INFLUENCE OF BITE FORCE ON DENTAL CROWDING IN CHILDREN AND ADOLESCENTS: A FOLLOW UP STUDY.

Estudiante
Laura Vélez Sánchez.

Asesores
Samuel Roldán
Peter Buschang
María Antonia Álvarez.
Diego Fernando Rojas

Grupo de investigación
Bioingeniería de cabeza y cuello

Línea de investigación
Crecimiento y desarrollo craneofacial

Facultad de Odontología
Universidad CES
Posgrado de ortodoncia
Maestría en Ciencias Odontológicas

Medellín 28 de mayo del 2020

ABSTRACT

Introduction: The purpose of this study was to analyze the influence of maximum bite force on dental crowding in subjects between 6 and 17 years of age. **Methods:** A total of 364 children and adolescents from three private schools from Medellín, Colombia were assigned to 4 age cohorts (ages 6, 9,12 and 15 years). Each age cohort was evaluated for 3 consecutive years. Incisor (IBF) and molar (MBF) bite forces were assessed by using an occlusal force transducer. Peer assessment rating index was used to quantify the lower crowding.

Results: Both, bite force and lower crowding increased from 6 to 17 years of age. Multilevel analyses showed that the influence of the bite force on dental crowding was only significant in age cohorts 6 and 9 and not in age cohorts 12 and 15 . The influence of IBF was inversely proportional while the MBF was directly proportional to dental crowding.

Conclusions: In age cohorts 6 and 9, by increasing the IBF the lower crowding tended to decrease and by increasing the MBF the lower crowding tended to increase.

Key words: Dental crowding, Incisal Bite Force, Molar Bite Force

INTRODUCTION

Several factors have been suggested to affect crowding, such as tooth size,(1) arch dimensions,(2) interproximal contact type,(3) premature tooth loss,(4) anterior component of force,(5) vertical growth,(6) and third molar presence(7) among others. However, anthropological studies have shown that malocclusions are a relatively recent phenomenon, showing a low prevalence in medieval civilizations compared to recent data.(8,9) Increased malocclusions incidence has been related to industrialization and changes in diet consistency.(10,11) It has been shown in animal studies that there is a direct causal relationship between alterations in masticatory muscle function, produced by a soft diet, and craniofacial skeletal growth. Additionally, a soft diet has been correlated with changes in fiber type muscular composition and diameters, therefore the reduction of total muscle weight, promotes a different craniofacial skeletal pattern and the establishment of malocclusions.(10,12–16)

Given the limitation of conducting studies that alter diet consistency in growing humans, bite force (BF) has been used as an indicator of functional capacity of the masticatory system, and it has been suggested that the presence of a decreased bite force could be due to the type of diet.(17) Bakke et al(18) measured the thickness of the masseter muscle and its correlation to bite force, electrical muscle activity, and morphologic and occlusal parameters. They found that the muscle thickness was significantly correlated to bite force, occusal contacts and cephalometic data. Thicker masseters were found when bite force increased and more teeth were present. Weak masseters were found when facial height and mandibular plane angle were increased. On the other hand, Gionhaku et al(19) found that individuals with bigger muscles showed greater bigonial width, wider arches, reduced gonial angles and anterior mandibular rotation.

There is an agreement that masticatory muscles strength and increased bite force alters craniofacial morphology. The impact on the transverse and vertical face dimensions is well documented;(10,18,20–23) However, the relationship between bite force and malocclusion remains unclear. Patients with open or cross bites tend to have a decrease bite force compared to patients with normal occlusions.(24,25) Nevertheless, when comparing bite force among Angle's classification of malocclusions the results are contradictory. Sonnesen and Bakke(20) concluded that bite force does not significantly differ between Class I and II malocclusions, however, they did not compare with normal occlusion. Roldan et al(26) in a semi-longitudinal study, reported that subjects with normal occlusion showed a greater molar and incisal bite force than those with Class I or Class II malocclusion.

It is still unclear whether bite force influences the development of dental crowding in growing individuals. Thus, the aim of this study was to analyze the influence of maximum bite force on dental crowding in a sample of subjects between 6 and 17 years of age.

MATERIAL AND METHODS

This cohort follow-up study was approved by the Ethics Committee of Universidad CES (Ae-207). Informed consent was obtained from all subjects and their parents. A total of 2954 students were examined in three private schools from Medellin, Colombia. The sample was selected according to the following criteria: Age: 6 and 17 years of age patients were screened and assigned to one of the following age cohorts: age cohort 6, between 5.5 and 6.5 years of age; age cohort 9, between 8.5 and 9.5 years; age cohort 12, between 11.5 and 12.5 years; and age cohort 15, between 14.5 and 15.5 years of age. Occlusal status was determined based on a clinical examination. Subjects with congenitally missing teeth, signs and symptoms of temporomandibular dysfunction, craniofacial anomalies, history of previous orthodontic treatment, parent-reported dental or jaw trauma and submerged teeth, ankylosed teeth, Class III molar relationship or any teeth with more

than two-thirds of their occlusal surfaces restored were not included in this study. Annual measurements were made over 3 consecutive years.

Maximum bite force: Bite forces were measured by the same investigator, who was calibrated before data collection, using an occlusal force transducer,(27) which was covered with a thin plastic and recovered with sterile latex after each subject. The total vertical height of the transducer was 7.5 mm, which is within the physiological range of the masticatory muscles' optimum functional vertical distance.(17) Subjects sat in an upright position without head support. Standardized bite force measurements were taken between the central incisors and right first permanent molars by one previously trained orthodontist. Recorded voice commands were used to instruct the subjects to bite as hard as possible for 3 seconds. This procedure was repeated three times, with 1 minute rest periods between bites. One day after data collection, 10% of the subjects (randomly selected) were remeasured. Reliabilities of the maximum bite force was 78% for the molars and 86% for the incisors.(28) The transducer was calibrated after every 50 subjects. Bite force readings were not taken for subjects who presented with restorations on the incisal surfaces of their anterior teeth, unerupted anterior teeth, or molars with extensive restorations involving the cusp tips. (26)

Lower crowding: Alginate impressions (New Stetic, Medellín, Colombia) were taken from all subjects, and dental casts (Whip Mix, Louisville, Ky) were produced as decribed Alvaran et all(29) Crowding was measured from each subject's dental cast according to the PAR index by the same investigator, who was calibrated prior to data collection. The PAR index(30) measure dental displacements between the contact points of adjacent teeth in millimeters using a special ruler. The greater this distance, the higher the assigned score.

Anthropometric measurements (covariates): The following anthropometric measurements were made: (1) bizygomatic breadth, zygoma to zygoma; (2) bigonial breadth, gonion to gonion; and (3) facial height, nasion to gnathion. All anthropometric measurements were taken of each of the subjects by one

experienced anthropologist, who was calibrated prior to data collection and undertook all the measurements with an anthropometer (Harpenden Anthropometer; Crosswell, Crymych, Pembrokeshire, UK). Three replicates were taken of each measurement and averaged; when one of the replicates deviated more than 3 per cent, a fourth was taken and the outlier was discarded. Intraclass correlations based on replicates of approximately 10 per cent of the subjects ranged from 0.96 to 0.99.

Transverse measurements of the dental arches were made directly on the plaster models with digital calipers (Mitutoyo, Japan) accurate to 0.05 mm. Measurements taken in the mandible and maxilla included the following.

1. Intercanine width, measured as the distance between cusp tips of the deciduous and permanent canines. When there was attrition, the measuring point was determined as the middle of the facet on the tooth.
2. Interpremolar width, measured as the distance between the distal pits on the occlusal surface of the first premolars or between the first deciduous molars.
3. Intermolar width, measured as the distance between the center point of the occlusal surface of the right and left first permanent molars.

Intraclass correlations for the model measurements, based on 2 measures for each of the 3 widths from 20 subjects, ranged from 0.99 to 1.00

Statistical analysis

Statistical analyses were performed in Stata version 12. Means and standard deviations were used to describe craniofacial anthropometric measurements by age-cohort and dentition type. For each age-cohort, annual average change of incisive and molar bite force (kg) and annual average change of lower crowding (mm) were estimated with independent linear multilevel models with repeated measurements, crowding as level 1 variable, participant as level 2 variable and age as covariate, robust estimation of variance was considered. The influence of bite force (per 10 kg)

and anthropometric characteristics on the annual average change in lower crowding (mm) was analyzed including covariates in the multilevel model, crude and adjusted estimates of influence are presented for each characteristic. Estimations are presented with 95% confidence intervals.

RESULTS

A total of 364 children and adolescents who presented the measurements of bite force and dental crowding in the three times of observation were included in the present study. Sample loss was due to children changed school, absence the day of the measurement, some started orthodontic treatment or restorative procedures, and others did not want to continue in the study (Figure 1).

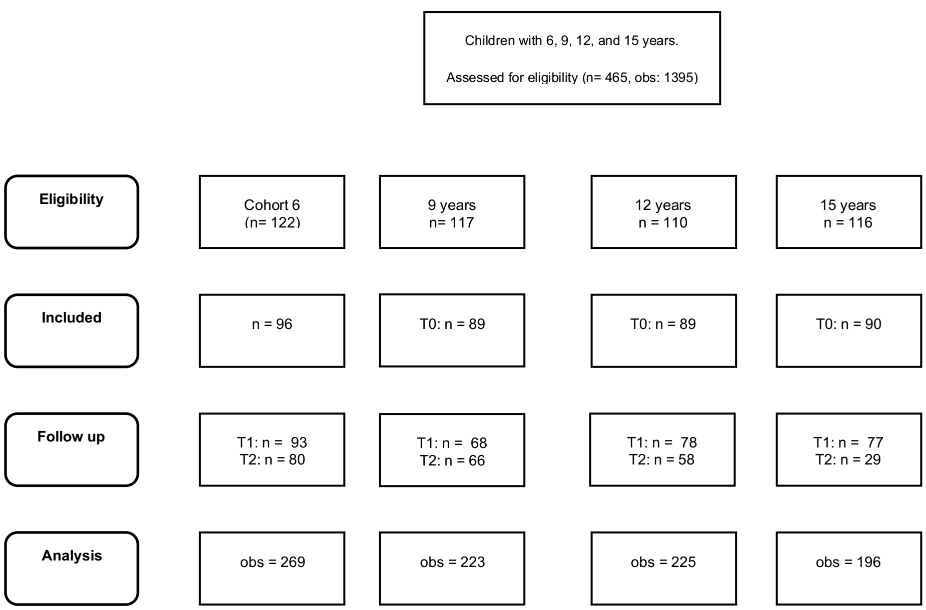

Figure 1. Flow diagram.

Maximum Bite Force

The average maximum bite force increased with age in all the cohorts. Molar bite force (MBF) increased in average per year 1.48kg (95%CI -0.17;3.13) in the age cohort 6, 5.03kg (95%CI 3.48; 6.68) in the age cohort 9, 5.51kg (95%CI -3.16;7.87) in the age cohort 12, and 3.04kg (95%CI 0.53;5.54) in the age cohort 15. In the age cohort 12 it was observed a slight decrease from age 12 to 13, which then returns and increase at age 14. The increase in MBF was statistically significant in all the age cohorts, except in age cohort 6 in which the increase in bite force up to 8 years was not statistically significant. (Figure 2)

The incisive bite force (IBF) increased in average per year 0.8kg (95%CI -0.07;1.66) in the age cohort 6, 1.69kg (95%CI 0.84;2.53)in the age cohort 9, 1.89kg (95%CI 0.72;3.06) in the age cohort 12, and decreased in average per year -1.18kg (95%CI -2.48; 0.12) in the age cohort 15. In the age cohort 6 it was observed a slight decrease from age 6 to 7, which then returns and increase at age 8. The increase in the IBF at age cohort 9 and 12 was statistically significant. (Figure 2)

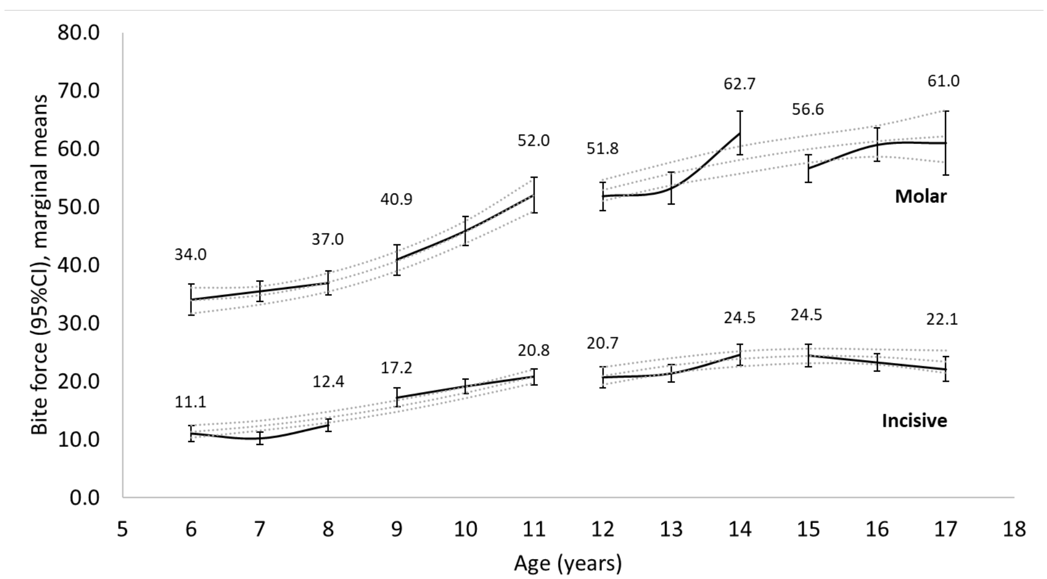

Figure 2. Annual average change of Incisive and molar bite force (kg) by age and cohort

Lower Crowding

Average lower crowding tended to increase with age (Figure 3). It increased in average per year 0.47mm (95%CI 0.22;0.73) in age cohort 6, (95%CI 0.49;0.99) in age cohort 9, 0.17mm (95%CI-0.05;0.38) in age cohort 12, and 0.03mm (95%CI-0.19;0.24) in age cohort 15. In the age cohort 12 it was observed a slight decrease in lower crowding from age 12 to 13, which then returns and increase at age 14. The increase in the lower crowding was statistically significant at age cohorts 6 and 9. (Figure 3).

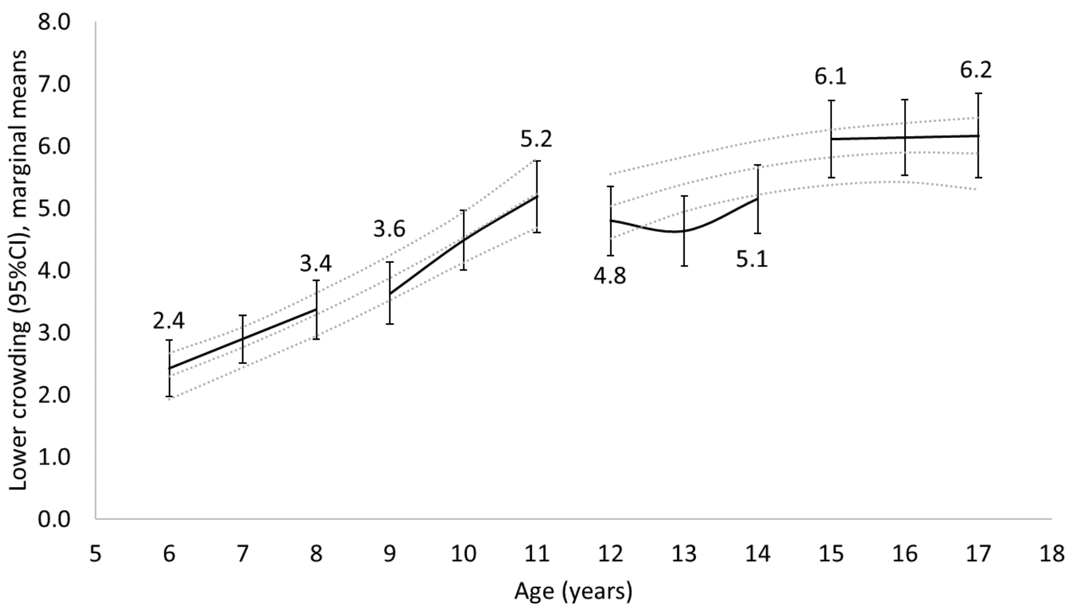

Figure 3. Annual average change of lower crowding (mm) by age and cohort

Anthropometric Characteristics

In general, the craniofacial anthropometric measurements tended to increase with age (Table 1).

Table 1. Baseline craniofacial anthropometric measurements by cohort

	Cohort							
	Age cohorts 6 and 9				Age cohorts 12 and 15			
	6		9		12		15	
	mean	sd	mean	sd	mean	sd	mean	sd
Inter-canine distance, upper (mm)	30.13	1.92	33.13	2,11	34.12	1.93	35.06	2.37
Inter-premolar distance, upper (mm)	34.84	1.68	36.66	2,04	37.16	2.56	37.64	2.21
Inter-molar distance, upper (mm)	44.59	2.51	46.40	2,33	47.12	2.59	47.90	2.56
Inter-canine distance, lower (mm)	23.88	1.79	26.64	1,96	26.69	1.92	26.76	2.04
Inter-premolar distance, lower (mm)	30.34	1.72	31.61	2,02	31.90	2.18	32.49	1.90
Inter-molar distance, lower (mm)	40.71	2.75	41.67	2,31	41.57	2.61	42.01	2.43
Bigonial with (cm)	9.43	0.37	9.91	0,47	10.38	0.48	10.62	0.44
Facial index (%)	78.14	3.93	81.28	3,83	82.37	4.33	84.99	4.36

Influence of bite force and anthropometric characteristics on lower crowding in age cohorts 6 and 9 .

The crude analysis showed that the influence of the annual average change of IBF (*p= 0.063*) and MBF (*p= 0.806*) on lower crowding was not statistically significant.

The adjusted analysis for anthropometric characteristics showed that both IBF *(p= 0.021)* and MBF *(p= 0.042)* significantly influenced the annual average change of the lower crowding. For every 10 kg of increase in IBF, lower crowding decreases 0.04mm (95%CI-0.08; -0.01), and for every 10 kg of increase in MBF, lower crowding increases 0.02mm (95%CI 0.00;0.04).

Among the covariates, lower intercanine distance, lower interpremolar distance and bigonial width, significantly influenced annual average change of the lower crowding in the crude analysis. When adjusted by craniofacial anthropometric measurements, only the lower intercanine distance remained statistically significant (Table 2).

Between-subject variability in cohorts 6 and 9 lower crowding was SD = 2.06 mm (95%CI 0.74; 1.82); the adjusted model explained 22.6% of this variability.

Table 2. Influence of bite force and anthropometric characteristics on the annual average change of lower crowding in age cohorts 6 and 9 .

	Crude			**Adjusted**		
	Coef.	**95%CI**	**p value**	**Coef.**	**95%CI**	**p value**
Incisive bite force	-0.03	(-0.07, 0.00)	0.06	-0.04	(-0.08, -0.01)	**0.02***
Molar bite force	0.00	(-0.01, 0.02)	0.80	0.02	(0.00, 0.04)	**0.04***
Inter-canine distance, upper	-0.06	(-0.20, 0.09)	0.45	0.10	(-0.21, 0.42)	0.51
Inter-premolar distance, upper	-0.02	(-0.15, 0.12)	0.81	0.06	(-0.34, 0.45)	0.77
Inter-molar distance, upper	0.01	(-0.12, 0.13)	0.93	0.05	(-0.24, 0.34)	0.75
Inter-canine distance, lower	-0.19	(-0.34, -0.04)	0.01	-0.29	(-0.53, -0.06)	**0.01***
Inter-premolar distance, lower	-0.28	(-0.46, -0.10)	0.00	-0.29	(-0.66, 0.07)	0.11
Inter-molar distance, lower	-0.07	(-0.23, 0.08)	0.36	0.24	(-0.06, 0.53)	0.11
Bigonial width	-0.64	(-1.22, -0.06)	0.03	-0.53	(-1.37, 0.32)	0.22
facial index	0.06	(-0.01, 0.13)	0.07	0.05	(-0.03, 0.14)	0.21

*$p < 0.05$

Influence of bite force and anthropometric characteristics on lower crowding in age cohorts 12 and 15 .

Crude analysis showed no statistically significant influence of the annual average change of IBF (*p= 0.25*) and MBF (*p= 0.61*) on lower crowding. When adjusted for anthropometric characteristics, both IBF (*p= 0.38*) and MBF (*p= 0.95*) remained no statistically significant. Among the covariates, the upper and lower interpremolar distance and the lower intermolar distance significantly influenced annual average change of the lower crowding in the crude analysis. When adjusted by craniofacial anthropometric measurements, only upper intercanine distance *(p= 0.00)* became significant (Table 3).

Between-subject variability in cohorts 12 and 15 lower crowding was SD = 2.88 mm (95%CI 0.92; 2.61); the adjusted model explained 15.5% of this variability.

Table 3. Influence of bite force and anthropometric characteristics on the annual average change of lower crowding in age cohorts 12 and 15 .

	Crude			Adjusted		
	Coef.	**95%CI**	**p value**	**Coef.**	**95%CI**	**p value**
Incisive bite force	-0.01	(-0.04, 0.01)	0.25	-0.01	(-0.04, 0.02)	0.38
Molar bite force	0.00	(-0.01, 0.01)	0.61	0.00	(-0.01, 0.01)	0.95
Inter-canine distance, upper	0.06	(-0.10, 0.23)	0.44	0.35	(0.11, 0.60)	**0.00***
Inter-premolar distance, upper	-0.23	(-0.34, -0.11)	0.00	-0.21	(-0.44, 0.02)	0.07
Inter-molar distance, upper	-0.12	(-0.24, 0.00)	0.05	0.09	(-0.15, 0.32)	0.47
Inter-canine distance, lower	-0.15	(-0.32, 0.01)	0.06	-0.12	(-0.38, 0.14)	0.36
Inter-premolar distance, lower	-0.22	(-0.36, -0.09)	0.00	-0.14	(-0.37, 0.10)	0.25
Inter-molar distance, lower	-0.18	(-0.31, -0.06)	0.00	-0.19	(-0.38, 0.01)	0.06
Bigonial width	0.23	(-0.33, 0.79)	0.42	0.27	(-0.42, 0.97)	0.44
facial index	0.06	(0.00, 0.12)	0.07	0.06	(-0.01, 0.13)	0.07

*$p < 0.05$

DISCUSSION.

Since dental crowding is the most prevalent form of malocclusion and the main complaint in the orthodontic office, it is important to study its etiology and understand the factors associated with it. This study analyzed the influence of maximum bite force on dental crowding in a sample of subjects between 6 and 17 years of age.

When the influence of the bite force on dental crowding was analyzed, the results showed that it was only significant in age cohorts 6 and 9 and not in age

cohorts 12 and 15 . The crude analysis in age cohorts 6 and 9 showed that the influence of the annual average change of IBF (*p= 0.063*) and MBF (*p= 0.806*) on lower crowding was not statistically significant. However when the analysis was adjusted for anthropometric characteristics, showed that both IBF *(p= 0.021)* and MBF *(p= 0.042)* significantly influenced the annual average change of the lower crowding.(Table 2) This may be due to the fact that the increase in bite force was greater between 6 and 11 years (age cohorts 6 and 9) than between 12 and 17 years (age cohorts 12 and 15). This might be explained by the continuous growth and development of the masticatory muscles in early ages,(31) and with the fact that crowding increase more in age cohorts 12 and 15 than in age cohorts 6 and 9 .(32) In addition to the factors that may influence the development of dental crowding commonly discussed in the literature, the bite force could be another that has not been explored.

In this study it was found that by increasing the IBF the lower crowding tended to decrease in the age cohorts 6 and 9 . For every 10 kg of increase in IBF, lower crowding decreases 0.04mm (p=0.02) (95%CI-0.08; -0.01). (Table 2) Although the relationship between MBF and crowding has been studied, this is the first study to analyze the IBF and dental crowding. It has been shown that bite force influences the craniofacial morphology.(10,19,20,33) A decreased bite force and weak muscles, could generate vertical growth of the face characterized by a posterior mandibular rotation, which has been shown to cause lingual compensation of the lower incisors, reducing the perimeter of the arch and thus generating dental crowding.(6,19) On the other hand, Bakke(20) found a positive correlation coefficient between the bite force and vestibular inclination of the lower incisors of 0.33. In addition, it has been reported that an increase in bite force can generate greater transverse development of the dental arches which increases the perimeter of the arch and therefore decreases the appearance of crowding. (16,19) According to the results of this study, it is possible to speculate that the IBF may increase the intercanine distance and thus reduce the dental crowding. For every 1mm of increase in the lower intercanine distance, crowding decreases 0.29mm (p=0.01)

(Table 2) This shows that IBF has a more important value than what has been given until now. The functions that the human being had related to the incisors have been lost with habits and dietary changes, tools to cut food, among others. The results of this study demonstrate the importance of recovering and improve the IBF to prevent the lower crowding.

On the other hand, the present study showed that by increasing the MBF the lower crowding tended to increase. For every 10 kg of increase in MBF, lower crowding increases 0.02mm (p=0.04) (95%CI 0.00;0.04). (Table 2) This can be explained by the anterior component of force (ACF). It is thought that while chewing on posterior teeth, a portion of the occlusal load projects towards the front of the mouth resulting in crowding.(5,34) Southard et al(35) found a proportional increase in ACF with increasing bite force from 50 to 200N, therefore a greater bite force in the molar zone, could generate a greater ACF which can cause slippage of contact points between the front teeth and contribute to crowding.(3) However, the increase of dental crowding generated by the increase of the MBF is lower than the decrease of dental crowding generated by the increase of the IBF. For this reason, muscular exercises to increase the IBF at growth stages are suggested to prevent dental crowding. Thompson et al(36) evaluated the effects of isometric exercise on maximum voluntary bite forces and jaw muscle strength. After exercise, subjects increased their maximum bite forces by 37%. Unfortunally, bite force in this study was measured in the first premolars. Studies measuring force in the incisors are suggested to assess the response of the incisor bite force to muscle exercises.

The sample used in this study showed on average slight and moderate crowding, this may be related to the low coefficient found. However, this increase in crowding, although little, is the first step in the development of greater dental crowding over time by contact displacements. It is suggested to conduct this study in a sample with severe crowding where it would be possible to find a greater influence coefficient of the bite force in the dental crowding.

In this study, the incisive and molar bite force increased with age. At 6 years the MBF was on average 34kg and at 17 years it was 61kg. The IBF at 6 years was on average 11.1kg and at 17 years it was 22.1kg. (Figure 2) This increment is in accordance with the improvement in the number of occlusal contacts during the transition through different dentition stages and with the gain of masticatory muscle size with maturation. Owais et al(37) also found that maximum occlusal bite force increased with age in children between 3 and 18 years. Similarly, Bakke(38) suggests that bite force increases with age from childhood to adulthood, stays fairly constant from 20 to 40 years of age, and then decrease. Other studies in growing patients have reported the same results.(20,26,39,40) On the other hand, Braun S et al(21) reported a lack of age differences in bite force. These dissimilarities could be related to the different growth stages of the sample in each study. Owais and Bakke included adolescents' patients and Braun's sample consisted of adults between 26 and 41 years. In the literature is has been explain that the increase in bite force with age is related to the gain in size of the chewing muscles, increase in body height, hormonal changes and presence of more teeth in the mouth(18,37,38,41–43)

The present study showed an increase of the lower crowding between 6 and 17 years. This increase was statistically significant at age cohorts 6 and 9. In the age cohort 12 it was observed a slight decrease in lower crowding from age 12 to 13, which then returns and increase at age 14. (figure 3) These changes in lower crowding are similar to those observed by Moorrees(32) who found a significant increase in crowding between 8 to 10 years, followed by a decrease between 12 to 14 years, and an increase from 14 to 18 years. Sinclair and Little(44) reported a slightly decrease of the incisor irregularity index between mixed and age cohorts 12 and 15 and then an increase between 12 and 20 years. Bishara et al(45) observed a small decrease of the mandibular intercanine width after 13 years that may correspond to the increase in lower crowding found in the present study from 13 years onwards. The increase of dental crowding have been related with decreases in inter-canine width and arch length in the years after eruption of the second

molars.(3)(34) Environmental and functional changes such as the increase in incisive bite force at early ages is essential because as explained before, at these ages dental crowding, facial growth pattern, dental compensations develop.

CONCLUSIONS.

- Bite force and dental crowding increased with age.
- The influence of bite force on dental crowding was significant in age cohorts 6 and 9 and not significant in age cohorts 12 and 15 .
- The IBF negatively influenced crowding. By increasing the IBF the lower crowding tended to decrease.
- The MBF positively influenced crowding. By increasing the MBF the lower crowding tended to increase, but in a lesser degree than the negative influence of the IBF.

REFERENCES.

1. Peck S, Peck H. Crown dimensions and mandibular incisor alignment. Angle Orthod. 1972 Apr;42(2):148–53.
2. Howe RP, McNamara JA, O'Connor KA. An examination of dental crowding and its relationship to tooth size and arch dimension. Am J Orthod. 1983 May;83(5):363–73.
3. Buschang PH. Class I malocclusions—The development and etiology of mandibular malalignments. Semin Orthod. 2014 Mar;20(1):3–15.
4. van der Linden FP. Theoretical and practical aspects of crowding in the human dentition. J Am Dent Assoc 1939. 1974 Jul;89(1):139–53.
5. Vardimon AD, Beckmann S, Shpack N, Sarne O, Brosh T. Posterior and anterior components of force during bite loading. J Biomech. 2007 Jan;40(4):820–7.
6. Buschang PH, Jacob HB. Mandibular rotation revisited: What makes it so important? Semin Orthod. 2014 Dec;20(4):299–315.
7. Richardson ME, Orth D. The role of the third molar in the cause of late lower arch crowding: A review. Am J Orthod Dentofacial Orthop. 1989 Jan;95(1):79–83.
8. Rose JC, Roblee RD. Origins of dental crowding and malocclusions: an anthropological perspective. Compend Contin Educ Dent Jamesburg NJ 1995. 2009 Jun;30(5):292–300.
9. Evensen JP, Øgaard B. Are malocclusions more prevalent and severe now? A comparative study of medieval skulls from Norway. Am J Orthod Dentofacial Orthop. 2007 Jun;131(6):710–6.
10. Abed GS, Buschang PH, Taylor R, Hinton RJ. Maturational and functional related differences in rat craniofacial growth. Arch Oral Biol. 2007 Nov;52(11):1018–25.
11. Lieberman DE, Krovitz GE, Yates FW, Devlin M, St. Claire M. Effects of food processing on masticatory strain and craniofacial growth in a retrognathic face. J Hum Evol. 2004 Jun;46(6):655–77.
12. Carmody RN, Wrangham RW. Cooking and the Human Commitment to a High-quality Diet. Cold Spring Harb Symp Quant Biol. 2009 Jan 1;74(0):427–34.
13. Ungar PS, Sponheimer M. The Diets of Early Hominins. Science. 2011 Oct 14;334(6053):190–3.
14. Garn SM, Leonard WR. What Did Our Ancestors Eat? Nutr Rev. 2009 Apr 27;47(11):337–45.
15. Kiliaridis S, Shyu BC. Isometric muscle tension generated by masseter stimulation after prolonged alteration of the consistency of the diet fed to growing rats. Arch Oral Biol. 1988 Jan 1;33(7):467–72.
16. Beecher RM, Corruccini RS. Effects of dietary consistency on maxillary arch breadth in macaques. J Dent Res. 1981 Jan;60(1):68.
17. Bakke M. Bite Force and Occlusion. Semin Orthod. 2006 Jun;12(2):120–6.
18. Bakke M, Tuxetv A, Vilmann P, Jensen BR, Vilmann A, Toft M. Ultrasound image of human masseter muscle related to bite force, electromyography, facial morphology, and occlusal factors. Eur J Oral Sci. 1992;100(3):164–171.
19. Gionhaku N, Lowe AA. Relationship between jaw muscle volume and craniofacial form. J Dent Res. 1989;68(5):805–809.
20. Sonnesen L, Bakke M. Molar bite force in relation to occlusion, craniofacial dimensions, and head posture in pre-orthodontic children. Eur J Orthod. 2005 Feb

1;27(1):58–63.
21. Braun S, Bantleon HP, Hnat WP, Freudenthaler JW, Marcotte MR, Johnson BE. A study of bite force, part 1: Relationship to various physical characteristics. Angle Orthod. 1995;65(5):367–72.
22. Andersen MK, Sonnesen L. Risk factors for low molar bite force in adult orthodontic patients. Eur J Orthod. 2013 Aug 1;35(4):421–6.
23. Proffit WR, Fields HW. Occlusal forces in normal- and long-face children. J Dent Res. 1983 May;62(5):571–4.
24. Castelo PM, Gaviao MBD, Pereira LJ, Bonjardim LR. Masticatory muscle thickness, bite force, and occlusal contacts in young children with unilateral posterior crossbite. Eur J Orthod. 2007 Jan 11;29(2):149–56.
25. Garcia-Morales P. Maximum bite force, muscle efficiency and mechanical advantage in children with vertical growth patterns. Eur J Orthod. 2003 Jun 1;25(3):265–72.
26. Roldán SI, Restrepo LG, Isaza JF, Vélez LG, Buschang PH. Are maximum bite forces of subjects 7 to 17 years of age related to malocclusion? Angle Orthod. 2016 May;86(3):456–61.
27. Isaza JF, Throckmorton GS, Roldán SI. Design and construction of a transducer for bite force registration. J Biomech. 2009 May;42(8):1146–9.
28. RoldáN S, Buschang PH, Isaza Saldarriaga JF, Throckmorton G. Reliability of maximum bite force measurements in age-varying populations. J Oral Rehabil. 2009 Nov;36(11):801–7.
29. Natalia Alvaran,a Samuel I. Roldan,b and Peter H. Buschangc. Maxillary and mandibular arch widths of Colombians. American journal of orthodontics and dentofacial orthopedics: official publication of the American Association of Orthodontists, its constituent societies, and the American Board of Orthodontics · May 2009. 2009;
30. Richmond S, Shaw WC, Roberts CT, Andrews M. The PAR Index (Peer Assessment Rating): methods to determine outcome of orthodontic treatment in terms of improvement and standards. Eur J Orthod. 1992;14(3):180–187.
31. Malina RM, Bouchard C, Bar-Or O. Growth, Maturation, and Physical Activity. Human Kinetics; 2004. 740 p.
32. J.A.S. The dentition of the growing child. A longitudinal study of dental development between 3 and 18 years of age: By Coenraad F. A. Moorrees. Cambridge, Mass., 1959, Harvard University Press. 245 pages. Illustrated. Price, $5.50. Am J Orthod Dentofacial Orthop. 1960 Sep 1;46(9):702–3.
33. Arboleda C, Buschang PH, Camacho JA, Botero P, Roldan S. A mixed longitudinal anthropometric study of craniofacial growth of Colombian mestizos 6-17 years of age. Eur J Orthod. 2011 Aug 1;33(4):441–9.
34. Richardson ME. The etiology of late lower arch crowding alternative to mesially directed forces: a review. Am J Orthod Dentofac Orthop Off Publ Am Assoc Orthod Its Const Soc Am Board Orthod. 1994 Jun;105(6):592–7.
35. Southard TE, Southard KA, Stiles RN. Factors influencing the anterior component of occlusal force. J Biomech. 1990 Jan;23(12):1199–207.
36. Thompson DJ, Throckmorton GS, Buschang PH. The effects of isometric exercise on maximum voluntary bite forces and jaw muscle strength and endurance. J Oral Rehabil. 2001;28(10):909–917.
37. Owais AI, Shaweesh M, Abu Alhaija ESJ. Maximum occusal bite force for children

in different dentition stages. Eur J Orthod. 2013 Aug 1;35(4):427–33.
38. Bakke M. Mandibular elevator muscles: physiology, action, and effect of dental occlusion. Eur J Oral Sci. 1993;101(5):314–331.
39. Marquezin MCS, Kobayashi FY, Montes ABM, Gavião MBD, Castelo PM. Assessment of masticatory performance, bite force, orthodontic treatment need and orofacial dysfunction in children and adolescents. Arch Oral Biol. 2013 Mar;58(3):286–92.
40. Ingervall B, Minder C. Correlation between maximum bite force and facial morphology in children. Angle Orthod. 1997;67(6):415–22; discussion 423-424.
41. Braun S, Hnat WP, Freudenthaler JW, Marcotte MR, Hönigle K, Johnson BE. A study of maximum bite force during growth and development. Angle Orthod. 1996;66(4):261–4.
42. Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. A cross-sectional study. Acta Odontol Scand. 1993 Oct;51(5):323–31.
43. Helle A, Tulensalo T, Ranta R. Maximum bite force values of children in different age groups. Proc Finn Dent Soc Suom Hammaslaakariseuran Toim. 1983;79(4):151–4.
44. Sinclair PM, Little RM. Maturation of untreated normal occlusions. Am J Orthod. 1983 Feb;83(2):114–23.
45. Bishara SE, Ortho D, Jakobsen JR, Treder J, Nowak A. Arch width changes from 6 weeks to 45 years of age. Am J Orthod Dentofacial Orthop. 1997 Apr;111(4):401–9.