ORIGINAL ARTICLE POJ 2012:4(2) 48-55

Comparison of tooth and arch dimensions in dental crowding and spacing

Saman Faruqui[a], Mubassar Fida[b], Attiya Shaikh[c]

Abstract

Introduction: Any disproportion between tooth and arch dimensions predisposes to dental crowding and spacing, which are the most common forms of malocclusion. Hence, the objective of this study is to compare these elements between normal, crowded and spaced dental arches.

Material and Methods: A sample of 90 dental casts was collected and space analysis was performed by subtracting the sum of mesio-distal (MD) dimensions of all teeth (except the permanent molars) from the arch length. On the basis of this space analysis, the sample was divided into three groups, namely normal, crowded and spaced arches. ANOVA and Bonferroni post-hoc were performed for the comparison between the groups. A level of significance ($p \leq 0.05$) was used for the statistical tests.

Results: There was a statistically significant difference in the MD dimensions of upper canines, upper first molars and lower incisors between crowded and normal arches ($p<0.05$), and upper incisors, lower canines and lower premolars between spaced and normal arches ($p<0.05$). A statistically significant difference was also found in the bucco-lingual (BL) dimensions of upper lateral incisors, upper right premolars, lower premolars and lower first molars between spaced and normal arches ($p<0.05$); in the arch perimeters between crowded and normal arches, as well as in the upper arch perimeters, lower inter-canine (IC) widths and lower inter-premolar (IP) widths between spaced and normal arches ($p<0.05$).

Conclusions: The normal dental arches differ from crowded and spaced dental arches in tooth and arch dimensions.

Keywords: Crowding; spacing; tooth dimension; arch dimension

Introduction

A well-aligned set of teeth ascertain esthetics and stability. Furthermore, a perfect tooth position provides ideal conditions for good health and optimal care of teeth. However, the dental arch continuity and integrity is a result of harmony between tooth and arch dimensions. Any disproportion between these elements predisposes to dental crowding and spacing,[1] which are considered detrimental to dental health and function. Apart from various functional incapacities, these malocclusions may be a source of compromised smile esthetics and low self-esteem.[2]

[a]BDS, Resident, Department of Orthodontics, The Aga Khan University Hospital, Karachi, Pakistan

[b]Corresponding Author; BDS, MCPS, FCPS, PGD HIMS, Associate Professor and Program Director, Department of Orthodontics, The Aga Khan University Hospital, Karachi, Pakistan. Email: mubassar.fida@aku.edu

[c]BDS, M.Orth, FCPS, Assistant Professor and Program Coordinator, Department of Orthodontics, The Aga Khan University Hospital, Karachi, Pakistan

Dental crowding and spacing are the most common forms of malocclusion.[3] Crowded dentition means that there is insufficient room for the teeth to erupt in an ideal position. As a result, the teeth may be impacted, rotated or displaced. On the other hand, dental spacing means that there is excessive space between the teeth or the proximal contact between the teeth is absent. A combination of etiological factors has been recognized in an attempt to better understand these dental problems. Although heredity,[4] environment,[4] ethnicity,[5] and secular trends[6] are possible etiologies of crowding and spacing reported in the literature, a relevant concern in this context is the causative role of various clinical characteristics. A range of studies[3-5,7] has been conducted to show the association of size of the teeth and arches but the results are contradictory.

The tooth-size arch-length discrepancy (TSALD) has been an area of interest of many

researchers and several factors such as tooth dimensions, arch widths and lengths have been found to be related to this discrepancy. Initially, Siepel[8] showed that the positions of teeth in the dental arch can be determined by considering the size of the teeth and the amount of space available for them in the dental arch. This was followed by a study by Lundström[9] reporting two factors accountable for dental crowding i.e. the increase in mesio-distal (MD) dimensions of teeth and the decrease in dental arch dimensions.

The biometric study by Puri et al[3] confirmed that crowded arches consistently had larger teeth than the normal arches. They also showed that smaller teeth, particularly the small mandibular incisors are responsible for dental spacing. In addition to the MD dimensions of teeth, the bucco-lingual (BL) dimensions have also been found to affect the dental alignment. In a recent study, the permanent crown dimensions in young men with naturally good occlusions were compared with those who required orthodontic treatment.[10] The results showed that tooth crown dimensions (MD as well as BL) were significantly larger in subjects with malocclusions than in those with good occlusions. In contrast, Bernabe and Flores-Mir[11] showed that crowded and normal arches differ significantly in their MD tooth sizes and arch length but not in their BL tooth sizes. Loren[12] found a significant association between malalignment of teeth and arch width, however he concluded that arch length and incisor crown diameter do not vary in individuals with and without malalignment.

Dental crowding and spacing are the consequences of TSALD which is a significant area to investigate because it has an influence on treatment methods and retention. Hence, the present study was planned with the objective of comparing the tooth and arch sizes between normal, crowded and spaced dental arches.

Material and Methods

This cross-sectional study was conducted at the orthodontic clinic. Prior to commencement of treatment, informed consent was obtained from patients and/or parents that their records might be used for research purpose. A sample of 90 dental casts of Pakistani subjects aged above 11 years was collected. The dental casts were selected from the records of the patients seeking orthodontic treatment which met the inclusion criteria: (1) pretreatment casts of subjects with no prior history of orthodontic treatment, (2) well erupted permanent dentition permitting proper measurements of crown dimensions, and (3) good quality orthodontic casts. Casts with any tooth developmental disorder, missing, supernumerary or carious teeth, worn out dentition, or large coronal restorations were not included in this study.

The TSALD was calculated in each arch as the numerical difference between the sum of MD tooth dimensions and the arch perimeter mesial to the first permanent molars. The grouping of sample was done on the basis this space discrepancy. In this study, arches with a space discrepancy of 0 ± 3 mm were defined as normal, arches with a space discrepancy of more than - 4 mm were defined as crowded and arches with a space discrepancy of more than + 4 mm were labeled as spaced arches.

A total of 90 casts met the criteria of grouping and they were divided into normal, crowded, and spaced dental arches groups with 30 casts in each group. Each group was further divided into 15 maxillary and 15 mandibular casts.

For each cast, the following parameters were recorded: the MD and BL crown diameters of all teeth except the second and third permanent molars; the inter-canine (IC), inter-premolar (IP) and inter-molar (IM) widths; the arch perimeter; and the arch depth. The MD crown width was measured as the greatest distance between the contact points

of the approximal surfaces of the dental crown, with the calipers parallel to the occlusal and buccal surfaces (Fig 1).[1] The BL crown diameter was measured as the greatest distance between the facial and lingual surfaces of the crown, taken at right angles to the plane in which the mesiodistal diameter is taken (Fig 2).[13] IC width was measured as the horizontal distance between the cusp tips of the canines (Fig 3),[14] IP width as the horizontal distance between the distal pit of the maxillary first premolar (Fig 3) or the distal fossae of the mandibular first premolar,[14] and IM width as the horizontal distance between the central fossae of the maxillary first molars (Fig 3) or the disto-buccal cusp tips of the mandibular first molars.[14]Arch depth was taken as the perpendicular distance between the incisor edges of central incisors and a line connecting the mesial surfaces of the first molars on both sides (Fig 3).[15]

Figure 1: Measurement of mesio-distal (MD) dimension of teeth

All the measurements were made by one examiner using a digital vernier caliper (0-150 mm ME00183, Dentaurm, Pforzheim, Germany) with accuracy of 0.02 mm and reliability of 0.01 mm manufacturer's specification.

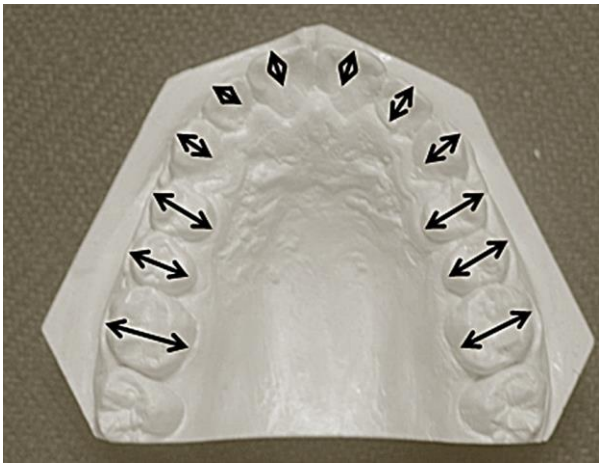

Figure 2: Measurement of bucco-lingual (BL) dimension of teeth

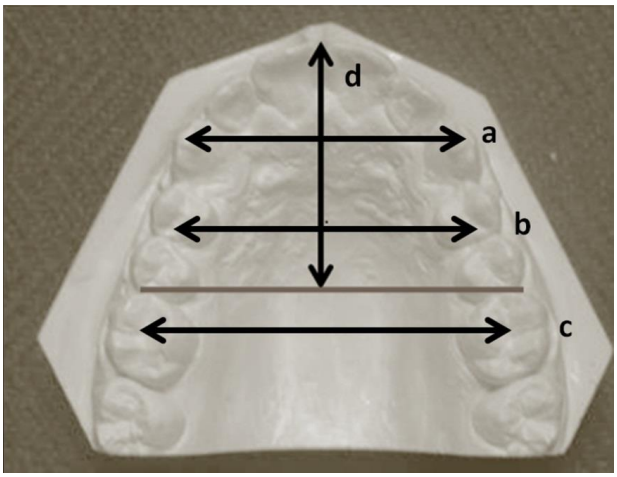

Figure 3: Measurement of arch dimensions: a, inter-canine (IC) width; b, maxillary inter-premolar (IP) width; c, maxillary inter-molar (IM) width; d, arch depth

Up to 5 pairs of dental casts were examined each day to evade eye exhaustion. One week after the data collection, 10 dental casts were randomly selected and replicated measurements were made by the same investigator to detect any measurement error, however, Pearson correlation did not show any statistically significant difference for the intra-examiner reliability ($r = 0.93$, $p = 0.01$).

All data were analyzed with SPSS software (version 19.0, SPSS Inc., Chicago). Descriptive measures such as means, standard deviations, and standard errors of the mean were calculated for each variable. Oneway analysis

of variance (ANOVA) was used to compare the three groups and Post Hoc Bonferroni test was applied to assess group differences in the crown and arch dimensions. A level of significance ($p \leq 0.05$) was used for the statistical tests.

Results

The comparison of MD dimensions of teeth between normal, crowded, and spaced dental arches by ANOVA showed that all teeth except mandibular first permanent molars were significantly different in the three groups (Table I). Table II illustrates the group differences in the MD tooth dimension using Post Hoc Bonferroni test. When the maxillary casts were compared, a statistically significant difference was found in the MD dimensions of canines and first permanent molars between normal and crowded arches, in the MD dimensions of all incisors between normal and spaced arches, and in the MD dimensions of all teeth between crowded and spaced arches. When mandibular casts were compared, there was a statistically significant difference in the MD dimensions of all incisors between normal and crowded arches, in the MD dimensions of canines and premolars between normal and spaced arches, and in MD dimensions of all teeth except first permanent molars between crowded and spaced arches.

The comparison of BL dimensions of teeth between normal, crowded, and spaced dental arches showed that maxillary lateral incisors and all premolars and first molars were significantly different in the three groups (Table III). When Post Hoc Bonferroni test was applied to further assess the inter-group variations (Table IV), no significant difference was noticed in the BL dimensions of teeth between normal and crowded arches. Whereas, a statistically significant difference was found in the BL dimensions of maxillary lateral incisors and right premolars, and mandibular premolars and first molars between normal and spaced dental arches.

A statistically significant difference was determined in all the arch dimensions between normal, crowded, and spaced dental arches with the exception of mandibular arch depth (Table V). Table VI shows the intergroup comparison confirming a statistically significant difference in the arch perimeter of maxillary and mandibular arches between normal and crowded arches. When normal and spaced arches were compared, a significant difference was observed in the arch perimeter of maxillary arches, and IC and IP widths of mandibular arches.

Table I: Comparison of MD dimensions of teeth in three groups

Dental Arch (N = 90)		Tooth											
		16	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**
Maxilla (n = 45)	**Normal (Mean)**	9.701	6.553	6.995	7.528	6.856	8.710	8.639	6.858	7.404	6.930	6.587	9.642
	Crowded (Mean)	10.220	6.795	7.134	7.981	7.170	8.747	8.769	7.152	7.967	7.254	6.769	10.167
	Spaced (Mean)	9.502	6.256	6.572	7.423	6.395	8.042	8.064	6.358	7.393	6.652	6.252	9.493
	p-value	**0.002**	**0.006**	**0.010**	**0.003**	**0.001**	**0.002**	**0.004**	**0.001**	**0.001**	**0.004**	**0.005**	**0.002**
		46	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**
Mandible (n = 45)	**Normal (Mean)**	10.866	7.048	7.057	6.712	5.862	5.318	5.272	5.845	6.701	7.060	7.097	10.563
	Crowded (Mean)	10.826	7.115	7.066	6.757	6.209	5.657	5.627	6.235	6.790	7.186	7.162	10.606
	Spaced (Mean)	10.301	6.561	6.467	6.293	5.568	4.994	5.067	5.572	6.304	6.467	6.560	10.302
	p-value	0.165	**0.001**	**0.003**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.002**	**0.001**	**0.001**	0.069

N = 90
One-way ANOVA
p-value ≤ 0.05

Table II: Comparison of MD dimensions of teeth between the three groups

Dental Arch (N = 90)		Tooth											
		16	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**
Maxilla (p-value)	**N-C**	**0.032**	0.412	1.000	**0.025**	0.230	1.000	1.000	0.239	**0.005**	0.196	0.702	**0.025**
	N-S	0.940	0.211	0.074	1.00	**0.033**	**0.007**	**0.026**	**0.012**	1.000	0.333	0.095	1.000
	C-S	**0.002**	**0.005**	**0.010**	**0.004**	**0.001**	**0.004**	**0.005**	**0.001**	**0.014**	**0.003**	**0.004**	**0.003**
		46	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**
Mandible (p-value)	**N-C**	1.000	1.000	1.000	1.000	**0.038**	**0.046**	**0.047**	**0.015**	1.000	1.000	1.000	0.621
	N-S	0.808	**0.007**	**0.010**	**0.005**	0.099	0.061	0.448	0.134	**0.015**	**0.013**	**0.004**	0.824
	C-S	0.181	**0.002**	**0.009**	**0.002**	**0.001**	**0.001**	**0.001**	**0.001**	**0.002**	**0.002**	**0.001**	0.064

N = normal arch, C = crowded arch, S = spaced arch
N = 90
Post Hoc Bonferroni
p-value ≤ 0.05

Table III: Comparison of BL dimensions of teeth in the three groups

Dental Arch (N = 90)		Tooth											
		16	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**
Maxilla (n = 45)	**Normal (Mean)**	11.208	9.412	9.445	7.870	6.766	7.490	7.421	6.745	7.967	9.341	9.248	11.271
	Crowded (Mean)	11.337	9.522	9.391	7.580	6.498	7.044	7.011	6.678	7.619	9.462	9.585	11.341
	Spaced (Mean)	10.812	8.734	8.764	7.870	6.018	7.149	7.179	6.079	7.544	8.801	8.824	10.784
	p-value	0.032	**0.003**	**0.007**	0.182	**0.004**	0.133	0.144	**0.006**	0.150	**0.013**	**0.013**	**0.030**
		46	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**
Mandible (n = 45)	**Normal (Mean)**	10.543	8.686	7.809	6.893	6.294	6.172	6.080	6.344	7.005	7.794	8.632	10.474
	Crowded (Mean)	10.600	8.786	7.903	7.153	6.322	6.176	6.215	6.382	7.119	7.719	8.712	10.436
	Spaced (Mean)	9.971	7.665	7.011	6.892	6.164	5.904	5.874	6.083	6.806	7.049	7.661	9.753
	p-value	**0.002**	**0.001**	**0.001**	0.413	0.615	0.242	0.272	0.170	0.325	**0.002**	**0.001**	**0.001**

N = 90
One-way ANOVA
p-value ≤ 0.05

Table IV: Comparison of BL dimensions of teeth between the three groups

Dental Arch (N = 90)		Tooth											
		16	**15**	**14**	**13**	**12**	**11**	**21**	**22**	**23**	**24**	**25**	**26**
Maxilla (p-value)	**N-C**	1.000	1.000	1.000	0.521	0.658	0.167	0.154	1.000	0.397	1.000	0.528	1.000
	N-S	0.165	**0.018**	**0.014**	0.237	**0.003**	0.419	0.730	**0.011**	0.207	0.066	0.275	0.097
	C-S	**0.004**	**0.005**	**0.026**	1.000	0.092	1.000	1.000	**0.025**	1.000	**0.017**	**0.010**	**0.045**
		46	**45**	**44**	**43**	**42**	**41**	**31**	**32**	**33**	**34**	**35**	**36**
Mandible (p-value)	**N-C**	1.000	1.000	1.000	0.756	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	N-S	**0.009**	**0.001**	**0.001**	1.000	1.000	0.444	0.995	0.391	1.000	**0.003**	**0.001**	**0.001**
	C-S	**0.004**	**0.001**	**0.001**	0.749	1.000	0.427	0.334	0.253	0.423	**0.008**	**0.001**	**0.001**

N = normal arch, C = crowded arch, S = spaced arch
N = 90
Post Hoc Bonferroni
p-value ≤ 0.05

Table V: Comparison of arch dimensions in the three groups

Dental Arch (N = 90)		Arch Dimension				
		IC Width	IP Width	IM Width	Arch Perimeter	Arch Depth
Maxilla (n = 45)	Normal (Mean)	33.171	35.275	46.100	73.066	27.680
	Crowded (Mean)	33.938	34.186	44.901	66.665	25.721
	Spaced (Mean)	35.572	37.244	47.992	76.598	28.508
	p-value	**0.052**	**0.011**	**0.023**	**0.001**	0.006
Mandible (n = 45)	Normal (Mean)	26.182	31.891	48.694	63.052	22.667
	Crowded (Mean)	27.616	30.566	47.093	58.532	22.113
	Spaced (Mean)	29.376	34.517	50.442	65.790	22.632
	p-value	**0.006**	**0.001**	**0.032**	**0.001**	0.644

N = 90
One-way ANOVA
p-value ≤ 0.05

Table VI: Comparison of arch dimensions between the three groups

Dental Arch (N = 90)		Arch Dimension				
		IC Width	IP Width	IM Width	Arch Perimeter	Arch Depth
Maxilla (p-value)	N-C	1.000	0.819	0.821	**0.001***	0.071
	N-S	0.053	0.153	0.262	**0.014**	0.980
	C-S	0.300	**0.010**	**0.020**	**0.001***	**0.005**
Mandible (p-value)	N-C	0.407	0.440	0.598	**0.003**	1.000
	N-S	**0.005**	**0.016**	0.486	0.114	1.000
	C-S	0.207	**0.001***	**0.028**	**0.001***	1.000

N = normal arch, C = crowded arch, S = spaced arch
N = 90
Post Hoc Bonferroni
p-value ≤ 0.05
*p-value ≤ 0.001

Discussion

It is well established that several etiological factors are associated individually or in groups to dental crowding and spacing in the permanent dentition. However, mesiodistal tooth width is considered a primordial causative factor in space anomalies.[16-18] Traditionally, orthodontic diagnosis has been limited to the determination of the amount of dental arch space deficiency considering only the MD tooth dimension and arch perimeter.[19] Recent research[13,20,21] suggests that other morphological characteristics such as tooth shape and arch dimensions play an important role in space discrepancies and these parameters have profound implications in orthodontic diagnosis and treatment planning. In this study, we aimed to determine the differences in normal, crowded and spaced dental arches in terms of tooth and arch dimensions to better understand the morphological relationships of these variables with dental crowding and spacing.

The MD tooth sizes in crowded arches were larger than in normal, although statistically significant differences were found only for maxillary first molars and canines, and for mandibular incisors. This was in concordance with Puriet[3] who found that the MD dimensions of individual teeth, the sum of the

incisors and the sum of the canines and the premolars were uniformly larger in crowded arches compared with normal dental arches. Our study results were also in agreement with Peck and Peck[22,23]and Norderval et al[4] who found a positive correlation between MD width of mandibular incisors and mandibular arch crowding.In contrast, some researchers do not agree with the idea and show no such correlation.[12,25,26]

The MD tooth dimensions in spaced arches were smaller than those in normal arches but statistically significant differences were found only for maxillary incisors, and mandibular canines and premolars. Previous reports have shown similar results.[22,23] In contrast, Puri et al[3] found statistically significant differences for maxillary premolars and mandibular incisors.

Peck and Peck[19,22,23] reported that the crowded arches not only had larger MD tooth size but also shorter BL tooth size, but their findings could not be supported in other studies. In our study, we observed no statistically significant difference in the BL tooth dimensions between normal and crowded arches. However, the BL tooth dimensions of maxillary lateral incisors and right premolars and mandibular premolars and first molars in spaced arches were found to be significantly smaller than in normal arches.

In relation to arch dimensions, statistically significant differences were found in all the variables between the normal, crowded and spaced dental arches. The only variable with insignificant difference was mandibular arch depth. This was in conflict to Bernabéet al[21] who found differences only for IM width and arch perimeter.

Previous studies[21,25] verified that arches with crowding were shorter than those without crowding; this was corroborated in our study where we observed that the arch perimeter of crowded arches were shorter and spaced arches were longer than the arch perimeter of normal arches and these differences were found to be statistically significant. However, no statistically significant difference was observed in the mandibular arch perimeter between spaced and normal arches. IC width was determined to be the arch dimension with more contradictory results. Some authors[25,27] have reported differences in IC width between crowded and uncrowded dentitions, whereas others[24,33] found no differences. In our study, we found that the IC width of spaced arches were significantly larger than those of the normal arches. In terms of IP width, spaced mandibular arches were found to be wider than the normal mandibular arches.

Conclusions

- The MD dimensions of all teeth are greater in crowded arches and smaller in spaced arches as compared to the teeth in normal dental arches.
- There is no difference in BL dimensions of teeth between crowded and normal dental arches; however, the BL dimensions of some teeth in spaced dental arches are smaller than in normal arches.
- The crowded arches are shorter than the normal dental arches, whereas spaced mandibular arches are longer than the normal mandibular arches. No significant difference is observed between the spaced and normal maxillary arches.
- The crowded arches and spaced maxillary arches do not differ from normal arches when arch widths are considered. However, spaced mandibular arches are wider than the normal mandibular arches.

Hence, we concluded that differences in the tooth and arch dimensions are associated with dental-arch discrepancies. The size and shape of the teeth and dental arches will have substantial implications in orthodontic diagnosis and treatment planning, affecting the space available, dental aesthetics, and stability of the dentition. These factors should be considered while planning an orthodontic

treatment to determine the requirements for inter-dental stripping, crown recontouring, prosthetic reconstruction or extraction, and to avoid compromising the final results.

References

1. Moorrees CFA, Reed RB. Correlation among crown diameters of human teeth. Arch Oral Biol 1964;9:685-97.
2. Jung M. Evaluation of the effects of malocclusion and orthodontic treatment on self-esteem in an adolescent population. Am J OrthodDentofacialOrthop 2010;138:160-6.
3. Puri N, Pradhan L, Chandna A, Sehgal V, Gipta R. Biometric study of tooth size in normal, crowded, and spaced permanent dentitions. Am J OrthodDentofacialOrthop 2007;132:279.e7-279.e14.
4. Normando D, Almeida MA, Quintão CC. Dental crowding: the role of genetics and tooth wear. Angle Orthod. 2013;83:10-15.
5. Merz ML, Isaacson RJ, Germane N, Rubenstein KL. Tooth diameters and arch perimeters in black and white populations. Am J OrthodDentofacialOrthop 1991;100:53-8.
6. Huang SY, Kang T, Liu DY, Duan YZ, Shao JL. Variability in permanent tooth size of three ancient populations in Xi'an, northern China.Arch Oral Biol 2012;57:1467-73.
7. Hashim HA, Al-Ghamadi SAF. Tooth width and arch dimensions in normal and malocclusion samples. An odontometric study. J Contemp Dent Pract 2005;2:36-51.
8. Siepel CM. Variation of tooth position. SvenskTandlakareTidskrift 1946;39(Suppl): 88.
9. Lundström A. The aetiology of crowding of the teeth (based on studies of twins and on morphological investigations) and its bearing on orthodontic treatment (expansion or extraction). EurOrthodSoc Trans 1951;176-91.
10. Agenter MK, Harris EF, Blair RN. Influence of tooth crown size on malocclusion Am J OrthodDentofacialOrthop. 2009;136:795-804.
11. Bernabé E, Flores-Mir C. Are the lower incisors the best predictors of the unerupted canine and premolar sums? An analysis of a Peruvian sample. Angle Orthod 2005;75:202-7.
12. Loren FM. Arch width, arch length, and tooth size in young adult males. Angle Orthod 1964;34:124-129.
13. Agenter MK, Harris EF, Blair RN. Influence of tooth crown size on malocclusion. Am J OrthodDentofacOrthop 2009;136:795-804.
14. Dalidjan M, Sampson W, and Townsend G. Prediction of dental arch development: An assessment of Pont's Index in three human populations. Am J OrthodDentofacOrthop 1995; 107:465-75.
15. Lindsten R, O¨ gaard B, Larsson E, Bjerklin K. Transverse dental and dental arch depth dimensions in the mixed dentition in a skeletal sample from the 14th to the 19th century and norwegian children and norwegiansami children of today. Angle Orthod2002;72:439–448.
16. Lundström A. Intermaxillary tooth width ratio and tooth alignment and occlusion. ActaOdontol Scand. 1955;12:265–292.
17. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod. 1958;28:113–130.
18. Bolton WA. The clinical application of tooth-size analysis. Am J Orthod. 1962;48:504–529.
19. Peck S, Peck H. Orthodontic aspects of dental anthropology. Angle Orthod 1975;43:95-102.
20. Shah AA, Elcock C, Brook AH. Incisor crown shape and crowding. Am J OrthodDentofacialOrthop 2003;123:562-7.
21. Bernabé E, del Castillo CE, Flores-Mir C. Intra-arch occlusal indicators of crowding in the permanent dentition. Am J OrthodDentofacialOrthop 2005;128:220-5.
22. Peck S, Peck H. Crown dimensions and mandibular incisor alignment. Angle Orthod 1972;42:148-53.
23. Peck H, Peck S. An index for assessing tooth shape deviations as applied to the mandibular incisors. Am J Orthod 1972;61:384-401.
24. Norderval K, Wisth PJ, Boe OE. Mandibular anterior crowding in relation to tooth size and craniofacial morphology. Scand J Dent Res 1975;83:263-73.
25. 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;83:363-73.
26. Radnzic D. Dental crowding and its relationship to mesiodistal crown diameters and arch dimensions. Am J OrthodDentofacialOrthop 1988;94:50-6.
27. Fastlicht J. Crowding of mandibular incisors. Am J Orthod 1970;58:156-63.
28. Melo L, Ono Y, Takagi Y. Indicators of mandibular dental crowding in the mixed dentition. Pediatr Dent 2001;23:118-22.