DENTAL ARCH EFFECTS AFTER EARLY AND LATER TIMED CERVICAL HEADGEAR TREATMENT – A RANDOMIZED CONTROLLED TRIAL

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Short title: OCCLUSION, GROWTH, TIMING AND CERVICAL HEADGEAR

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SUMMARY

Background: Cervical headgear (CH) is a commonly used orthodontic appliance and its dentoalveolar changes are known. However, the effects related to gender and timing have gained less attention.

Objectives: To examine dimensions of dental arches among children with Class II occlusion without posterior mandibular rotation according to timing of Kloehn-type CH treatment.

Trial design: Prospective, randomized, parallel-group controlled trial.

Methods: Sixty-seven seven-year-old children with a Class II occlusion were included in the study. The children were randomized into two equal-size groups in 1:1 ratio by sealed-envelope randomization. The early group (EG, n = 33) was treated between T_0 and T_1 (26 months), right after eruption of the first maxillary molars. The late group (LG, n = 34) was treated between T_1 and T_2 (24 months). The children were treated with CH until normal Class I occlusion on first molars was achieved. Impressions for dental casts were taken from all participants at T_0, T_1 and T_2. Blinding was applicable for outcome assessors. Changes in dental cast measurements were compared between the groups and genders using *t*-test, Mann-Whitney *U*-test, and repeated measures analysis of variance.

Results: Of the children, 56 completed the study. The maxillary arch length and the transversal changes between the upper canines and upper first molars were significantly increased in EG at T_0-T_1 ($P < 0.001$). At T_2, the transversal dimension between the upper first molars was larger ($P < 0.05$), and in the lower arch the mandibular arch length ($P < 0.05$) and the transversal dimension between the lower first molars ($P < 0.01$) were increased in EG males compared to LG males. No harms were encountered.

Conclusions: The male gender benefits most from early timing of the CH treatment, showing larger dimensions at the end of the follow-up. The results clearly indicated a wider and longer upper dental arch and spontaneous expansion of the lower dental arch after treatment.

Clinical Registration: NCT02010346.

Keywords: Dental occlusion, growth, timing, cervical headgear

INTRODUCTION

A Kloehn-type cervical headgear (CH) is commonly used in orthodontic treatment among children with a Class II occlusion and moderate crowding. Several studies have reported its dentoalveolar effects. Since CH's force to maxilla is transmitted through the first molars, distal movement of the first molars has been displayed (1, 2). Consequently, anterior parts of the upper dental arch are also affected, as distal movement of canines and a more vertical pattern on canine eruption have been demonstrated (2, 3). Lengthening of the maxillary dental arch has also been reported (4, 5). Both anterior and posterior parts of the upper dental arch are found to be lengthened as a result of CH treatment (6).

There have been several reports concerning widening of maxillary dental arches after CH treatment. Especially the use of an expanding CH seems to increase both intercanine (4, 6) and intermolar distances (5, 7). However, less increase in the intermolar distance has been reported after non-expanding CH treatment while the intercanine distance increases significantly (8).

The lengthening and widening of the maxillary dental arch as a consequence of CH treatment can cause spontaneous space correction in the mandibular dental arch. This phenomenon is followed by widening of the mandibular arch (4-7, 9). A similar spontaneous effect on the mandibular arch has also been reported after Haas-type maxillary expansion (10, 11). Lengthening of the mandibular dental arch after CH treatment has also been shown (4, 5).

Proper timing of orthodontic treatment is a topic of continuous discussion in orthodontic literature (12). In the treatment of Class II malocclusion, CH seems to be effective when used in both early and late mixed dentition. The general conclusion, however, is that it is more efficient to treat Class II malocclusion later in late mixed dentition (13-15). What these previous studies have in common is that they view early versus late treatment as 1-phase versus 2-phase treatment, rather than focusing on the timing of treatment at different ages.

In the studies of Class II malocclusion, patients' gender, age and treatment timing have usually been reported but mostly not adjusted for in the analyses. Our previous cephalometric study with the same participants has shown that both timing of treatment and gender have an influence on skeletal outcomes as a result of CH treatment (16). Therefore, it was in our interest to study the dentoalveolar effects of early and later timed CH treatment in both genders.

Objective

The aim of the present study was to examine the dimensions of dental arches among children with Class II occlusion without posterior mandibular rotation according to timing of the Kloehn-type CH treatment. The hypothesis was that timing of the CH treatment is associated with treatment outcomes on dental arch dimensions. Another hypothesis was that gender is also associated with treatment results when the timing of treatment is taken into account.

SUBJECTS AND METHODS

Study design, ethical consideration, and registration

The study was designed according to the CONSORT guidelines as a controlled, prospective, parallel-group, randomized (1:1 ratio) trial. The Ethics Committee of Oulu University Hospital, Finland (EETTMK: 46/2003) and the health service authorities in the municipalities involved in the study approved the study protocol. The trial is registered at ClinicalTrials.gov, number NCT02010346.

Sample size calculation

The sample size was calculated using GPower 3.1 software, 80% power and 0.05 significance level, and it was based on previous research with a similar study protocol (4). According to the sample size calculation, sufficient power would be obtained by having at least 11 subjects in each group.

Screening and randomization of the participants

The study sample was selected from birth cohorts in three municipalities in northern Finland. Healthy seven-year-old schoolchildren were screened for the study by clinicians in municipal health centres. The screening was based on clinical examination. The children were eligible for the study if they had a Class II occlusion based on the occlusal relationship of the first permanent molars, and overjet more than 6 mm and a deep bite. Lateral cephalograms were taken of the children fulfilling the clinical criteria. The children with the angle between the palatal line and the mandibular line (PL-ML angle) over 35 degrees, previous orthodontic treatment, inborn facial syndrome or severe facial asymmetry, suspected sleep-disordered breathing and chronic or recurrent upper airway infections were excluded.

Sixty-seven children (28 females, 39 males, mean age 7.2 years, standard deviation [SD] 0.55) were eligible for the study. All agreed to participate in the research and signed an informed consent with their parents. The children were randomly divided into two groups. A more detailed description of the randomization is available in the previous article on this sample (16).

Interventions

The early group (EG, *n* = 33; 13 female and 20 male) was treated between T_0 and T_1 (26 months). CH therapy was started right after eruption of the first maxillary molars (mean age 7.8 years, SD 0.53). The children were treated with CH until normal Class I occlusion on first molars was achieved. The mean active treatment time for EG was 1.6 years (SD 0.76). When necessary, reduced use of CH was applied following active treatment.

The late group (LG, *n* = 34; 15 female and 19 male) was treated between T_1 and T_2 (24 months), and no active treatment was performed during T_0-T_1. In the LG, the active CH therapy started about one and a half years later (mean age 9.5 years, SD 0.59). The treatment protocol was the same as among EG. The mean active treatment time for LG was 1.4 years (SD 0.80).

For CH therapy, first maxillary molars were banded with gingival tubes. A Kloehn-type CH with a long outer bow was used. The inner bow was held 5 mm wider than the distance between the CH tubes and the long outer bows were bent 10-degree upwards. To provide orthodontic force to the maxilla and upper dental arch, a force of 500 g was used. The participants were instructed to wear the CH for 8 – 10 hours during the night.

Blinding

Blinding was not possible either for the participants, their parents or orthodontic treatment providers. Beforehand, the participants were coded (JJ) so that the data collectors, outcome adjudicators (MH) and data analysts could not identify the participants and the groups when the documents and the material were evaluated.

Outcomes

Alginate impressions and wax bite indexes recording the intercuspal position for plaster casts were taken from all the subjects during the follow-up. The impressions were taken from all the participants at T_0 (mean age 7.3 years, SD 0.56), at T_1 (mean age 9.5 years, SD 0.50) and at T_2 (mean age 11.5 years, SD 0.62).

All the plaster casts were checked. The bases and the backs of the maxillary and mandibular casts were paralleled to occlusal plane and centric occlusion by one of the authors (JJ). The plaster casts were scanned into 3D-models (3Shape, R700 Scanner, Denmark) and the 3D-models were measured with an analysis program (3Shape, Ortho Analyzer 2012, Denmark). The validation of the method, accuracy and reliability has been published earlier (17). The scanning and measuring of the landmarks were done by one of the authors (MH).

Definitions of the maxillary and mandibular dental arch landmarks, linear and angular measurements are presented in Figures 1 and 2. Twenty randomly chosen plaster casts were traced and measured on two separate occasions at 2-week intervals in order to calculate the error of the method.

Participant flow

The number of participants at different phases of the study and the timeline of the study are presented in Figure 3. A total of 270 subjects were screened for eligibility. Of these, 203 were excluded from the study. Sixty-seven children were randomized in a 1:1 ratio to either EG or LG. The primary analysis (T_0) was intended for all randomly assigned patients. Sixty-two children participated in the second analysis (T_1) and fifty-six children in the third analysis (T_2). Dental casts ineligible for measurements (i.e. distorted or missing) were excluded from the analysis. In the EG, the number of casts at time points T_0, T_1, and T_2 was 13, 12 and 10 for female and 20, 16 and 13 for male participants, respectively. In the LG, the numbers were 15, 11 and 11 for female and 19, 19 and 16 for male participants, respectively. A more detailed description of the participant flow is available in the previous article of this study (16).

Patient recruitment commenced in March 2004 and ended in March 2008. The follow-up study of the patients is still ongoing. No changes occurred in the methods after commencement of the trial.

Baseline data

The background information of the patients including gender and age distributions in the early and late groups is presented in our previous study (16). The baseline values for both groups at the beginning of the trial are shown in Tables 1 to 3. These tables show the comparability of the two groups based on age, gender distribution and baseline values.

Statistical methods

The reliability for the measurements was tested by intraclass correlation coefficients (ICCs) to compare the repeated measurements in dental cast analyses.

For linear measurements in maxillary and mandibular arches and angular measurements, mean values with 95% confidence intervals, and change scores for time periods T_0-T_1 and T_0-T_2 were calculated separately for EG and LG groups and genders. For the mean values of each time point, all participants at that time point were included, but in mean change scores, only those for whom we have both time points in question were included. For single measures, statistical significances of the differences in mean values and change scores between the groups were evaluated with the independent samples *t*-test. If the distributions were asymmetrical, the Mann-Whitney *U*-test was used. For combined measures, statistical comparison was performed using repeated measures analysis of variance. Analyses were conducted using SAS and IBM SPSS Statistics 20.

RESULTS

Outcomes

Error of the method

The ICC value for linear measurements varied from 0.990 to 0.999 in the maxillary arch and from 0.971 to 0.999 in the mandibular arch. For angular measurements, the value varied from 0.907 to 0.990 in the maxillary arch and from 0.890 to 0.984 in the mandibular arch. The ICC value indicated an excellent level of intra-investigator reliability. The mean difference between repeated measurements for linear measurements was 0.1 mm (SD 0.18) and for angular measurements 1.1 degrees (SD 1.23).

Maxillary dental arch measurements

The linear measurements of the upper dental arch are shown in Table 1. In the upper arch, the lateral segments (U1 + U4) were longer in the EG (27.6 mm) compared to the LG (26.4 mm) at the time point T_1 ($P < 0.01$). When genders were examined separately, a significant difference was seen between the EG females (27.3 mm) compared to the LG females (25.7 mm) ($P < 0.01$) at T_1 and in the EG males (27.9 mm) compared to the LG males (26.8 mm) ($P < 0.05$) at T_1.

The change at T_0-T_1 in the upper anterior segments (U2 + U3) was larger for the EG (2.6 mm) compared to the LG (1.1 mm) ($P < 0.001$). A significant change was seen in both genders; the EG females compared to the LG females (2.7 mm versus 1.0 mm, $P < 0.01$), and in the EG males compared to the LG males (2.6 mm versus 1.2 mm, $P < 0.05$) at T_0-T_1. The maxillary arch length (U5 + U6) change at T_0-T_1 was larger for the EG (2.9 mm) compared to the LG (0.8 mm) ($P < 0.001$). Corresponding changes at T_0-T_1 were seen in both genders (EG females 2.9 mm versus LG females 0.6 mm, $P < 0.01$; and EG males 2.9 mm versus LG males 0.9 mm, $P < 0.01$).

The transversal change between the upper canines (U7) at T_0-T_1 was increased for the EG (3.4 mm) compared to the LG (0.7 mm) ($P < 0.001$). A corresponding change was found in both genders (EG females 3.3 mm versus LG females -0.1 mm, $P < 0.001$; and EG males 3.6 mm versus LG males 1.2 mm, $P < 0.01$). The transversal change between the upper first molars (U8) was 1.6 mm in the EG and 0.7 mm in the LG ($P < 0.001$) at T_0-T_1. A significant change in U8 was found only in females (EG females 2.4 mm versus LG females 0.4 mm, $P < 0.01$) at T_0-T_1. Furthermore, transversal change between the palatal surfaces of the upper first molars (U9) at T_0-T_1 was larger in the EG (2.1 mm) than in the LG (0.2 mm) ($P < 0.001$). This change was found in both genders (EG females 2.5 mm versus LG females 0.0 mm, $P < 0.01$; and EG males 1.9 mm versus LG males 0.4 mm, $P < 0.01$).

At T_2, the transversal dimension between the upper first molars (U8) was longer in the EG males (54.4 mm) compared to the LG males (52.3 mm) ($P < 0.05$). The transversal dimension measured on the palatal surface of the upper first molars (U9) at T_2 was increased in the EG males (35.1 mm) compared to the LG males (33.3 mm) ($P < 0.05$).

Mandibular dental arch measurements

The linear measurements of the lower dental arch are shown in Table 2. The change at T_0-T_1 in the transversal dimension between the lower first molars (L8) was increased in the EG (1.0 mm) compared to the LG (0.1 mm) ($P < 0.01$). The change in L8 was significant only in males (EG males 0.9 mm versus LG males 0.0 mm, $P < 0.05$). The transversal dimension change measured between the lingual surfaces of the first lower molars (L9) was also increased at T_0-T_1 in the EG (0.9 mm) compared to the LG (0.0 mm) ($P < 0.001$). Only male gender displayed significant change in L9 at T_0-T_1 (EG males 0.9 mm versus LG males -0.1 mm, $P < 0.001$).

At time point T_2, the lateral segments of the lower arch (L1 + L4) were longer in the EG (27.8 mm) than in the LG (25.9 mm) ($P < 0.01$). When gender was taken into account, only male gender displayed an increase in the lower segments (L1 + L4) at T_2 (EG males 28.1 mm versus LG males 26.0 mm, $P < 0.01$). The mandibular arch length (L5 + L6) was longer in the EG (39.0 mm) compared to the LG (37.7 mm) when the genders were combined at T_2 ($P < 0.05$). A significant increase was found in the EG males (39.6 mm) compared to the LG males (38.1 mm) ($P < 0.05$) at T_2.

The transversal dimension between the lower first molars (L8) was longer in the EG (48.5 mm) compared to the LG (46.5 mm) at T_2 ($P < 0.01$). Only male gender displayed an increase in transversal measure L8 at T_2 (EG males 49.6 mm versus LG males 46.8 mm, $P < 0.01$). The change at T_0-T_2 for the EG males was 1.7 mm and for the LG males 0.4 mm ($P < 0.05$). The transversal dimension measured on lingual surface of lower first molars (L9) was increased in the EG (33.1 mm) compared to the LG (31.5 mm) when the genders were combined at T_2 ($P < 0.05$). A significant increase in L9 at T_2 was found in males (EG males 33.9 mm versus LG males 31.8 mm, $P < 0.05$).

Angular measurements in maxillary and mandibular dental arches

The angular measurements of both the upper and lower dental arch are shown in Table 3. The change in the upper arch measurement UA1 + UA2 was increased in the EG (4.9 degrees) compared to the LG (-0.7 degrees) at T_0-T_1 ($P < 0.001$), indicating mesiobuccal rotation of the upper first molar or distal movement of the upper canine in the EG subjects. The change was significant in both genders ($P < 0.01$). The change for the measurement UA3 + UA4 at T_0-T_1 decreased significantly in the EG (-4.5 degrees) compared to the LG (-1.2 degrees) ($P < 0.05$), indicating a mesiobuccal rotation of the upper molar in EG subjects or distal movement of the molar. The same change was seen in both genders, being significant only in females ($P < 0.01$). The change for UA5 + UA6 at T_0-T_1 was significantly increased in the EG (2.5 degrees) compared to the LG (-1.1 degrees) ($P < 0.01$), indicating a mesiobuccal rotation of the upper first molar. The same change was seen in both genders, being significant only in females ($P < 0.05$).

In the lower arch, the change for the angular measurement LA3 + LA4 at T_0-T_1 was significantly more reduced in EG (-4.5 degrees) than in LG (-1.9 degrees) ($P < 0.05$), indicating mesiobuccal rotation of the lower first molars. The change was significant only in males ($P < 0.05$). At T_2, there were no significant differences in angular measurements between EG and LG.

Harms

There were no harms during the follow-up of the two groups between time points T_0 and T_2.

DISCUSSION

Interpretation

The results of the present study prove the effectiveness of CH treatment, which is seen in both upper and lower dental arch dimensions, confirming the previous findings (4-7, 9, 18). The measurements showed lengthening in both anterior and posterior parts of the maxillary arch, as well as widening in intercanine and intermolar regions of the upper dental arch after early CH treatment in both genders. After treatment of both groups, a tendency for larger and wider maxillary arches in EG subjects was found. However, the differences were significant between EG and LG subjects only in the male gender for transversal width of the upper first molars, which was increased.

Narrow maxillary arch is a typical feature of untreated Class II malocclusions. This feature is seen already in the deciduous dentition and is transmitted to the mixed dentition (6, 19, 20). Several studies of rapid maxillary expansion (RME) have demonstrated that maxillary expansion before the peak of skeletal growth velocity and sutural ossification is effective and stable (21, 22). Our study showed the effectiveness of CH with expanded inner bow in both groups. The stability of expansion after expanding CH treatment has been shown in follow-up studies, and a long-term study evaluating intermolar expansion after Haas-type RME or after CH with expanded inner bow showed equally good stability (5, 18).

As narrow maxilla has been linked to the development of Class II malocclusion, there have been speculations as to the effect of occlusion on the forward growth of the mandible and dentoalveolar complex. Previous studies have emphasized the effect of maxillary arch expansion allowing the forward growth of mandible or unlocking the occlusion, allowing the spontaneous correction of Class II malocclusion (23-25).

The present results confirm the previous reports of the spontaneous expansion of the lower dental arch at the end of CH treatment in both groups (5-7, 9, 18). However, we found that after treatment of both groups, the early timed CH treatment proved to be more effective for the lower arch, especially in the male gender, as compared to the later timed treatment. This was seen in both lengthening of the dental arch and in widening of the intermolar region. Thus, the CH treatment presumably has potential value in releasing lower jaw crowding and possibly avoiding mandibular extractions in borderline cases, especially in EG males. It has been previously stated that early dental arch expansion with CH diminishes the need for extractions (5).

Mesiopalatal rotation of upper first molars has been reported in patients with Class II malocclusion and correction of molar rotation has been shown to improve molar relationship and increase arch space (26). The effectiveness of timing in male subjects was found in angular measurements as well. Even though the first maxillary molars rotated mesiobuccally in both groups, only male gender displayed significant spontaneous mesiobuccal rotation of the first mandibular molars. Although mesiobuccal rotation of the first maxillary molar is clinically acknowledged after CH treatment, only few studies have reported the findings of molar rotations. This is probably a consequence of the poor reliability of methods measuring rotation (1, 27). The mesiobuccal rotation of the maxillary first molar has been stated previously, but only one study mentioned rotation of the first mandibular molar, and the rotation was opposite to the present finding during active treatment (18, 28). Nonetheless, long-term follow-up revealed stability on molar rotations in their study (18). It is noteworthy that in the present study the molar rotations resulted in relapse with no significant rotation at the end of follow-up.

After treatment of EG group at T_1, our study showed that early CH treatment has more influence on the maxillary arch in females than in males. On other hand, in lower arch the male gender was more prone to the early effects of CH treatment. At T_2, the values of both groups showed that EG males benefit most from early timing of CH treatment, especially in transverse dimensions. The effect of treatment was evident both in the upper and lower dental arch. In females, the same tendency was seen but the effect was not as clear as in males.

It has been stated that the maxillary complex is most responsive to orthopaedic treatment before the skeletal maturation of the midpalatal suture. The transverse growth of the palatal suture ceases earlier in females than in males, which may explain the efficiency of CH in the transverse dimension on EG males (29). A change in both earlier pubertal maturation and increased body height has been seen over the past decades. A population study for new Finnish growth references revealed a secular change in linear growth with typical age- and sex-related features. The increase in height was more evident in males. Growth references also showed a connection between increase in height and earlier timing of pubertal growth spurt (30). Our findings may be partly explained by differences in pubertal status while undergoing orthodontic treatment (31). It has also been shown that tooth eruption in females is more advanced compared to males (32). We assume that males are more responsive to orthodontic forces due to later onset of puberty while some of the females have already reached early stages of puberty during the treatment.

The effects of treatment timing according to chronological age and gender, on the other hand, have not been evaluated before. Our previous study already showed that early treated male subjects were more prone to skeletal changes than females or later treated males (16). We assume that immature bony structures in males are more mouldable before puberty, whereas in females, more mature structures respond less to the forces created by CH, especially in the lower dental arch.

The current results clearly show that orthodontic and orthopaedic modification as a result of CH therapy is most efficient on dental arches in EG males, probably due to differences in skeletal maturation. Secular trends have changed the timing of growth over the years, and in the future, we need to evaluate the timing of treatment as well as take gender more into account when planning orthodontic treatments. Our findings confirm the importance of identifying the children who might benefit from timing of treatment.

Limitations

The subjects used the CH for the requested time. Monitoring of the exact wearing time of CH was not possible in this study. Thus, the outcome was based on measured results. There was some overlapping of the CH treatment between the groups at time point T_1 because the major priority of the CH therapy was to achieve and maintain a good treatment result. It is important to notice that CH is not a suitable treatment option for all children. Children with suspected sleep-disordered breathing were excluded since CH treatment may worsen snoring and apnoea symptoms (33). Metal allergy, on the other hand, was not regarded as a contraindication. However, CH treatment should be carried out with special care in children with known nickel allergy due to possible adverse reactions (34). There were no reports of hypersensitivity in our study.

Generalization

The current trend in the field of orthodontics has been towards an increasing extent of modern orthodontic techniques. However, CH still advocates its role as having a competitive cost-benefit ratio compared to many other treatment options. The results of the present study confirm CH's strength as an effective orthodontic tool in the developing dentition with mild or moderate crowding and Class II occlusion.

CONCLUSION

The present study proved CH treatment with expanded facebow to be effective in widening and lengthening the maxillary dental arch. Spontaneous expansion of the lower dental arch was found after expansion of the upper dental arch. Especially early timed CH treatment proved to be effective in the male gender.

PROTOCOL

The protocol was not published prior to trial commencement.

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CONFLICT OF INTEREST

None declared.

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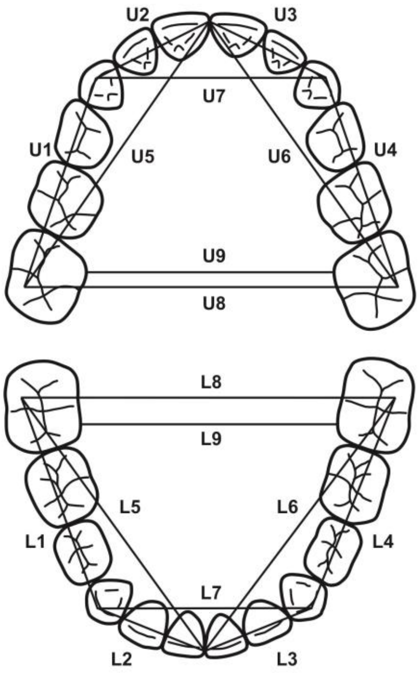

Figure 1. Dental arch landmarks in linear measurements

Maxillary arch – **U1, U4**: the distance between the distobuccal cusp of the first permanent molar and the crown tip of the canine in the same quadrant. **U2, U3**: the distance between the crown tip of the canine and the most mesial point of the central incisor in the same quadrant. **U5, U6**: the distance between the distobuccal cusp of the first permanent molar and the most mesial point of the central incisor in the same quadrant. **U7**: the distance between the canine tips. **U8**: the distance between the distobuccal cusps of the first permanent molars. **U9**: the shortest distance between the palatal surfaces of the first permanent molars.

Mandibular arch – **L1, L4**: the distance between the distobuccal cusp of the first permanent molar and the crown tip of the canine in the same quadrant. **L2, L3**: the distance between the crown tip of the canine and the most mesial point of the central incisor in the same quadrant. **L5, L6**: the distance between the distobuccal cusp of the first permanent molar and the most mesial point of the central incisor in the same quadrant. **L7**: the distance between the canine tips. **L8**: the distance between the distobuccal cusps of the first permanent molars. **L9**: the shortest distance between the lingual surfaces of the first permanent molars.

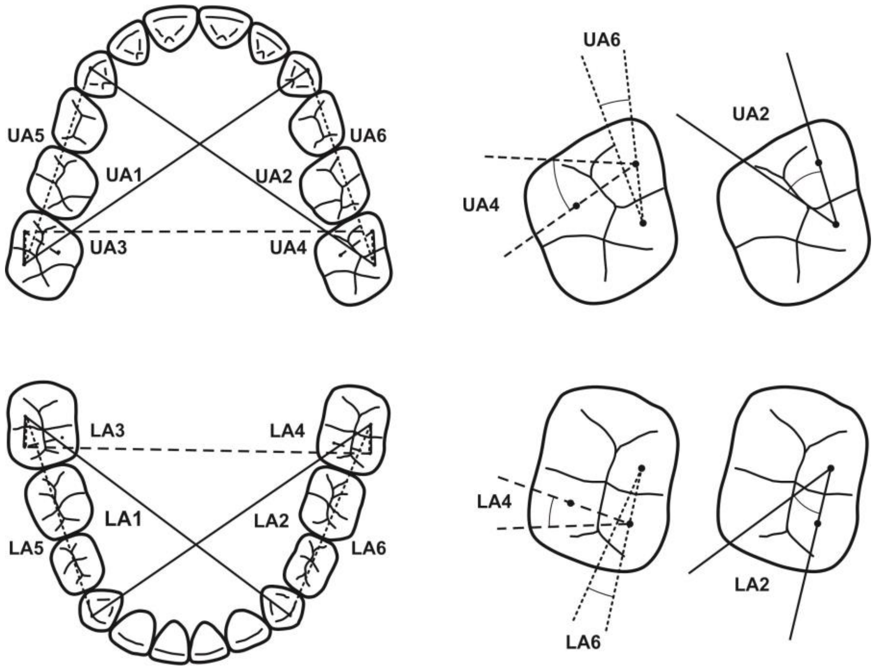

Figure 2. Dental arch landmarks in angular measurements

Maxillary arch – **UA1, UA2**: the angle between the lines drawn from the tips of the mesiobuccal cusp to the distobuccal cusp of the first molar and from the tip of the distobuccal cusp of the first molar to the canine in the opposite quadrant. **UA3, UA4**: the angle between the lines drawn from the tips of the mesiopalatal cusp to the mesiobuccal cusp of the first molar and from the tip of the mesiobuccal cusp of the first molar to the tip of the mesiobuccal cusp of the first molar on the opposite quadrant. **UA5, UA6**: the angle between the lines drawn from the tips of the mesiobuccal cusp to the distobuccal cusp of the first molar and from the tip of the distobuccal cusp of the first molar to the canine in the same quadrant.

Mandibular arch – **LA1, LA2**: the angle between the lines drawn from the tips of the mesiobuccal cusp to the distobuccal cusp of the first molar and from the tip of the distobuccal cusp of the first molar to the canine in the opposite quadrant. **LA3, LA4**: the angle between the lines drawn from the tips of the mesiolingual cusp to the mesiobuccal cusp of the first molar and from the tip of the mesiobuccal cusp of the first molar to the tip of the mesiobuccal cusp of the first molar on the opposite quadrant. **LA5, LA6**: the angle between the lines drawn from the tips of the mesiobuccal cusp to the distobuccal cusp of the first molar and from the tip of the distobuccal cusp of the first molar to the canine in the same quadrant.

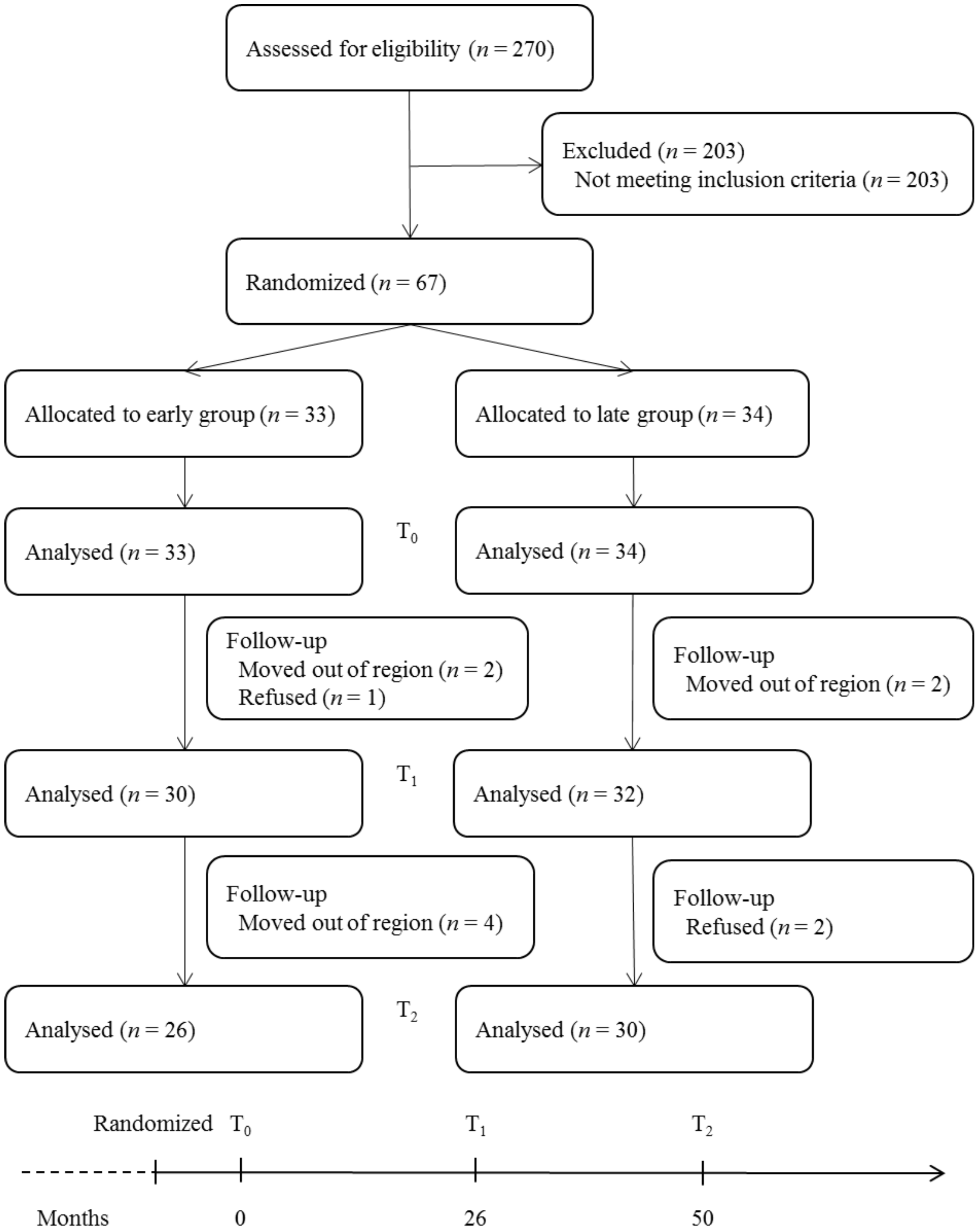

Figure 3. Flow chart and timeline of the study.

Table 1. Mean values with 95% CIs for linear measurements in maxillary arch (mm) at different time points according to group and gender, and significances of the differences between the groups. Change scores describe change from T_0. In the EG, the number of casts at time points T_0, T_1, and T_2 was 13, 12 and 10 for female and 20, 16 and 13 for male participants. In the LG, the numbers were 15, 11 and 11 for female and 19, 19 and 16 for male participants. CI = confidence interval.

			All			Females			Males		
	Time	Group	Mean	95% CI	Change	Mean	95% CI	Change	Mean	95% CI	Change
U1 + U4	T_0	EG	26.4	25.7–27.1		26.1	24.9–27.4		26.6	25.7–27.5	
		LG	26.8	26.4–27.2		26.6	26.0–27.1		27.1	26.5–27.6	
	T_1	EG	**27.6	27.2–28.0	*0.4	**27.3	26.6–27.9	0.3	*27.9	27.4–28.3	0.5
		LG	**26.4	25.9–26.9	*-0.4	**25.7	25.0–26.4	-0.5	*26.8	26.2–27.5	-0.3
	T_2	EG	27.7	27.2–28.2	1.0	27.0	26.3–27.7	0.9	28.3	27.6–28.9	1.0
		LG	27.5	26.8–28.2	0.7	27.2	26.3–28.1	0.7	27.8	26.7–28.8	0.6
U2 + U3	T_0	EG	17.7	17.3–18.2		17.2	16.8–17.7		18.0	17.4–18.7	
		LG	17.8	17.3–18.3		17.3	16.6–17.9		18.2	17.6–18.9	
	T_1	EG	*20.3	19.8–20.7	***2.6	19.9	19.3–20.5	**2.7	20.5	19.9–21.1	*2.6
		LG	*19.2	18.8–19.7	***1.1	18.8	18.2–19.5	**1.0	19.5	18.9–20.1	*1.2
	T_2	EG	19.6	19.1–20.0	2.1	19.5	18.6–20.3	2.4	19.6	19.1–20.2	1.9
		LG	19.3	18.9–19.8	1.7	18.8	18.2–19.5	1.6	19.8	19.2–20.4	1.6
U5 + U6	T_0	EG	41.4	40.6–42.3		40.5	39.4–41.7		41.9	40.8–43.0	
		LG	42.0	41.4–42.6		41.1	40.4–41.8		42.7	41.9–43.6	
	T_1	EG	**45.0	44.4–45.6	***2.9	*44.3	43.4–45.3	**2.9	*45.4	44.7–46.2	**2.9
		LG	**42.9	42.2–43.6	***0.8	*41.7	40.7–42.7	**0.6	*43.6	42.7–44.5	**0.9
	T_2	EG	44.4	43.8–45.0	2.5	44.0	42.9–45.0	2.7	44.7	43.9–45.4	2.4
		LG	43.8	42.9–44.6	2.0	42.9	41.7–44.1	2.0	44.4	43.2–45.5	1.9
U7	T_0	EG	32.0	31.3–32.8		31.5	30.6–32.5		32.3	31.2–33.5	
		LG	31.7	31.0–32.5		31.6	30.4–32.8		31.8	30.7–32.9	
	T_1	EG	***35.4	34.5–36.3	***3.4	**34.9	33.7–36.0	***3.3	**35.8	34.4–37.1	**3.6
		LG	***32.9	32.2–33.5	***0.7	**32.4	31.3–33.5	***-0.1	**33.2	32.4–34.0	**1.2
	T_2	EG	34.2	33.1–35.3	2.4	33.6	31.7–35.6	2.2	34.7	33.2–36.1	2.5
		LG	34.4	33.5–35.2	2.6	33.6	32.4–34.8	1.8	35.1	33.7–36.4	3.5
U8	T_0	EG	51.0	50.1–51.9		50.1	48.9–51.3		51.5	50.2–52.8	
		LG	50.6	49.7–51.5		50.3	48.8–51.7		50.9	49.7–52.2	
	T_1	EG	52.9	51.4–54.4	***1.6	52.7	51.1–54.4	**2.4	53.0	50.5–55.5	1.0
		LG	51.3	50.2–52.4	***0.7	50.5	48.4–52.5	**0.4	51.8	50.5–53.2	0.9
	T_2	EG	53.6	52.5–54.7	2.4	52.5	50.6–54.4	2.5	*54.4	53.1–55.6	2.3
		LG	52.3	51.2–53.3	1.8	52.2	50.3–54.0	2.2	*52.3	50.9–53.8	1.5
U9	T_0	EG	32.4	31.6–33.2		31.5	30.8–32.3		32.9	31.7–34.1	
		LG	32.5	31.5–33.6		32.4	31.0–33.8		32.7	31.0–34.3	
	T_1	EG	*34.5	33.7–35.4	***2.1	34.1	32.7–35.4	**2.5	34.8	33.6–36.1	**1.9
		LG	*32.7	31.5–33.8	***0.2	32.1	30.2–33.9	**0.0	33.0	31.4–34.7	**0.4
	T_2	EG	34.6	33.8–35.5	2.1	33.9	32.5–35.4	2.3	*35.1	34.0–36.3	2.0
		LG	33.4	32.4–34.4	1.2	33.5	31.7–35.4	1.8	*33.3	32.0–34.7	0.8

*P < 0.05, **P < 0.01, ***P < 0.001

Table 2. Mean values with 95% CIs for linear measurements in mandibular (mm) arch at different time points according to group and gender, and significances of the differences between the groups. Change scores describe change from T_0. In the EG, the number of casts at time points T_0, T_1, and T_2 was 13, 12 and 10 for female and 20, 16 and 13 for male participants. In the LG, the numbers were 15, 11 and 11 for female and 19, 19 and 16 for male participants. CI = confidence interval.

			All			Females			Males		
	Time	Group	Mean	95% CI	Change	Mean	95% CI	Change	Mean	95% CI	Change
L1 + L4	T_0	EG	28.2	27.5–28.9		27.8	27.0–28.6		28.4	27.4–29.5	
		LG	27.7	27.1–28.3		27.5	26.9–28.1		27.9	26.9–28.9	
	T_1	EG	28.5	28.0–29.0	-0.4	28.2	27.4–29.0	-0.2	28.8	28.1–29.5	-0.6
		LG	27.4	26.8–28.1	0.0	26.9	26.0–27.8	-0.4	27.7	26.8–28.6	0.2
	T_2	EG	**27.8	27.2–28.3	-1.2	27.4	26.4–28.4	-1.1	**28.1	27.4–28.7	-1.3
		LG	**25.9	25.1–28.3	-1.7	25.8	24.3–27.3	-2.0	**26.0	25.2–26.8	-1.4
L2 + L3	T_0	EG	12.5	12.1–12.9		12.3	11.8–12.9		12.6	12.1–13.1	
		LG	12.8	12.4–13.2		12.9	12.4–13.4		12.7	12.1–13.3	
	T_1	EG	13.5	13.0–13.9	0.8	13.2	12.5–13.9	0.8	13.6	13.1–14.2	0.9
		LG	13.7	13.3–14.1	0.7	13.6	13.0–14.2	0.5	13.8	13.2–14.4	0.9
	T_2	EG	14.1	13.8–14.4	1.6	13.7	13.4–14.1	1.3	14.3	13.9–14.7	1.9
		LG	14.1	13.7–14.5	1.7	13.8	13.2–14.3	1.3	14.4	13.7–15.0	1.3
L5 + L6	T_0	EG	38.0	37.3–38.7		37.5	36.7–38.3		38.2	37.2–39.2	
		LG	38.1	37.6–38.5		37.6	37.1–38.1		38.4	37.6–39.2	
	T_1	EG	39.1	38.6–39.6	0.4	38.5	37.7–39.3	0.4	39.6	39.0–40.1	0.3
		LG	38.2	37.5–38.8	0.0	37.6	36.8–38.4	0.0	38.5	37.6–39.4	0.0
	T_2	EG	*39.0	38.4–39.5	0.5	38.1	37.2–39.0	0.1	*39.6	39.1–40.2	0.8
		LG	*37.7	37.0–38.4	-0.2	37.1	36.0–38.2	-0.4	*38.1	37.2–39.0	-0.1
L7	T_0	EG	23.6	23.0–24.2		23.1	22.4–23.9		23.9	23.0–24.8	
		LG	23.9	23.2–24.6		24.0	22.9–25.0		23.9	22.8–25.0	
	T_1	EG	25.0	24.2–25.9	1.6	24.6	23.4–25.8	1.5	25.4	24.0–26.8	1.6
		LG	25.1	24.1–26.1	0.9	24.9	23.4–26.3	0.5	25.3	23.9–26.7	1.1
	T_2	EG	26.1	25.3–26.9	2.5	25.8	24.9–26.6	2.7	26.3	25.0–27.7	2.3
		LG	25.8	24.8–26.8	2.4	25.2	23.6–26.7	1.7	26.3	24.9–27.7	3.0
L8	T_0	EG	46.7	45.9–47.5		46.0	44.8–47.3		47.1	46.1–48.2	
		LG	46.0	45.2–46.8		45.4	44.1–46.7		46.5	45.4–47.6	
	T_1	EG	**47.9	47.2–48.7	**1.0	*47.3	46.0–48.5	1.2	**48.5	47.5–49.5	*0.9
		LG	**46.0	45.1–46.9	**0.1	*45.2	43.4–47.0	0.2	**46.5	45.4–47.5	*0.0
	T_2	EG	**48.5	47.5–49.5	1.5	47.1	45.7–48.5	1.1	**49.6	48.4–50.8	*1.7
		LG	**46.5	45.4–47.6	0.7	46.1	44.0–48.2	1.2	**46.8	45.4–48.2	*0.4
L9	T_0	EG	31.7	31.0–32.4		31.1	30.4–31.9		32.0	31.1–33.0	
		LG	31.4	30.6–32.1		31.3	30.1–32.6		31.4	30.4–32.4	
	T_1	EG	*32.6	31.8–33.3	***0.9	31.9	31.1–32.7	0.8	*33.1	31.9–34.3	***0.9
		LG	*31.2	30.3–32.1	***0.0	31.1	29.2–33.0	0.0	*31.3	30.3–32.3	***-0.1
	T_2	EG	*33.1	32.2–33.9	*1.1	32.0	30.8–33.1	0.8	*33.9	32.8–35.1	1.2
		LG	*31.5	30.4–32.5	*0.3	31.1	29.1–33.1	0.1	*31.8	30.4–33.1	0.4

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Table 3. Mean values with 95% CIs for angular measurements in maxillary and mandibular arches (degrees) at different time points according to group and gender, and significances of the differences between the groups. Change scores describe change from T_0. In the EG, the number of casts at time points T_0, T_1, and T_2 was 13, 12 and 10 for female and 20, 16 and 13 for male participants. In the LG, the numbers were 15, 11 and 11 for female and 19, 19 and 16 for male participants. CI = confidence interval.

			All			Females			Males		
	Time	Group	Mean	95% CI	Change	Mean	95% CI	Change	Mean	95% CI	Change
UA1 + UA2	T_0	EG	49.3	47.6–51.0		46.1	43.4–48.8		51.0	48.9–53.1	
		LG	48.8	47.0–50.6		48.6	45.5–51.8		48.9	47.0–50.8	
	T_1	EG	***53.2	51.4–55.1	***4.9	*52.1	49.7–54.4	**6.4	**54.2	51.4–57.0	**3.9
		LG	***47.7	46.0–49.4	***-0.7	*46.6	43.5–49.6	**-0.7	**48.4	46.4–50.5	**-0.7
	T_2	EG	49.9	47.8–52.0	1.8	49.6	46.0–53.2	3.4	50.1	47.3–52.9	0.9
		LG	49.6	47.9–51.3	1.1	49.4	46.5–52.4	1.5	49.8	47.6–52.0	0.7
UA3 + UA4	T_0	EG	35.9	33.8–37.9		37.3	33.8–40.9		35.0	32.5–37.5	
		LG	37.1	35.6–38.6		35.5	33.2–37.8		38.5	36.7–40.4	
	T_1	EG	***30.3	28.6–31.9	*-4.5	**30.3	27.5–33.2	**-6.3	**30.2	28.2–32.3	-3.2
		LG	***36.3	34.6–37.9	*-1.2	**37.6	35.0–40.3	**0.6	**35.5	33.3–37.6	-2.4
	T_2	EG	32.9	31.1–34.7	-2.3	33.2	30.5–35.9	-3.8	32.6	30.1–35.2	-1.5
		LG	32.9	31.1–34.6	-4.4	33.0	30.9–35.1	-3.9	32.8	30.0–35.5	-4.9
UA5 + UA6	T_0	EG	11.7	10.3–13.2		8.9	6.5–11.2		13.3	11.6–15.0	
		LG	11.9	10.4–13.4		11.8	9.2–14.4		12.0	10.4–13.6	
	T_1	EG	**13.4	11.8–15.1	**2.5	12.2	9.9–14.5	*4.1	*14.4	12.1–16.7	1.4
		LG	**10.1	8.8–11.4	**-1.1	9.2	6.7–11.7	*-0.8	*10.7	9.1–12.2	-1.3
	T_2	EG	11.8	10.1–13.5	1.4	10.7	7.5–13.9	3.0	12.6	10.6–14.6	0.5
		LG	11.1	9.6–12.6	-0.5	11.7	9.4–14.0	0.6	10.6	8.5–12.6	-1.7
LA1 + LA2	T_0	EG	38.0	36.2–39.9		*36.6	34.0–39.1		38.8	36.3–41.4	
		LG	38.4	36.6–40.3		*41.4	39.3–43.4		35.9	33.1–38.6	
	T_1	EG	39.8	37.8–41.7	1.7	37.9	35.5–40.2	0.6	41.5	38.5–44.6	2.7
		LG	39.5	37.7–41.3	0.7	41.4	38.7–44.2	-0.8	38.4	36.0–40.8	1.6
	T_2	EG	40.9	39.2–42.7	2.6	39.7	36.8–42.6	3.0	41.9	39.6–44.1	2.3
		LG	39.7	39.7–42.4	3.0	41.2	39.4–43.1	-0.9	40.9	38.9–42.9	6.4
LA3 + LA4	T_0	EG	16.3	14.5–18.1		16.0	13.3–18.7		16.5	14.0–19.0	
		LG	17.7	16.2–19.1		17.0	15.0–19.0		18.2	16.0–20.4	
	T_1	EG	**11.1	9.2–13.0	*-4.5	11.9	9.1–14.6	-4.1	**10.5	7.7–13.2	*-4.8
		LG	**15.7	14.2–17.3	*-1.9	14.2	12.0–16.4	-2.6	**16.7	14.6–18.8	*-1.4
	T_2	EG	11.4	9.5–13.2	-3.6	12.8	9.8–15.8	-2.1	10.3	8.0–12.7	-4.6
		LG	14.1	12.4–15.8	-3.6	12.7	9.8–15.5	-3.9	15.2	13.0–17.4	-3.4
LA5 + LA6	T_0	EG	12.1	10.8–13.3		11.4	9.8–13.1		12.4	10.6–14.2	
		LG	12.3	11.0–13.7		13.5	12.0–15.0		11.3	9.1–13.5	
	T_1	EG	11.7	10.2–13.2	-0.7	9.4	7.5–11.4	-1.7	13.8	11.9–15.7	0.2
		LG	11.2	9.7–12.7	-1.2	12.5	10.2–14.8	-1.2	10.5	8.5–12.4	-1.1
	T_2	EG	12.2	10.7–13.6	-0.6	9.3	7.3–12.0	-1.3	14.0	12.4–15.7	-0.1
		LG	11.9	10.4–13.4	-0.4	12.9	10.8–15.0	-1.1	11.1	8.9–13.3	0.2

$^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$