# Morphometric analysis of dental arch form changes in class II patients treated with clear aligners



DOI:10.1007/s00056-020-00224-8



(Article begins on next page)

***Title***

MORPHOMETRIC ANALYSIS OF DENTAL ARCH FORMS VARIATION IN CLASS II PATIENTS TREATED WITH CLEAR ALIGNERS

**Short Title**

ARCH FORMS IN CLASS II PATIENTS WITH CLEAR ALIGNERS

***Authors***

Andrea Deregibus[1], Luca Tallone[2], Gabriele Rossini[3], Simone Parrini[4], Maria Grazia Pancino[5] , Tommaso Castroflorio[6]

1. MD, PhD, Department of Surgical Sciences, CIR Dental School, University of Turin, Turin, Italy
2. DDS, Orthod. Resident, Department of Surgical Sciences, CIR Dental School, University of Turin, Turin, Italy
3. DDS, PhD Student, Spec Orthod, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, University of Turin, Turin, Italy

4. DDS, Spec Orthod, Orthod. Resident, Department of Surgical Sciences, CIR Dental School, University of Turin, Turin, Italy
5. MD, DDS, PhD, Department of Surgical Sciences, CIR Dental School, University of Turin, Turin, Italy.
6. DDS, PhD, Spec Orthod, Department of Surgical Sciences, CIR Dental School, University of Turin, Turin, Italy

**ABSTRACT**

PURPOSE: to evaluate the arch form changes in Class II Caucasian patients treated with Invisalign© (Align Technology, San José, CA, USA).

METHODS: 27 Class II patients were enrolled for this study. Both maxillary and mandibular digital cast were compared at 3 different times: pre-treatment (T0), final step of first accepted set-up and retention phase (T2). Each digital model was imported in GOM Inspect© software (GOM GmbH, Braunschweig, Germany) to identify the Facial Axis (FA) and cusp points and to create a coordinate system. In each model the origin of coordinates was locate in the contact point of central incisors and a system of cartesian axes was identified. Using the FA points, an average arch form was obtained for each clinical step and then the following comparison were performed for each class group: T0-T1, T0-T2 and T1-T2.

RESULTS: T2 maxillary arch showed a more buccal positioning of most of considered teeth ($P<0,05$-$P>0,0001$) with respect to T0. In mandibular arch a buccal movement of molars and premolars was observed. Transverse dimensions increased from T0 to T2 for all measurements in the upper arch and the lower arch.

CONCLUSIONS: Class II patients treated with Invisalign© aligners results in significant increase in arch width at molars and premolars level on both arches, with a significant modification also on canines and lateral incisors in the upper arch. Transverse dimensions increased in the whole upper and lower arch for Class II and the arch shape was transferred from virtual set-up to clinical setting with high accuracy.

**INTRODUCTION**

In the last decades, clear aligners orthodontic underwent a considerable technological development. Technological innovations resulted in new materials, different aligner-tooth interaction thanks to customized, biomechanically optimized attachments and altered aligner geometries, and in treatment customization for both orthodontists and patients [16, 21, 22, 24, 34, 39]. A key aspect is the simulation of the treatment plan using 3D digital models, which allows to set the displacement of each tooth and to obtain arch forms that are independent from those dictated by orthodontic archwires adopted in conventional fixed orthodontics.

Dental position, and the resulting arch form, is the outcome of the interaction between perioral muscles and intraoral functional forces guided by the alveolar bone limits [8, 31].

Several studies on arch forms have been performed and presented in the existing literature [7, 17, 19, 37]. Initially, research teams focused on pursuing the ideal arch form, but no significant results were obtained due to the great individual variability. Therefore, various authors tried to classify arch forms in different types: squared, ovoid and tapered [13].

To improve the accuracy of arch form representation, several authors adopted different mathematical formulas: ellipse, parabola, catenary curve, beta functions, Bezier curves and quartic polynomial expressions [7, 9, 17, 19, 32, 37, 41]. In particular, the last one seems to be the one that best reflects the real arch form [1].

Considering the individuality of arch form, the identification of factors affecting the arch shape is a hot topic in orthodontic literature. Several studies reported a significant correlation between ethnicity and specific arch forms [5, 18, 23, 26]. A correlation between Angle class malocclusion and arch shape was not revealed; however, Angle class malocclusion seems to have effects on the arch width and length [4, 10].

Regarding Class II division 1 malocclusion, it is generally accepted that in these patients the maxillary dental arches are narrower than those with ideal occlusion [9, 30, 36, 42, 40]; however, the agreement on the mandibular arch form is more fleeting.

Braun et al described that Class II Division 1 lower arch form were narrower and shorter than Class I mandibular arch form [9]. Sayin and Turkkahraman assert that mandibular inter-canine width is greater in Class II Division 1 arches compared with Class I ideal occlusion arches, without significant differences in the widths of molars and premolars between the 2 groups [36]. In contrast, few studies argued that mandibular inter-canine widths were similar in Class I normal occlusion and Class II Division 1 malocclusion arches, whereas Staley et al stated that male subjects with Class I normal occlusion had greater inter-molar widths [2, 40]. Usyal et al reported that mandibular inter-canine widths of Class II Division 1 patients were significantly larger than patients with normal occlusion [42]. Other studies reported that arch shapes were not significantly different in the two groups [4, 30]; however, Nye et al asserted that mandibular arches of subjects with Class II Division 1 malocclusion were larger than those of Class I normal occlusion ones [30].

The heterogeneity of samples (age, sex, ethnicity) and the adoption of different methods to measure and analyse arch form might partially account for these contrasting results.

Many authors agreed that the preservation of the initial arch form is crucial to reduce the risk of relapse, with particular reference to the inter-molar and the inter-canine distances [2, 6, 15, 17, 27, 30, 38]. However, as highlighted by Lombardo et al, orthodontic archwire shapes available on the market does not cater for all the types of natural arch form observed in their sample population [29].

The customization of arch form is one of the key aspects to preserve long-term results, and to optimize aesthetics and function [7, 17].

Despite the widespread of aligner orthodontics there are no available data related to the final arch shape of patients treated with aligners. In aligner patients, the final arch shape is the result of the interaction between the orthodontist and the software technician in the development of the initial virtual set-up. Information regarding the buccal limit adopted by the technicians in defining the final arch shape are still missing. Furthermore, there are few data regarding the reliability of aligners in obtaining the prescribed final arch shape.

On the basis of these considerations, the aim of present study was to evaluate the arch form changes in Class II Caucasian patients treated with Invisalign® (Align Technology, San José, Ca, USA) and to evaluate the reliability of aligners in producing the arch shape prescribed with the virtual set-up.

## MATERIALS AND METHODS

Digital casts of 102 Caucasian adult patients were collected for this study but only 27 patients fulfilled the following inclusion criteria:

- Complete permanent dentition in both arches
- No alterations of number and shape of teeth
- Mesomorphic craniofacial typology (SpP^GoGn= 25°±6°)
- Crowding ≤ 6mm.

The sample consisted of 27 Class II (19 females, 8 males) patients. All the treatment plans were designed by the same operator (TC). The Class II patients were treated with upper molars distalization with the support of aligners, attachments and class II elastics [14, 33]. Arch shape prescription was not provided.

For this study, both maxillary and mandibular digital casts were compared at 3 different times: pre-treatment (T0), final stage of the first accepted virtual set-up (T1) and retention phase models (T2).

To evaluate the arch form, Facial Axis (FA) point of each tooth was identified on 3D models by using a freeware mechanical engineering software (GOM Inspect®, GOM GmbH, Braunschweig, Germany) [3]. As described by Lee et al, the X-axis and Y-axis of each model were set respectively as the transverse and anteroposterior direction on the occlusal view and the line perpendicular to these planes was marked as the Z-axis [26]. The contact point of the two central incisors was set as the origin of the coordinates. Moreover, the X-axis was adjusted to be parallel to the mean inclination of the line that connects the bilateral contact points of first and second premolars and second premolars and first molars. The Z coordinates were not considered in the dental position comparisons (Figure 1) [26].

The inter-canines, inter-premolars and inter-molars distances were collected and analysed. Comparisons between T0 and T2 measurements were performed, using canine cusp tip(3-3), first (4-4) and second premolar (5-5) buccal cusps and first molars mesial-buccal cusps (6-6) as landmarks (Figure 2) [41].

*Statistical analysis*

The two-way ANOVA test was used to compare the arch forms at different timepoints, while the Student' t-Test for paired samples was adopted to compare measurements collected on the occlusal view. Statistical significance was set at $p<0.05$. PRISM (GraphPad Software - San Diego, CA, USA) software was used to perform statistical analysis.

## RESULTS

According to the two-way ANOVA test, significant differences were found in maxillary and mandibular mean dental arches comparing pre-treatment (T0), final stage of the first accepted virtual set-up (T1) and retention phase models (T2).

In T0-T1 comparison, T1 showed a wider maxillary dental arch compared to T0. In particular significant buccal movements of tooth 16, tooth 15, tooth 14, tooth 13, tooth 12, tooth 22, tooth 23, tooth 24, tooth 25 and tooth 26 were detected. Moreover, a mesial movement of tooth 14, tooth 24 and tooth 25 was observed (Figure 1, 2 and Table 1, 2)

In T1 mandibular arch buccal movements of tooth 35, tooth 34, tooth 43, tooth 44, tooth 45 and tooth 46 and mesial movement of tooth 43 were observed.

Comparing T0 and T2, T2 maxillary arch showed a more buccal positioning of tooth 17, tooth 16, tooth 15, tooth 14, tooth 13, tooth 12 and tooth 24 with respect to T0. Furthermore, a significant mesial movement of tooth 14 was reported.

In T2 mandibular arch a buccal movement of tooth 37, tooth 36, tooth 35, tooth 34, tooth 44, tooth 45, tooth 46 and tooth 47 was observed (Figure 3, 4 and Table 3, 4).

In T1-T2 comparison, a more buccal position of tooth 22, tooth 23 and tooth 24 in the maxillary arch and a more lingual position of tooth 37, tooth 36 and tooth 47 were observed at T1 with respect to T2. No significant differences in mesial-distal dental positions were showed when T1 was compared to T2 (Figure 5, 6 and Table 5, 6)

Regarding transverse dimensions (Table 7), significant differences between T0 and T2 were observed for all measurements in the upper arch and the lower arch.

## DISCUSSION

According to the obtained outcomes, Invisalign Class II non-extraction treatment results in a significant increase in arch width at molars and premolars level on both arches, with a significant modification also on canines and lateral incisors final positions in the upper arch.

Regarding the modifications in arch width, inter-canine distance remains one of the most important assessed parameters with a strong influence on the orthodontic treatment, strictly related to long-term stability of treatment results [28]. The results of the present study reveal that Invisalign treatment planning was designed without significant changes of the lower inter-canine distance in Class II treatment. This aspect of Invisalign treatment planning could be clinically relevant regarding long term stability. As demonstrated by Burke et al in their meta-analysis, mandibular inter-canine distance tends to increase for about one to two millimetres in each malocclusion during conventional orthodontic treatment with expansion of the dental arch as well as with extraction of premolars [20]. However, during retention period this distance returns approximately to its original pre-treatment dimension. Long-term stability in Invisalign cases was analysed by Kuncio et al. in 2007 [25]. The authors observed a greater relapse in clear aligner treatment (CAT) with respect to fixed orthodontics treatment, but these differences were not significant. Therefore, on the basis of what mentioned above, dedicated trials are encouraged to verify the influence of intercanine width preservation on long term stability with CAT.

Regarding discrepancies between the planned final position and the real final position, significant differences were observed for lower molars and for tooth 22, tooth 23 and tooth 24 on the transversal dimension, while no significant differences were found for arch length. However, according to the recent literature, the discrepancy threshold for clinical significance on model measuring is 0.5 mm [11]; thus, the only clinically significant differences are the ones regarding lower molars, which were moved buccally more than planned, respectively of 0.81 mm for tooth 37, 0.53 mm for tooth 36 and 0.64 mm for tooth 47. In terms of accuracy, these results are consistent with what was stated by Rossini et al in their 2017 review regarding efficacy of arch expansion with clear orthodontic aligners [34].

Regarding arch width in upper arch, it could be noticed that, with respect to the planned movements, there is a noticeable difference between right and left side of the same arch, even if not statistically significant. In our opinion, this variation may be related to two factors: occlusal features and material's elasticity. As stated by Cattaneo et al in 2009, occlusal forces can affect the expression of orthodontic ones [12]. Thus, transverse positioning of posterior teeth may be influenced by occlusal bite force. On the basis of these assumptions, it could be stated that if the aligners do not express enough force to overcome the resistance of the system, teeth may not achieve the planned positioning even without any fitting problem between aligner and teeth. Djeu et al reported that occlusal features may influence the final resulting score of treatment with aligners; in particular, the amount of overjet is one of the most influencing aspects [16]. The influence of overjet on tooth movement with aligners may be related to the increasing of intra-arch undesired tensions, because the incisors area represents the maximum resistance point of the aligner and the buccal inclination of these teeth could lead to an increase in aligner stiffness.

Thus, according to the available literature, occlusal features may have an impact on the elasticity of aligners, which increases from the anterior towards the posterior teeth. Thus, an excessive flexibility could lead to less force exerted on teeth and to a significant loss in accuracy of movements.

Therefore on the basis of our results we can conclude that even if not prescribed by the orthodontist, the arch shape of Class II Division I patients treated with Invisalign aligners accordingly to previous published treatment protocols (14,33) undergoes to a significant modification, with an increase of the inter-premolar and inter-molar width on both upper and lower arches, with lower inter-canine width preservation. Furthermore the arch shape was transferred from the virtual set-up to the clinical setting with high accuracy.

*Limitations of the study*

This study presented several limitations; in particular, small sample size, the absence of standardization of treatment duration and lack of patient compliance monitoring could be identified as the main concerns. Future studies with wider sample sizes and more standardization are encouraged to improve level of evidence regarding arch shape obtained with clear aligners.

**CONCLUSIONS**

- Invisalign Class II treatment results in a significant increase in arch width at molars and premolars level on both arches, with a significant modification also on canines and lateral incisors in the upper arch.
- Considering the lower arch as the guide for the final arch shape of the upper one, the mandibular inter-canine distance did not undergo any significant change. Therefore,

this orthodontic approach might produce functional and stable outcomes accordingly to the existing literature.

- The arch shape was transferred from the virtual set-up to the clinical setting with high accuracy.
- 

**REFERENCES**


1. Al Harbi S, Alkofide EA, AlMadi A (2008) Mathematical analyses of dental arch curvature in normal occlusion. Angle Orthod 78(2):281-287.
2. Al Khateeb SN, Abu Alhaija ES (2006) Tooth size discrepancies and arch parameters among different malocclusions in a Jordanian sample. Angle Orthod 76(3):459-465.
3. Andrews LF (1975) The straight-wire appliance: syllabus of philosophy and techniques. LF Andrews.
4. Ball RL, Miner RM, Will LA, Arai K (2010) Comparison of dental and apical base arch forms in Class II Division 1 and Class I malocclusions. Am J Orthod Dentofacial Orthop 138(1):41-50.
5. Bayome M, Sameshima GT, Kim Y, Nojima K, Baek SH, Kook YA (2011) Comparison of arch forms between Egyptian and North American white populations. Am J Orthod Dentofacial Orthop 139(3): e245-e252.
6. Bishara SE, Chadra JM, Potter RE (1973) Stability of intercanine width, overbite and overjet correction. Am J Orthod 63(6):588–95.
7. Brader AC (1972) Dental arch form related with intraoral forces: PR=C. Am J Orthod 61(6):541-61.
8. Brash JC (1956) The etiology of irregularity and malocclusion of the teeth, 2[d] ed London: Dental Board of the United Kingdom.
9. Braun S, Hnat WP, Frender D, Legan HL (1998) The form of the human dental arch The Angle Orthod 68:29-36.
10. Burke SP, Silveira, AM, Goldsmith LJ, Yancey JM, Van Stewart A, Scarfe WC (1998). A meta-analysis of mandibular intercanine width in treatment and postretention. Angle Orthod, 68(1):53-60.
11. Casko JS, Vaden JL, Kokich VG, Damone J, James RD, Cangialosi TJ, et al (1998). Objective grading system for dental casts and panoramic radiographs. Am J Orthod Dentofacial Orthop 114(5):589-599.

12. Cattaneo PM, Dalstra M, Melsen B (2009) Strains in periodontal ligament and alveolar bone associated with orthodontic tooth movement analyzed by finite element. Orthodontics & craniofacial research 12(2):120-128.

13. Chuck G C (1934) Ideal arch Form Angle Orthod 4:312-327.

14. Comba B, Parrini S, Rossini G, Castroflorio T, Deregibus A (2017) A Three-Dimensional Finite Element Analysis of Upper-Canine Distalization with Clear Aligners, Composite Attachments, and Class II Elastics. Journal of clinical orthodontics: JCO 51(1):24.

15. De la Cruz A, Sampson P, Little RM, Artun J, Shapiro PA (1995) Long-term change in arch form after orthodontic treatment and retention. Am J Orthod Dentofacial Orthop 107(5):518–30.

16. Djeu G, Shelton C, Maganzini A (2005) Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. Am J Orthod Orthop 128(3): 292-298.

17. Felton JM, Sinclair PM, Jones DL, Alexander RG (1987) A computerized analysis of the shape and stability of mandibular arch form. Am J Orthod Dentofacial Orthop *92*(6):478-483.

18. Gafni Y, Tzur-Gadassi L, Nojima, K, McLaughlin RP, Abed Y, Redlich M (2011) Comparison of arch forms between Israeli and North American white populations. Am J Orthod Dentofacial Orthop 139(3):339-344.

19. Hawley CA (1905) Determination of the normal arch and its implication to Orthodontia Dent Cosmos 47(2):541-52.

20. Heiser W, Richter M, Niederwanger A, Neunteufel N, Kulmer S (2008) Association of the canine guidance angle with maxillary and mandibular intercanine widths and anterior alignment relapse: extraction vs nonextraction treatment. Am J Orthod Dentofacial Orthop 133(5):669-680.

21. Hennessy J, Garvey T, Al-Awadhi EA (2016) A randomized clinical trial comparing mandibular incisor proclination produced by fixed labial appliances and clear aligners. Angle Orthod 86(5):706-712.

22. Kassas W, Al-Jewair T, Preston BC, Tabbaa S (2013) Assessment of Invisalign treatment outcomes using the ABO Model Grading System. J World Fed Orthod 2(2):e61-e64.

23. Kook YA, Nojima K, Moon HB, McLaughlin RP, Sinclair PM (2004) Comparison of arch forms between Korean and North American white populations. Am J Orthod Dentofacial Orthop 126(6):680-686.

24. Kravitz ND, Kusnoto B, Agran B, Viana G (2008) Influence of attachments and interproximal reduction on the accuracy of canine rotation with Invisalign: a prospective clinical study. Angle Orthod 78(4):682-687.

25. Kuncio D, Maganzini A, Shelton C, Freeman K (2007) Invisalign and traditional orthodontic treatment postretention outcomes compared using the American Board of Orthodontics objective grading system. Angle Orthod 77(5):864-9.

26.

27. Lee KJ, Trang VTT, Bayome M, Park JH, Kim Y, Kook YA (2013) Comparison of mandibular arch forms of Korean and Vietnamese patients by using facial axis points on three-dimensional models. Korean J Orthod 43(6):288-293.

28. Little RM (1990) Stability and relapse of dental arch alignment. Br J Orthod 17(3):235–41.

29. Little RM (2002) Stability and relapse: early treatment of arch length deficiency. Am J Orthod Dentofacial Orthop 121: 578–581.

30. Lombardo L, Fattori L, Molinari C, Mirabella D, Siciliani G (2013) Dental and alveolar arch forms in a Caucasian population compared with commercially available archwires. International orthodontics 11(4):389-421.

31. Nie Q, Lin J (2006) A comparison of dental arch forms between Class II Division 1 and normal occlusion assessed by Euclidean distance matrix analysis. Am J Orthod Dentofacial Orthop 129:528-35.

32. Nojima K, McLaughlin RP, Isshiki Y, Sinclair PM (2001) A comparative study of Caucasian and Japanese mandibular clinical arch Forms. Angle Orthod 71:195–200.

33. Noroozi H, Hosseinzadeh NT, Saeeda R (2001) The dental arch form revisited Angle Orthod 71(5):386-389.

34. Ravera S, Castroflorio T, Garino F, Daher S, Cugliari G, Deregibus A (2016) Maxillary molar distalization with aligners in adult patients: a multicenter retrospective study. Progress in orthodontics 17(1):12.

35. Rossini G, Parrini S, Castroflorio T, Deregibus, A, Debernardi CL (2014). Efficacy of clear aligners in controlling orthodontic tooth movement: a systematic review. *Angle Orthod 85*(5):881-889.

36. Rossini G, Parrini S, Deregibus A, Castroflorio T (2017). Controlling orthodontic tooth movement with clear aligners. Journal of Aligner Orthodontics 1(1):7-20.

37. Sayin MO, Turkkahraman H (2004) Comparison of dental arch and alveolar widths of patients with Class II, Division 1 malocclusion and subjects with Class I ideal occlusion. Angle Orthod 74:356-60.

38. Scott JH (1957) The shape of the dental arches J Dent Res 36(6):996-1003.

39. Shapiro PA (1974) Mandibular dental arch form and dimension. Treatment and postretention changes. Am J Orthod 66(1):58-70.

40. Simon M, Keiling L, Schwarze J, Jung BA, Bourauel C (2014) Treatment outcome and efficacy of an aligner technique–regarding incisor torque, premolar derotation and molar distalization. BMC Oral Health 14:68.

41. Staley RN, Stuntz WR, Peterson LC 1985) A comparison of arch widths in adults with normal occlusion and adults with Class II, Division 1 malocclusion. Am J Orthod 88:163-9.

42. Taner T, Ciger S, EI H, Germec D, Es A (2004) Evaluation of dental arch width and form after orthodontic treatment and retention with a new computerized method Am J Orthod Dentofacial Orthop 126:464-475.

43. Uysal T, Memili B, Usumez S, Sari Z (2005) Dental and alveolar arch widths in normal occlusion, Class II Division 1 and Class II Division 2. Angle Orthod 75:941-7.

44.