (I-V).

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

Study	Analysis	Age	Cleft type, number of subjects				
		Mean (SD)	CP	CL(A)	UCLP	BCLP	Total
I	Cephalometry Misarticulations	6.1 (0.2)	33	38	44	19	134
II	Misarticulations Dental occlusion	6.1 (0.2)	79	76	78	27	260
III	Cephalometry Velopharyngeal function Adenoidectomy	6.1 (0.2)	33		44	19	96
IV	Velopharyngeal function	3.1 (0.1) 6.1 (0.2) 8.1 (0.1)	35		30		65
V	Velopharyngeal function Misarticulations	6.1 (0.2)	81	82	84	31	278

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

7.2. Methods

7.2.1. Speech analysis

Evaluation of speech at the age of 6 years was made during the routine follow up by one of the two experienced speech pathologists of the cleft team, and the data was registered in the hospital records. Misarticulations of sounds /r/, /s/ and /1/ were evaluated immediately in spontaneous speech and words elicited by the Remes Articulation test for the Finnish language (Remes, 1975). For the present study it was relevant to differentiate adequately the correctly and incorrectly produced /r/, /s/ and /l/ sounds from each other. To add to the power of differential diagnosis between correct and incorrect articulation, several factors were controlled. The history of speech development before the age of 6 years and the speech therapy given was available in the hospital records. These data served as confirmative documentation of the speech problem, even though the speech assessment was based on the speech condition at the age of 6 years. When categorising the dental sounds studied into incorrect and into correct ones maturational aspects were taken into account. At the age of 6 years the /r/ sounds produced with a slightly immature anterior trill were categorised as correct. Some inconsistency in the production of /s/ and /1/ sounds was allowed. If these sounds were mainly produced normally, even though sometimes slightly too anteriorly, they were categorised as correct. The misarticulations were categorised into distortions and substitution, because this was found to add to the reliability of differentiation between correct and incorrect sound production. Omissions and additions were not examined in the present study because they are extremely rare in 6-year-old children. The errors typical for VPI or palatal fistula were not included in the misarticulation studied. Information of any speech therapy given before the six-year-follow-up visit was collected from the hospital records and by interviewing the subjects' parents.

7.2.2 Assessment of velopharyngeal function

Velopharyngeal function was examined according to a prospectively established schema and described in terms of perceptual velopharyngeal signs by an experienced speech pathologist. Velopharyngeal function was assessed as competent in the absence of the following speech characteristics: nasal air emission (NAE), hypernasality (HNA), weakness of pressure consonants (WPC) and compensatory articulations (glottal, lingual or pharyngeal stops and nasal and pharyngeal fricatives) (COMP). Each parameter was judged to be absent or present. NAE and WPC were recorded as present if they were heard more than twice in any of the consonant at one examination period. HNA was present if it was heard constantly or temporarily in a specific phonetic context i.e. in high vowels or in the approximates. Only the fact that speech therapy had or had not been given was recorded, not its focus or quantity. The presence of a hard palatal fistula diagnosed by a speech pathologist, orthodontist or surgeon was identified and its effect on articulation assessed in order to differentiate the speech problems due to VPI from those caused by a palatal fistula. Seclusion of fistula, adenoidectomy and tonsillectomy were recorded.

Velopharyngeal function was judged in terms of velopharyngeal competence (VPC) or incompetence (VPI) according to a three point scale based on combinations of registered perceptual speech signs. A scale value of 0 indicated velopharyngeal competence. A scale value of 1 indicated marginal VPC (mVPC), and this included cases with temporary signs of VPI, e.g. hypernasality in high vowels, or mild, occasional nasal air emissions noted in association with pressure consonants. The scale value 2 indicated obvious VPI (oVPI), included cases with constant hypernasality with or without constant nasal air emission noted typically in association with pressure consonants, as well as cases with weakness of plosives and compensatory articulation. The presence of VPI was identified on the basis of perceptual speech characteristics and confirmed by instrumental examinations with nasalance measurements and/or the x- ray or videofluorographic examinations.

The reliability of speech assessments was studied as follows. To ensure that the interpretation of the articulatory data in hospital records was identical for the two speech pathologists interjudge agreement was assessed by checking each patient`s /r/, /s/ and /l/ data at the same time by both speech pathologists. The categorisation of the /r/, /s/ and /1/ errors to distortions and substitutions was based on a 100% consensus between the judges. The assessment of velopharyngeal competence or incompetence, cognitive or neuromotor disorders reflected in speech and language development was found to be based on a 91.3 to 94.2 % agreement level between the two judges. The specific characteristics of VPF (NAE, HNA, WPC, COMP) were analysed twice by the same speech specialist and intrajudge agreement was 98.8%. The data which were first analysed were used.

7.2.3. Analysis of occlusion

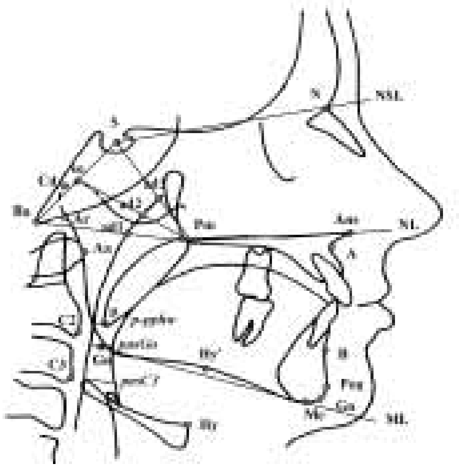
Occlusal anomalies were evaluated from dental plaster casts by a senior orthodontist. Posterior crossbites were registered by the intermaxillary relationship of the permanent first molars (dd 16, 26), the second deciduous molars (dd 55, 65), and the deciduous canines (dd 53, 63). Posterior crossbite included uni- or bilateral crossbites. Unilateral crossbite included crossbites of molar and/or canine tooth. Bilateral crossbite included crossbites of molars and canines 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 to be 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).

The reliability of measures of crossbite, overbite and overjet was tested by measuring 35 subjects` occlusions twice (20 CP and 15 UCLP cases) with a one month interval. Intrajudge agreement for crossbite measures was 97.4%, 95.3% for maxillary overjet and 92.6% for overbite.

7.2.4. Cephalometric measurements

Cephalometric measurement points were determined from standardised lateral roentgen-cephalograms taken at the age of six years with the children`s heads positioned according to the Frankfort horizontal plane in the standing position with their molar teeth occluded. The cephalograms were traced twice by the same person using a computer-connected digitizer. The computer was programmed to calculate the mean of the two digitalizations, which were to be at an accuracy of one mm. Any landmark that could not be properly identified was left unidentified. Distances are reported in millimeters, and angles in degrees. All the linear dimensions were corrected for the radiographic enlargement (9%). The reference points and landmarks are given in Fig 1.

Fig. 1. The cephalometric landmarks.



Reference points:
A (A-point): deepest point of the anterior contour of the maxillary alveolar arch
Aa (anterior Atlas): most anterior point of the first vertebral corpus
ad1 intersection of the line Pm-Ba and the posterior nasopharyngeal wall
ad2 intersection of the line Pm-so and the posterior nasopharyngeal wall
ad3 intersection of the line Pm-S and the posterior nasopharyngeal wall
Ans (Anterior nasal spine): tip of anterior nasal spine
Ar (Articulare): intersection between the external contour of the cranial base and the dorsal contour of the mandible
B (B-point): deepest point of the anterior contour of the mandibular alveolar arch
Ba (Basion): most inferior point of the clivus of the occipital bone
C2 (second vertebra): most anterior inferior point of the second vertebral corpus
C3 (third vertebra): most anterior inferior point of the third vertebral corpus
Cd (Condylion): most posterior and superior point of the condylar head
Gn (Gnathion): most anterior and inferior point of bony chin
Go (Gonion): intersection between the external contour of the mandible and the bisector of the angle between ramus line and mandibular line
Hy (Hyoid): most anterior and superior point of hyoid bone
Hy` (projection point of Hy): perpendicular distance of point Hy on the mandibular line
Me (Menton): most inferior point on the mandibular symphysis
N (Nasion): most anterior point on the nasofrontal suture
p tip of the soft palate
Pm (Pterygomaxillare): intersection between the nasal floor and the posterior contour of maxilla
Pog (Pogonion): most prominent point of the bony chin
S (Sella): centre of the sella turcica
so midpoint of the distance from points S to Ba

Lines and distances:

ML (Mandibular line): tangent to the lower border of mandible through Me
NL (Nasal line): line through points Ans and Pm
NSL (Nasion-Sella line): line through points N and S
pasGo (posterior airway space at the gonion level): sagittal depth of the pharynx on the line through points B and Go
pasC3 (posterior airway space at the level of C3): sagittal depth of the pharynx on the line perpendicular to the posterior pharyngeal wall at the level of C3
p-pphw sagittal depth of the pharynx on the line perpendicular to the posterior pharyngeal wall through point p

7.2.5 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 category variables such as the occurrence of articulatory errors and occlusal characteristics between genders, cleft types and between different timings and methods of primary palatoplasty (I-V). The dimensions of continuous variables like lateral cephalometric dimensions were analysed using two sample t-test and the nonparametric Mann-Whitney U-test. For all analyses, a p-value of less than 0.05 was accepted as significant.

8. RESULTS

8.1.Craniofacial morphology and dentoalveolar misarticulations

8.1.1. Cephalometric dimensions and misarticulations (I)

The size and shape of the cranial base did not show any significant associations with /r/, /s/ or /l/ sound distortions except for a linear measurement of N-S in the CL(A) children with /r/ distortion. The anteroposterior relationship of the maxilla and the mandible did not have any association with dentoalveolar misarticulations. The two sample t- tests did not show any significant difference in any cleft group or in any studied misarticulation in subgroups with ANB angles more or less than four degrees.

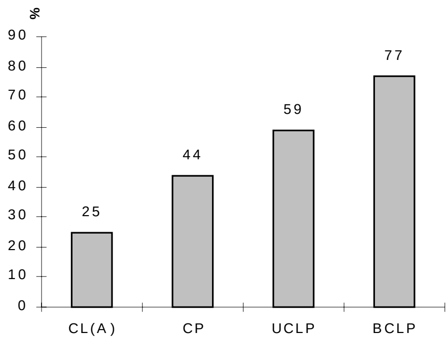
The results revealed some significant associations between cephalometric measurements and misarticulations, especially that of the /r/ sound in CP and BCLP group. Children with /r/ distortion had upward rotation of the mandible (NSL/ML and NL/ML), maxillary protrusion (SNA angle) and a higher position of the hyoid bone (Hy-Hy´) in the CP group. In the BCLP group, on the other hand, the mandible had downward rotation, mandibular retrusion (S-N-Pog angle) and a narrower nasopharyngeal port (ad1-Pm). The /s/ and /l/ sounds had weaker association with craniofacial morphology.

8.1.2. Dental occlusion and misarticulations (II)

In the study group (n=260) 57% percent of the subjects had anterior and/or posterior crossbite, 8% had large maxillary overjet, and 29% had deep bites. 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 dental crossbites, large maxillary overjets, or deep bite in different cleft types did not reveal any significant gender differences. Therefore, the boys and the girls were combined in the comparisons.

Figure 2. shows the distribution of 148 subjects with any type of crossbite associated with at least one misarticulation of /r/, /s/ or /l/ or their combinations by the type of cleft.

Fig. 2. Occurrence of at least one misarticulation of /r/, /s/ or /l/ or their combinations in subjects with any type of dental crossbite (n=148) by the type of cleft.



Altogether, 43% of subjects misarticulated at least one of the studied sounds, and they had crossbites significantly more often (73%) than subjects with correct /r/, /s/ and /l/ production (45%). Posterior crossbites were significantly associated with any misarticulations of /r/ or /s/ or /l/ or their combinations, whereas anterior crossbite alone (Table 2), large maxillary overjet, or deep bite were not. Subjects with at least /s/ errors had anterior crossbites associated with unilateral posterior crossbite significantly more often than subjects with correct /s/ production, but there were no significant differences in this crossbite type in the the production of /r/ or /l/ sounds.

Table 2. Statistical comparisons (X^2 or Fisher`s exact test, see abreviations) between subjects with different types of crossbites (n=81) and subjects without any crossbite (n=30) according to the occurrence of at least one misarticulations or their combinations of /r/, /s/ or /l/.

Type of crossbite		/r/, /s/ or /l/ sound p	X^2
1.	Anterior	ns	0.120
2.	Anterior and posterior one side	0.042*	4.152
3.	Anterior and posterior both sideone side	0.000***	17.549
4.	Posterior one side	0.002**	9.723
5.	Posterior one side with or without anterior	0.000***	16.197
6.	Posterior both side with or without anterior	0.000***	23.044

*p<0.05, **p<0.01, ***p<0.001, ns = not significant

8.2. Craniofacial morphology and velopharyngeal function

8.2.1. Craniofacial characteristics, velopharyngeal function and adenoidectomy (III)

The associations between velopharyngeal function, craniofacial morphology and adenoidectomy were analysed in different subgroups in a sample of 96 boys. No significant differences were observed for the studied variables between the cleft types and therefore the cleft groups were combined.

The cranial base, the relationship of the maxilla and mandible and their relationship to the cranial base or the bony nasopharynx (triangle S-Ba-Pm) did not differ between the velopharyngeal competent (VPC), velopharyngeal incompetent (VPI) and velopharyngoplasty (VPP) groups.

The nasopharyngeal airway (Pm-ad1, Pm-ad2, Pm-ad3) was significantly wider and the thickness of posterior pharyngeal wall (ad1-Ba, ad2-so) significantly thinner in the VPP group as compared to the VPC group. Correspondingly the sagittal dimension of oropharynx (p-pphw) was significantly shorter in the VPP group. The length of the velum did not differ between these groups (Table 3).

Table 3. The means of linear measures in millimetres and standard deviations for nasopharyngeal cephalometric dimensions at the age of six years and significance of difference between the groups given with t- test p- values.

	VPC(n=45)		VPI (n=36)		VPP (n=15)		VPC vs VPI	VPC vs VPP
	Mean	S.D.	Mean	S.D.	Mean	S.D.	p- values	p- values
Pm-Ba	38	2.2	38.1	2.6	38.3	2.4	0.786	0.668
ad1-Ba	22.7	4.2	21.3	4.3	20.2	2.8	0.128	**0.012***
ad2-so	20.8	3.2	19.7	3.2	18.2	3.1	0.123	**0.008*****
Pm-ad3	11.6	2.4	12.8	2.9	13.3	2.2	0.050	**0.016***
Pm-ad2	11.1	3.3	12	3	14.1	2.7	0.197	**0.004****
Pm-ad1	15.3	4.1	16.9	3.5	18.2	2.8	0.078	**0.017***
Pm-p	26.5	3.4	25.4	2.4	27.7	2.3	0.161	0.223
p-pphw	10.7	3	10.5	2.6	6.1	2.1	0.766	**0.000*****

VPC= velopharyngeal competence, VPI= velopharyngeal incompetence
VPP= velopharyngoplasty

* p< 0.05, ** p< 0.01, ***p< 0.001

The previous adenoidectomy decreased the thickness of the posterior pharyngeal wall (ad1-Ba, ad2-so) and thus increased airway size. The thickness of the posterior pharyngeal wall did not differ in the VPC and VPI children without adenoidectomy but was significantly thinner in the VPI than in the VPC children with adenoidectomy (Table 4). Airway size and the thickness of the posterior pharyngeal wall did not differ between the VPC and VPP children with adenoidectomy. The length of the velum did not differ between the VPC, VPI and VPP groups or their subgroups with and without adenoidectomy. Thus, adenoidectomy may be a risk to velopharyngeal function because of widening of the nasal airway. However, velopharyngeal incompetence does not seem to be exclusively related to adenoidectomy.

Table 4. The means of linear measures in millimetres and statistical comparisons of nasopharyngeal cephalometric dimensions in subjects with (Ad+) and without (Ad-) previous adenoidectomy within the groups of VPC and VPI and between the VPC/VPI and VPC/VPP groups.

	VPC(n=45) Ad- vs Ad+		VPI(n=36) Ad- vs Ad+		Ad- VPC vs VPI		Ad+ VPC vs VPI		Ad+ VPC vs VPP	
ad1-Ba	23.5	21.2	**22.7**	**18.0****	23.5	22.7	**21.2**	**18.0***	21.2	20.2
ad2-so	21.3	19.7	**21.0**	**16.6*****	21.3	21.0	**19.7**	**16.6****	19.7	18.2
Pm-ad3	**11.0**	**12.9****	12.5	13.3	11.0	**12.5***	12.9	13.3	12.9	13.3
Pm-ad2	**10.1**	**13.0****	**10.8**	**14.7*****	10.1	10.8	13.0	14.7	13.0	14.1
Pm-ad1	**14.2**	**17.5***	**15.8**	**19.3****	14.2	15.8	17.5	19.3	17.5	18.2
Pm-p	26.2	26.9	25.1	26.3	26.2	25.1	26.9	26.3	26.9	27.7
p-pphw	10.0	12.0	10.6	10.1	10.0	10.6	12.0	10.1	**12.0**	**6.1*****

VPC= velopharyngeal competence, VPI= velopharyngeal incompetence
VPP= velopharyngoplasty

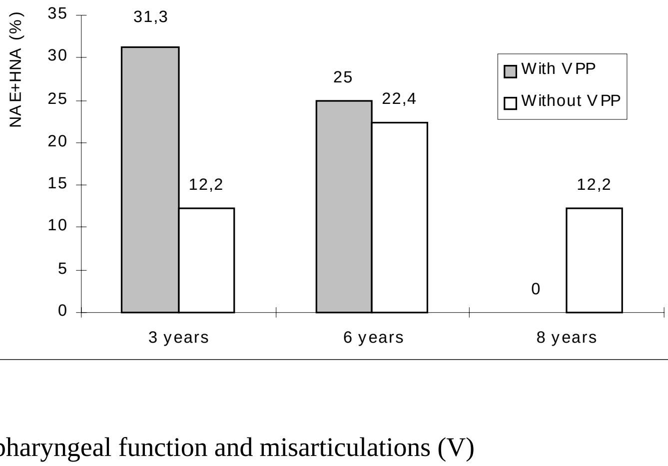
* p< 0.05, ** p< 0.01, ***p< 0.001

8.2.2. The changes of velopharyngeal function with age (IV)

The presence of nasal air emission (NAE), hypernasality (HNA), weakness of pressure consonants (WPC) and compensatory articulation (COMP) at the age groups of 3, 6 and 8 years was statistically compared in different subgroups. The results indicated that those variables which were boys versus girls, cleft type CP versus UCLP, techniques of primary palatoplasty Veau-Wardill-Kilner versus Cronin modification and timing of palatoplasty at the ages under 1.3 years versus over 1.3 years did not correlate significantly with the quality of velopharyngeal function in any of the studied age groups. The patients who required velopharyngeal flap before the age of eight years did not differ significantly from those who did not require the flap operation at the age groups of 3, 6 and 8 years with respect to the presence of NAE, HNA, WPC and COMP.

Velopharyngeal function was good at the age of 8 years both in children treated conservatively or with VPP. No child with VPP and only 12% of the children without VPP had simultaneous nasal air emissions and hypernasality (Fig. 3). Compensatory articulation was completely eliminated and weakness of pressure consonants was diagnosed only in one child without VPP. The children with a velopharyngeal flap required speech therapy significantly more often than children without VPP. The CP children required significantly more often (34.3%) a velopharyngeal flap than the UCLP children (13.3%) but they developed a similar velopharyngeal function.

Fig 3. Presence of combined simultaneous VPI signs of NAE and HNA at 3, 6 and 8 years of age in subgroups with (n=16) and without (n=49) VPP done before the age of 8 years.



8.3. Velopharyngeal function and misarticulations (V)

The occurrences of misarticulation of /r/, /s/ and /l/ or their combinations were compared in relation to velopharyngeal competence (VPC), marginal velopharyngeal competence (mVPC) and obvious velopharyngeal incompetence (oVPI). No significant differences were observed.

In later comparisons mVPC and oVPI subgroups were combined and taken as a group of velopharyngeal incompetence (VPI).

There were no significant differences in the velopharyngeal function (VPF) between boys and girls in any cleft group. Thus, the boys and girls were combined. Although the VPC group included more misarticulations than the VPI group, the only significant difference was observed in the BCLP group where all /s/ disorders appeared in the VPC group.

The timing (before or after the age of 1.3 years) or the method of primary palatal repair (Veau-Wardill-Kilner or Cronin) and the presence of the residual fistulae were not significantly associated with the presence of the studied misarticulations in any of the cleft groups.

Subjects without previous speech therapy had significantly less misarticulations (p=0.002) than those who had had speech therapy before the age of 6 years. Speech therapy was not significantly associated with velopharyngeal function (p=0.205). Subjects with previous velopharyngoplasty did not differ from those without previous velopharyngoplasty in the frequency of misarticulations. Thus dental consonant misarticulations occur independently of velopharyngeal function, primary palatal surgical technique and timing of palatoplasty.

9. DISCUSSION

The size and consistency of the material are considered adequate for examining the associations between craniofacial morphology, misarticulations of /r/, /s/, /l/ sounds and velopharyngeal function. The reliability of rating and categorising misarticulations and assessment of velopharyngeal function was based on agreement of the cleft team's two speech pathologists. Since the treatment of cleft-affected children is centralised in Finland, we had information about them since their births, and that is considered to add to the reliability of the data. The intrajudge reliability concerning determination of crossbites, maxillary overjet and overbites was high. The cephalometric dimensions of the present study are commonly used, and the double tracings of the landmarks was performed to confirm the reliability of the measurements. In the cephalometric studies only boys were studied to avoid any gender bias in the results. However, it is not probable that the girls would differ from boys with respect to the relationship of cephalometric morphology and speech articulation or velopharyngeal function.

Associations have not been sufficiently studied between dental consonant articulation and **craniofacial cephalometrics** in different cleft types. In this study the size and shape of the cranial base and the anteroposterior relationship of the maxilla and the mandible did not have any association with dentoalveolar misarticulations. However, systematic vertical, particularly the posterior relationship of the jaws were found to have association with /r/ sound production in CP and BCLP boys **(I)**. The results revealed new findings of cephalometric angles and dimensions that are significantly associated with dental misarticulations in CP and BCLP groups. In CP boys with /r/ sound disorder the results showed more parallel planes between the cranial base and mandible as well as also between maxilla and mandible due to the longer posterior facial height indicating an upward rotation of the mandible. The BCLP boys with /r/ sound distortions demonstrated a downward rotation of the mandible. As mandibular and speech like movements are closely interrelated (Enacar et al. 1994), it is probable that the results of the present study, i.e. upward rotation in CP and downward rotation in BCLP boys, may change the movement patterns of the speech articulators and hence be involved in disordered /r/ sound production. The present morphological findings and earlier findings of posterior crossbites in the present children (Laitinen et al. 1999) indicate that occlusal and rotational changes in the posterior part of oral cavity are probably associated with unfavourable movements of the articulatory organs. The misarticulations of the present UCLP boys did not have any association with cephalometric measurements. Instead, /r/, /s/ and /1/ misarticulations significantly coexisted with posterior crossbites in the earlier study of these children (Laitinen et al. 1999).

Many studies have shown correlations between the position of the mandible, hyoid bone and the tongue, and their effect on respiratory dysfunctions or misarticulations (Subtelny et al. 1964, Enacar et al. 1994, Achilleos et al. 2000). In the present study the hyoid bone seems to have slightly higher position in /r/ and /1/ sound distorting CP boys **(I)**. The position of the hyoid bone may be associated with the upward rotation of the mandible in /r/ sound distorting CP boys. The /r/ sound distorting CL(A) boys seem to have slightly more anteriorly positioned hyoid bones. It is noteworthy that an anterior position of the hyoid bone has been earlier found to be significantly associated with /r/ sound disorders and low laryngeal resistance in adult CLP patients, who had in addition wider SNA angle (Laitinen et al. 2001), just like the present CP boys with /r/ sound distortions. The movements and function of the larynx is associated with the hyoid bone and mandible, and thus may be related to /r/ sound production.

Deviant **dental occlusion**, including the dental and skeletal relationship between maxilla and mandible, is suggested to affect the precise coordination between the lip, tongue, and mandible needed for correct speech sound articulation (Lindblom and Sundberg 1971, Van Dyke et al. 1984). In this study the frequency of dental crossbite increased with the severity of the cleft, and subjects with dental crossbite had significantly more misarticulations than subjects without any crossbite **(II)**. Especially posterior bilateral crossbite were correlated to articulation problems, while anterior crossbite was related to articulatory errors only when they were combined with posterior crossbite. Non-cleft subjects with Class III occlusion and anterior crossbite resulting from an excessive growth of the mandible are reported to have a higher risk of having articulatory speech disorders than those with incisal open bites (Laine 1992). Probably because cleft patients' occlusions only resembles Class III occlusion due to their retruded maxilla, anterior crossbite alone did not seem to explain the articulatory errors of cleft patients.

According to the present study, either a large maxillary overjet or a deep bite did not influence the occurrence of misarticulations. These findings support earlier results concerning incisor relationship and articulatory defects in non-cleft adults (Oliver and Evans 1986, Laine et al. 1987), although weak associations between / r/ disorders and large maxillary overjet have been reported (Laine 1992).

Good articulation can exist in the presence of severe dental deviations due to the highly adaptable speech mechanisms and compensatory behaviour (Star 1971). Since many of patients with posterior crossbites in this study had correct /r/, /s/ and /l/ articulation, and many patients without posterior crossbites still misarticulated at least one studied consonant, occlusal abnormalities should be considered only as one of many factors that may influence correct dental consonant production in cleft palate patients.

The associations between **craniofacial morphology, velopharyngeal function and the effect of adenoidectomy on the size of nasopharynx** in cleft children are unclear. Therefore, a cephalometric study was carried out **(III)**. The results showed that the craniofacial and nasopharyngeal bony morphology observed on the lateral cephalograms does not seem to explain velopharyngeal incompetence in cleft palate children. The present results did not reveal any significant difference between the groups of VPC, VPI and VPP in the size or shape of the cranial base, in the relationship of the maxilla to mandible or their relationship to the cranial base and the bony nasopharynx. This is in accordance with the findings made by Wu et al. (1996) that there are no significant difference in pharyngeal height, inclination of soft palate, and hard-tissue pharyngeal depth among the velopharyngeal competent, borderline competent and incompetent cleft patients and competent noncleft subjects.

Velopharyngeal incompetence has been attributed to significantly larger soft-tissue pharyngeal depth than found in competent patients (Haapanen et al. 1991, Wu et al. 1996). The nasopharyngeal airway was sagittaly significantly longer and the posterior pharyngeal wall significantly thinner in the VPP group than in the other studied groups. This is probably due to the adenoidectomy performed on every VPP child. The length of the velum did not differ significantly between the VPC, VPI and VPP groups. Adenoidectomy widens the nasopharyngeal airway and therefore seems to be a risk factor for velopharyngeal function in cleft children. However, the results did not show any significant difference in nasopharyngeal airway and thickness of the posterior pharyngeal wall between the adenoidectomized children with VPC or VPP. Therefore it is reasonable to conclude that adenoidectomy is not the primary reason for velopharyngeal insufficiency and adenoidectomy should not be avoided if it is important to the health of the ears (Haapanen and Pettay 1995).

In cleft lip and/or palate patients **speech production changes with age** as also does orofacial morphology because of surgical interventions and growth. In addition to dental misarticulations, cleft palate patients also frequently suffer from velopharyngeal incompetence (Haapanen, 1992, Laitinen et al. 2000). In the present study **(IV)** a clear trend for improvement of velopharyngeal function with advancing age was seen. In the total material the occurrence of audible nasal air emissions, weakness of plosives and compensatory articulations decreased from the age of three to eight years. The presence of a velopharyngeal flap, the age or method of primary palatoplasty, the type of the cleft or the gender of the child did not explain the distribution of any of the VPI characteristics in the total material at any follow-up age. By the age of eight years the children with CP had required more velopharyngeal flaps than the children with UCLP, and this trend continued after the age of eight years. Even though almost one-third of the children had minimal signs of VPI at the age of eight years, the speech result must be regarded to be good taking into account that no child had compensatory articulation, only 2% demonstrated weakness of plosives, and 12% simultaneous nasal air emissions and hypernasality.

It is noteworthy, that the need for speech therapy and the need for a velopharyngeal flap correlated. The children with a velopharyngeal flap required significantly more often speech therapy than the children without a flap. Even though the focus of speech therapy was not controlled for it is probable that the speech therapy given revealed true velopharyngeal insufficiency resistant to logopedic treatment. The results concerning of speech at the age of six and eight years indicated that the children with UCLP may develop as good velopharyngeal function as the children with CP, but without requiring a velopharyngeal flap. This is a new finding, and refers to different development of velopharyngeal function in UCLP and CP children in association with similar background factors, e.g. the method of primary palatal repair.

The present results are parallel with other findings on concerning differences between cleft types, such as different genetic etiology, orofacial growth, articulatory and cognitive development in CP and UCLP children (Ceponiene et al. 1999, Laitinen et al. 2000). The difference of the development of velopharyngeal function in CP and UCLP children requires further confirmation and warrants further studies focusing on optimal surgical procedures and timing.

The correlation between **velopharyngeal function and dental consonant misarticulations** has not been earlier studied. This information is, however, important for evolving their adequate treatment. Dental misarticulations impair speech intelligibility and they may cause psychosocial problems. Besides their treatment covers a large proportion of the costs of the treatment of speech, especially in cleft patients. Velopharyngeal incompetence results directly or compensational fashion in specific speech characteristics, which usually can be eliminated with plastic surgery or with speech therapy or a combination of both interventions. However dental consonant errors are quite resistant to therapy (Qvarnström et al. 1991, Luotonen 1995, Laitinen et al. 1998a). They are known to be associated with occlusal or cephalometric abnormalities (Laine 1987, Laine et al. 1987) or aerodynamic problems (Laitinen et al. 1998c) but so far there has not been evidence what is the role of velopharyngeal incompetence in relation to /r/ /s/, and /1/ sound misarticulations.

The children with velopharyngeal incompetence did not have more dental consonant errors than the children with velopharyngeal competence, thus the present results indicate, for the first time, that dental consonant misarticulations do not significantly depend on velopharyngeal incompetence **(V)**. The studied articulatory errors were not dependent on the timing or the method of primary palatal repair or the velopharyngeal surgery, which further confirms their independence on velopharyngeal function.

An important conclusion of the present study is that when designing cleft palate treatment procedures, attention should be paid to the treatment of misarticulations not depending on velopharyngeal function. It is obvious that the treatment of dental misarticulations should be designed separately from the treatment protocol and timetable of velopharyngeal function. It is noteworthy, that while velopharyngeal function improves remarkably by the age of 8 years, dental consonant misarticulations still persist at high frequency at the same age (Laitinen et al. 2000). Some features specific to velopharyngeal incompetence may, of course, occur also in association with dental consonant misarticulations, but according to the present results dental consonant misarticulations are not significantly related to velopharyngeal function, whether it is competent or not.

To date there have not been any studies on the effect of the treatment of dentofacial dysmorphology on the production of dental consonants. This would warrant further studies. As the surgical treatment of cleft palate does not correlate with dental consonant misarticulations, and as these defects may be associated with dentofacial dysmorphology, it will be important in future to focus the research on the diagnosis and treatment of dentofacial structure.

10. CONCLUSIONS

The anteroposterior relationship of the maxilla and the mandible does not have any association with dentoalveolar misarticulations. Instead posterior vertical relationship of the maxilla and mandible seem to have association with /r/ sound production but not /s/ and /l/ sound in isolated cleft palate and bilateral cleft lip and palate. In isolated cleft palate children with /r/ distortion have an upward rotation of the mandible but the misarticulating children with bilateral cleft lip and palate have a downward rotation of the mandible. Posterior crossbites are significantly associated with any misarticulations of /r/ or /s/ or /l/ or their combinations, whereas anterior crossbite alone, large maxillary overjet or deep bite are not.

The cranial base, the interrelationship of the maxilla and mandible and their relationship to the cranial base, the bony nasopharynx (triangle S-Ba-Pm) and the length of the passive velum were not associated with velopharyngeal function. Adenoidectomy widens the nasal airway but is not solely responsible for velopharyngeal insufficiency.

With advancing age and growth improvement of the velopharyngeal function is apparent. No significant differences were observed between subgroups with patient requiring or not requiring velopharyngoplasty before the age of 8 years. Even though isolated cleft palate and unilateral cleft lip and palate children achieve as good velopharyngeal function by the age of eight years, they differ from each other in obtaining velopharyngeal competence. The isolated cleft palate children require significantly more often (34.3%) a velopharyngeal flap than the unilateral cleft lip and palate children (13.3%).

The dental consonant misarticulations of the sounds /r/, /s/ and /l/ or their combinations occur independently of velopharyngeal function, and are independent of cleft type and previous velopharyngoplasty.

11. ACKNOWLEDGEMENTS

The present thesis was carried out at the Cleft Center, Department of Plastic Surgery, Helsinki University Central Hospital, headed by Professor Sirpa Asko-Seljavaara, M.D., Ph.D. I wish to express my sincere gratitude to her for providing me with excellent working facilities.

My deepest gratitude goes to my supervisor Docent Reijo Ranta, D.D.S., Ph.D., Chief Orthodontist of the Cleft Center, Department of Plastic Surgery, Helsinki University Central Hospital. The idea of this project came from him and I wish to thank for his friendly guidance and encouragement throughout all stages of this work. He unstintingly gave of him free time to supervise this thesis, and was infinitely patient with my work.

I am sincerely grateful to my other supervisor Docent Marja-Leena Haapanen, M.A., M.D., Ph.D., who introduced me to the fascinating world of phoniatrics. Her neverfailing enthusiasm for the scientific work and life, optimistic attitude and brilliant ideas also during the hard times made a deep impression on me.

I wish to thank co-workers of this study Marjukka Paaso, speech therapist, Arja Heliövaara, D.D.S., Ph.D., for their valuable cooperation. My special thanks belong to my co-worker Jaana Laitinen D.D.S., Ph.D., for her friendship and help throughout this work. I am grateful to Docent Marjatta Nyström for her advise and friendship.

I thank the official referees of this work Docent Eeva Sala, M.D., Ph.D., and Professor Juha Varrela, D.D.S., Ph.D., for their careful and precise work with constructive criticism and suggestions to improve the form and contents of the manuscript.

My warm thanks to Timo Pessi, M.Sc., for his invaluable help in the biostatistical problems and in the statistical analysis.

I wish to thank sincerely Donald Smart, B.Sc., M.A., for his professional linguistic revision of this manuscript.

I owe much to Eila Nousiainen for her friendship and assistance with countless practicalities.

It has been privilege to work with the surgeons of the Department of Plastic Surgery, I am sincerely thankful for their assiduous interest in research.

Warm thanks are due to dental hygienists Pirjo Ikonen and Merja Söderholm and nurse Marja-Liisa Harjula for their kind contribution. My special thanks belong to dental hygienist Irmeli Välimäki for her endless patience with collecting materials for this research. I wish to thank Jukka Alstela for preparing photographs and drawings.

I want to express special thanks to my colleague and close friend Jukka Kentala, D.D.S., for stimulating discussions, good advice, and friendship.

My very special thanks belong to my sisters and my brothers for their warm support through these years. I am also grateful to my cousin Ismo for his amazing ability to solve all computer problems.

I want to thank all my personal friends, Tiina, Sari, Mikko, Eeva and many others. They have reminded me of the other values keeping me right in the middle of real life.

My warm thanks go to Arja Asikainen, interior architect, for her help in lay- out and more than this, for her friendship during years.

This research was supported by grants from the Emil Aaltonen Foundation and is gratefully acknowledged.

12. REFERENCES

Achilleos S, Krogstad O, Lyberg T. Surgical mandibular setback and changes in uvuloglossopharyngeal morphology and head posture: a short- and long- term cephalometric study in males. Eur J Orthod 2000;22:384-394.

Akguner M. Velopharyngeal anthropometric analysis with MRI in normal subjects. Ann Plast Surg 1999;43:142-147.

Arnold GE. Physiology and pathology of speech and language; in Luchsinger R and Arnold GE (eds): Voice, speech, language. Wadsworth, Belmont 1965, pp 337-790.

Bankson NW, Byrne MC. The relationship between missing teeth and selected consonant sounds. J Speech Hearing Dis 1962;27:341-348.

Beitchman JH, Nair R, Clegg M, Patel PG. Prevalence of speech and language disorders in 5-year-old kindergarten children in the Ottawa-Carleton region. J Speech Hear Disord 1986;51:98-110.

Birch MJ, Sommerlad BC, Fenn C, Butterworth M. A study of the measurement errors associated with the analysis of velar movements assessed from lateral videofluoroscopic investigations. Cleft Palate Craniofac J 1999;36:499-507.

Bishara SE, VanDemark DR, Henderson WG. Relation between speech production and oro-facial structures in individuals with isolated clefts of the palate. Cleft Palate J 1975;12:452-460.

Blyth P. The relationship between speech, tongue behaviour, and occlusal abnormalities. Dent Pract 1959;10:11-20.

Broad W. Phonation; in Minifie F, Hixon T, Williams F (eds): Normal aspects of speech, hearing and language. Prentice-Hall Inc, New Jersey 1973, pp 127-149.

Bronsted K, Liisberg WB, Orsted Å, Prytz S, Fogh-Andersen P. Surgical and speech results following palatopharyngoplasty operations in Denmark 1959-1977. Cleft Palate J 1984;21:170-179.

Bzoch KR. Measurement and assessment of categorical aspects of cleft palate language, voice, and speech disorders. In: KR Bzoch (ed.), Communicative disorders related to cleft lip and palate. 3rd ed. Boston: A College-Hill Publication. Little, Brown and Company. 1989;137-173.

Ceponiene R, Hukki J, Cheour M, Haapanen ML, Ranta R, Naatanen R. Cortical auditory dysfunction in children with oral clefts: relation with cleft type. Clin Neurophysiol 1999;110:1921-1926.

Cermak SA, Ward EA, Ward LM. The relationship between articulation disorders and motor coordination in children. Am J Occup Ther 1986;40:546-550. Cleft Palate J 1989;26:68-70.

Conley SF, Gosain AK, Marks SM, Larson DL. Identification and assessment of velopharyngeal inadequacy. Am J Otolaryngol 1997;18:38-46.

Dahl E. Craniofacial morphology in congenital clefts of the lip and palate. Acta Odontol Scand 1970;28:Suppl 57 Copenhagen.

Dalston RM, Warren DW, Dalston ET. The identification of nasal obstruction through clinical judgements of hyponasality and nasometric assessment of speech acoustics. Am J Orthod Dentofacial Orthop 1991;100:59-65.

D`Antonio LL, Eichenberg BJ, Zimmerman GJ, Patel S, Riski JE, Herber SC, Hardesty RA. Radiographic and aerodynamic measures of velopharyngeal anatomy and function following Furlow z-plasty. Plast Reconstr Surg 2000;106:539-549.

D`Antonio LL, Rice RD Jr, Fink SC. Evaluation of pharyngeal and laryngeal structure and function in patients with oculo-auriculo-vertebral spetrum. Cleft Palate Craniofac J 1998;35:333-341.

Darley FL, Aronson AE, Brown JR. Motor speech disorders. W B Sounders, Philadelphia 1975, pp 3-6.

Enacar A, Aksoy AU, Sencift Y, Haydar B, Aras K. Changes in hypopharyngeal airway space and in tongue and hyoid bone positions following the surgical correction of mandibular prognathism. Int J Adult Orthod Orthognath Surg 1994;9:285-290.

Enemark H, Bolund S, Jorgensen I. Evaluation of unilateral cleft lip and palate treatment: long term results. Cleft Palate J 1990;27:354-361.

Epker BN, Wu J. The modified superior based pharyngeal flap. Part I. Surgical technique. Oral Surg Oral Med Oral Pathol 1990;70:247-250.

Ericsson G, Yström B. Speech after cleft palate treatment - analysis of a 10-year material. Phonetic Experimental Research, Institute of Linquistics, University of Stockholm (PERILUS), Vol IX, 1989;1-28.

Evans D, Renfrew C. The timing of primary cleft palate repair. Scand J Plast Reconstr Surg 1974;8:153-155.

Ferry PC, Hall SM, Hicks JL. 'Dilapidated' speech: Developmental verbal dyspraxia. Dev Med Child Neurol 1975;17:749-756.

Fletcher SG. ”Nasalance” vs listener judgements of nasality. Cleft Palate J 1976;13:31-44.

Fletcher SG. Palatometric specification of stop, affricate, and sibilant sounds. J Speech Hear Res 1989;32:736-748.

Folkins JW. Issues in speech motor control and their relation to the speech of individuals with cleft palate. Cleft Palate J 1985;22:106-119.

Folkins JW. Velopharyngeal nomenclature: incompetence, inadequacy, insufficiency, and dysfunction. Cleft Palate J 1988;25:413-417.

Fox DR, Lynch JI, Cronin TD. Change in nasal resonance over time: a clinical study. Cleft Palate J 1988;25:245-247.

Friede H, Persson E-C, Lilja J, Elander A, Lohmander-Agerskov A, Söderpalm E. Maxillary dental arch and occlusion in patients with repaired clefts of the secondary palate. Scand J Plast Reconstr Hand Surg 1993;27:297-305.

Gracco VL. Sensorimotor mechanisms in speech motor control; in Peters HFM et al. (eds): Speech motor control and stuttering. Proceedings of the 2nd Conference on Speech motor control and stuttering. June 13-16, 1990 Nijmegen, Netherlands. Excerpta Medica, Amsterdam 1991, pp 53-76.

Greene MCL. Speech analysis of 263 cleft palate cases. J Speech Hear Dis 1960;25:43-48.

Guay AH, Maxwell DL, Beecher R. A radiographic study of tongue posture at rest and during the phonation of /s/ in Class III malocclusion. Angle Orthod 1978;48:10-22.

Haapanen ML. A simple clinical method of evaluating perceived hypernasality. Folia Phoniatr 1991a;43:122-132.

Haapanen ML. Nasalance scores in normal Finnish speech. Folia Phoniatr 1991b;43:197-203.

Haapanen ML. Factors affecting speech in patients with isolated cleft palate. A methodic, clical and instrumental study. Scand J Plast Reconstr Surg Hand Surg Suppl 1992;Nr 26:1-61.

Haapanen ML, Ertama L. Videofluorography as a method of evaluating hypernasality. Duodecim;1994;110:891-895.

Haapanen ML, Heliövaara A, Ranta R. Hypernasality and the nasopharyngeal space. A cephalometric study. J Craniomaxillofac Surg 1991;19:77-80.

Haapanen ML, Iivonen A. Sound spectra in cleft palate patients with a Sanvenero-Rosselli and modified Honig secondary velopharyngeal flap. Folia Phoniatr 1992;44:291-296.

Haapanen ML, Pettay M. Comparison of speech quality in 6-year-old cleft palate patients with and without simultaneous acenoidectomy and primary palatal repair. Scand J Logop Phon 1995;20:15-20.

Haapanen M-L, Rantala SL. Correlation between the age at repair and speech outcome in patients with isolated cleft palate. Scand J Plast Reconstr Hand Surg 1992;26:71-78.

Hardcastle WJ. Physiology of speech production; An introduction for speech scientists. Academic Press, London 1976, pp 83-86.

Hardin MA, Lachenburg PA, Morris HL. Contribution of selected variables to the prediction of speech proficiency for adolescent with cleft lip and palate. Cleft Palate J 1986;23:10-23.

Hardin MA, Van Demark DR, Morris HL, Payne MM. Correspondence between nasalance scores and listener judgments of hypernasality and hyponasality. Cleft Palate Craniofac J 1992;29:346-351.

Heliövaara A, Rintala A, Ranta R. One-stage closure of isolated cleft palate with The Veau-Wardill-Kilner V to Y pushback procedure or the Cronin modification. Scand J Plast Reconstr Surg Hand Surg 1993;27:49-54.

Hellquist R, Ponten B. Skoog T. The influence of cleft length and palatoplasty on the dental arch and the deciduous occlusion in cases of clefts of the secondary palate. Scand J Plast Reconstr Surg 1978;12:45-54.

Henningsson G, Isberg A. Velopharyngeal movement patterns in patients alternating between oral and glottal articulation. A clinical and cineradiographical study. Cleft Palate J 1986;23:1-9.

Henningsson G, Isberg A. Influence of palatal fistulae on speech and resonance. Folia Phoniatr 1987;39:183-191.

Henningsson G, Isberg A. Comparison between multiview videofluoroscopy and nasendoscopy of velopharyngeal movements. Cleft Palate Craniofac J 1991;28:413-418.

Hirschberg A, Roithmann R, Parikh S, Miljeteig H, Cole P. The airflow resistance profil of healthy nasal cavities. Rhinology 1995;33:10-13.

Hoenig JF, Schoener WF. Radiological survey of the cervical spine in cleft lip and palate. Dentontaxillofac Radiol l992;21:36-39.

Howell PGT. The variation in the size and shape of the human speech pattern with incisor-tooth relation. Arch Oral Biol 1987;32:587-592.

Jakobsson OP. Computer data base for cleft lip and palate research. Scand J Plast Reconstr Surg Hand Surg 1990;24:47-51.

Karlsson F. Suomen kielen äänne- ja muotorakenne. WSOY, Porvoo-Helsinki-Juva 1982, pp 56-80.

Keuning KH, Wieneke GH, Dejonckere PH. The intrajudge reliability of the perceptual rating of cleft palate speech before and after pharyngeal flap surgery: the effect of judge and speech. Cleft Palate Craniofac J 1999;36:328-333.

Kummer AW, Curtis C, Wiggs M, Lee L, Strife JL. Comparison of velopharyngeal gap size in patients with hypernasality, hypernasality and nasal emission, or nasal turbulence (rustle) as the primary speech characteristic. Cleft Palate Craniofac J 1992;29:152-156.

Kummer AW, Strife JL, Grau WH, Creaghead NA, Lee L. The effects of Le Fort I Osteotomy with maxillary movement on articulation, resonance, and velopharyngeal function. Cleft Palate J 1989;26:193-200.

Krause CJ, Tharp RF, Morris HL. A Comparative study of results of the Von Langenbeck and V-Y pushback palatoplasties. Cleft Palate J 1976;13:11-19.

Laine T. Associations between articulatory disorders in speech and occlusal anomalies. Eur J Orthod 1987;9:144-150.

Laine T. Malocclusion traits and articulatory components of speech. Eur J Orthod 1992;14:302-309.

Laine T, Jaroma M, Linnasalo A-L. Articulatory disorders in speech related to the position of the incisors. Eur J Orthod 1985;7:260-266.

Laine T, Jaroma M, Linnasalo A-L. Relationships between interincisal occlusion and articulatory components of speech. Folia Phoniatr 1987;39:78-86.

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 1998a;50:92-100.

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 2001;53:85-92.

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 1998b;56:308-312.

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.

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 2000;52:253-259.

Laitinen JM, 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 1998c; 26:813-815.

Leske MC. Prevalence estimates of communicative disorders in the U.S. Speech disorders. ASHA 1981;23:217-224.

Lewis R. Tongue thrust and protrusion lisp. J Canad Dent Assoc 1971;37:381-383.

Lindblom BEF, Sundberg EF. Acoustical consequences of lip, tongue, jaw, and larynx movement. J Acoust Soc Am 1971;50:1166-1179.

Lindholm H. Phoniatric speech evaluation after velopharyngoplasty. Scand J Plast Reconstr Surg 1971;5:47.52.

Loney RW, Bloem TJ. Velopharyngeal dysfunction: recommendations for use of nomenclature. Cleft Palate J 1987;24:334-335.

Lubit EC. The relationship of malocclusion and faulty speech articulation. J Oral Med 1967;22:47-55.

Luotonen M. Early speech development, articulation and reading ability up to the age of 9. Folia Phoniatr Logop 1995;47:310-317.

Maddieson I. Patterns of sounds. Cambridge University Press, Cambridge 1984, p 275.

Mayo R, Warren DW, Zajac DJ. Intraoral pressure and velopharyngeal function. Cleft Palate Craniofac J 1998;35:299-303.

McReynolds LV, Elbert MF. Articulation disorders of unknown etiology and their remediation; in Lass N J et al. (eds): Speech, language, and hearing, W B Sounders, Philadelphia 1982, pp 591-610.

McWilliams BJ, Musgrave RH. Diagnosis of speech problems in patients with cleft palate. Br J Disord Commun 1971;6:26.32.

McWilliams BJ, Morris HL, Shelton RL. Cleft palate speech. B.C.Decker INC., Toronto Philadephia 1990.

Muhler G, Erler K. Comparative rhinomanometric measurements in children with cleft palate after cleft closure with and without velopharyngoplasty. Folia Phoniatr Logop 1997;49:194-200.

Nyström M, Ranta, R. Effect of timing and method of cleft palate repair on dental arches at the age of three years. Cleft Palate J 1990;27:349-352.

Nyström M, Ranta, R. Effect of timing and method of closure of isolated cleft palate on development of dental arches from 3 to 6 years of age. Eur J Orthod 1994;16:377-383.

Nyström M, Ranta R, Kataja M. Sizes of dental arches and general body growth up to 6 years of age in children with isolated cleft palate. Scand J Dent Res 1992;100:123-129.

Okazaki K, Kato M, Onizuka T. Palate morphology in children with cleft palate with palatalized articulation. Ann Plast Surg 199l;26:156-163.

Oliver RG, Evans SP. Tongue size, oral cavity size and speech. Angle Orthod 1986;56:234-243.

Osborne GS, Pruzansky S, Koepp-Baker H. Upper cervical spine anomalies and osseous nasopharyngeal depth. J Speech Hear Res 1971;14:14-22.

Ozgur F, Tuncbilek G, Cila A. Evaluation of velopharyngeal insufficiency with magnetic resonance imaging and nasoendoscopy. Ann Plast Surg 2000;44:8-13.

Pahkala R, Laine T, Lammi S. Developmental stage of the dentition and speech sound production in a series of first-grade schoolchildren. J Craniofac Gen Dev Biol 1991;11:170-175.

Pinborough-Zimmerman J, Canady C, Yamashiro DK, Morales L Jr. Articulation and nasality changes resulting from sustained palatal fistula obturation. Cleft Palate Craniofac J 1998;35:81-87.

Powers GR, Dunn C, Erickson CB. Speech analyses of four children with repaired cleft palates. J Speech Hear Disord 1990;55:542-549.

Proffit WR, Norton LA. The tongue and oral morphology: Influences of tongue activity during speech and swallowing. ASHA report 1970;5:106-115.

Qvarnström MJ, Laine MT, Jaroma SM. Prevalence of articulatory disorders of different sounds in a group of Finnish first-graders. J Commun Disord 1991;24:381-392.

Qvarnström MJ, Jaroma SM, Laine MT. Changes in peripheral speech mechanisms of children from the age of 7 to 10 years. Folia Phoniatr Logop 1994;46:193-202.

Redenbaugh MA, Reich AR. Correspondence between an accelerometric nasal/voice amplitude ratio and listeners` direct magnitude estimations of hypernasality. J Speech Hear Res 1985;28:273-281.

Remes K. Artikulaatiotesti. Kuvakortisto puheenkehityksen ja äännevirheisyyden tutkimiseen ja tarkkailuun. Koulun Erityispalvelu Oy, Helsinki 1975.

Riski JE, Delong E. Articulation development in children with cleft lip/palate. Cleft Palate J 1984;21:57-64.

Robbins J, Klee T. Clinical assessment of oropharyngeal motor development in young children. J Speech Hear Disord 1987;52:271-277.

Rocrich RJ, Rowsell AR, Johns DF, Drury MA, Grieg G, Watson DJ, Godfrey AM, Poole MD. Timing of palatal closure: a critical long-term analysis. Plast Reconstr Surg 1996;98:236-246.

Ross BR, Johnston MC. Cleft Lip and Palate. Williams and Wilkins, Baltimore 1972, pp 206-226.

Ruscello DM, Tekieli ME, Van Sickels JE. Speech production before and after orthognathic surgery: A review. Oral Surg Oral Med Oral Pathol 1985;59:10-14.

Satoh K, Wada T, Tachimura T, Hara H, Sakoda S, Shiba R. A cephalometric study of the stability of the base of the pharyngeal flap following a modified 'unified velopharyngoplasty procedure'. J Craniomaxillofac Surg 1999;27:358-63.

Scaf G, Capelozza Filho L, Freitas JA. Assessment of the nasopharyngeal area by cephalometry in cases of cleft lip and palate. J Nihon Univ Sch Dent 1991;33:98-107.

Schulz R, Heller JC, Gens GW, Lewin M. Pharyngeal flap surgery and voice quality-factors related to success and failure. Cleft Palate J 1973;10:166-175.

Searl JP, Carpenter MA. Speech sample effects on pressure and flow measures in children with normal or abnormal velopharyngeal function. Cleft Palate Craniofac J 1999;36:508-514.

Seyfer AE, Simon CD. Long-term results following the repair of palatal clefts: a comparison of three different techniques. Plast Reconstr Surg 1989;83:785-90;discussion 791-792.

Sharkey SG, Folkins JW. Variability of jaw and lip movements in children and adults: Implications of the development of speech motor control. J Speech Hear Res 1985;28:8-15.

Shprintzen RJ, Goldberg D. The genetics of clefting and associated syndromes; in Shprintzen RJ, Bardach J (eds): Cleft palate speech management. A multidisciplinary approach. Mosby-Year Book Inc., Missouri 1995, pp 16-43.

Shprintzen RJ, Golding-Kushner KJ. Evaluation of velopharyngeal insufficiency. Otolaryngol Clin North Am 1989;22:519-536.

Shprintzen RJ, Lewin ML, Croft CB, Daniller AI, Argamaso RV, Ship AG, Strauch B. A comprehensive study of pharyngeal flap surgery: tailor made flaps. Cleft Palate J 1979;16:46-55.

Silva PA. The prevalence, stability and significance of developmental language delay in pre-school children. Dev Med Child Neurol 1980;22:768-777.

Smahel Z, Kasalova P, Skvarilova B. Morphometric nasopharyngeal characteristics in facial clefts. J Craniofac Genet Dev Biol 1991;11:24-32.

Sonninen A, Sonninen E. Logopedic-phoniatric observations on 8-year-old schoolchildren in the town of Jyväskylä. Nord Tidskr Logop Foniat 1976;1:74-82.

Sovijärvi A. Suomen kielen äännekuvasto. K.J. Gummerus Osakeyhtiön kirjapaino Jyväskylä 1963.

Speirs RL, Maktabi MA. Tongue skills and clearance of toffee in two age-groups and in children with problems of speech articulation. J Dent Child 1990;57:356-360.

Starr CD. Dental and occlusal hazards to normal speech production; in: Grapp WC, Rosenstein SW, Bzoch KR, (eds): Cleft lip and palate: Surgical, Dental and Speech Aspects. Little, Brown and Company; Boston 1971, pp670-680.

Stellzig-Eisenhauer A. The influence of cephalometric parameters on resonance of speech in cleft lip and palate patients. An interdisciplinary study. J Orofac Orthop 2001;62:202-203.

Stevenson J, Richman N. The prevalence of language delay in a population of three-year-old children and its association with general retardation. Dev Med Child Neurol 1976;18:431-441.

Subtelny JD, Mestre JC, Subtelny JD. Comparative study of normal and defective articulation of /s/ as related to malocclusion and deglutition. J Speech Hear Disord 1964;29:269-285.

Trier WC. The pharyngeal flap operation. Clin Plast Surg 1985;12:697-710.

Trost JE. Articulatory additions to the classical description of the speech of persons with cleft palate. Cleft Palate J 1981;18:193-203.

Trost-Cardamone JE. Coming to terms with VPI: a response to Loney and Bloem. Cleft Palate J 1989;26:68-70.

Vallino-Napoli LD, Montgomery AA. Examination of the standard deviation of mean nasalance scores in subjects with cleft palate: implications for clinical use. Cleft Palate Craniofac J 1997;34:512-519.

Van Demark DR, Gnoinski W, Hotz MM, Perko M, Nussbaumer H. Speech results of the Zurich approach in the treatment of unilateral cleft lip and palate. Plast Reconstr Surg 1989;83:605-613.

Van Demark DR, Hardin MA. Longitudinal evaluation of articulation and velopharyngeal competence of patients with pharyngeal flaps. Cleft Palate J 1985;22:163-172.

Van Demark DR, Morris HL, VandeHaar C. Patterns of articulation abilities in speakers with cleft palate. Cleft Palate J 1979;16:230-239.

Van Dyke DC, Yeacer D, McInerney JF, Schellinger D, Fox AA. Speech and language disorders in children. Am Fam Physician 1984;29:257-268.

Van Riper C, Emerick L. Speech correction: An introduction to speech pathology and audiology, 7th edition. Prentice-Hall, New Jersey 1984.

Wada T, Satoh K, Tachimura T, Tatsuta U. Comparison of nasopharyngeal growth between patients with clefts and noncleft controls. Cleft Palate Craniofac J 1997;34:405-409.

Warren, DW. Perci: A method for rating palatal efficiency. Cleft Palate J 1979;16:279-285.

Warren DW. Compensatory speech behaviors in individuals with cleft palate: A regulation/control phenomenon. Cleft Palate J 1986;23:251-260.

Warren DW, Dalston RM, Trier WC, Holder MB. A pressure-flow technique for quantifying temporal patterns of palatopharyngeal closure. Cleft Palate J 1985;22:11-19.

Warren DW, Duany LF, Fischer ND. Nasal airway resistance in normal and cleft palate children. Cleft Palate J 1969;6:134-140.

Warren DW, Dubois AB. A pressure-flow technique for measuring velopharyngeal orifice area during continuous speech. Cleft Palate J 1964;1:52-71.

Warren DW, Drake AF, Davis JU. Nasal airway in breathing and speech. Cleft Palate Craniofac J 1992;29:511-519.

Watkins KL, Fromm D. Labial coordination in children: Preliminary considerations. J Acoust Soc Am 1984;75:629-632.

Watterson T, Lewis KE, Deutsch C. Nasalance and nasality in low pressure and high pressure speech. Cleft Palate Craniofac J 1998;35:293-298.

Wiik K. Fonetiikan perusteet. WSOY, Juva 1981, pp 70-71.

Witsell DL, Drake AF, Warren DW. Preliminary data on the effect of pharyngeal flaps on the upper airway in children with velopharyngeal inadequacy. Laryngoscope 1994;104:12-15.

Wood JL, Smith A. Cutaneous oral-motor reflexes of children with normal and disordered speech. Dev Med Child Neurol 1992;34:797-812.

Wu JT, Huang GF, Huang CS, Noordhoff MS. Nasopharyngoscopic evaluation and cephalometric analysis of velopharynx in normal and cleft palate patients. Ann Plast Surg 1996;36:117-123.

Wyatt R, Sell D, Russel J, Harding A, Harland K, Albery E. Cleft palate speech dissected: a review of current knowledge and analysis. Br J Plast Surg 1996;49:143-149.

Yoss KA, Darley FL. Developmental apraxia of speech in children with defective articulation. J Speech Hear Res 1974;17:399-416.

Zajac DJ. Laryngeal airway resistance in children with cleft palate and adequate velopharyngeal function. Cleft Palate Craniofac J 1995;32:138-144.