UNIVERSIDADE DE SÃO PAULO
FACULDADE DE ODONTOLOGIA DE BAURU

FELICIA MIRANDA

Comparison of miniscrew-anchored maxillary protraction protocols: a randomized clinical trial

Comparação de protocolos de protração maxilar ancorada em mini-implantes: um ensaio clínico randomizado

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Orientadora: Profª. Drª. Daniela Gamba Garib Carreira

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ABSTRACT

Comparison of two miniscrew-anchored maxillary protraction protocols: a randomized clinical trial

Introduction: The aim of this randomized clinical trial was to compare the dentoskeletal and airway outcomes of miniscrew-anchored maxillary protraction using hybrid and conventional hyrax expanders in growing Class III subjects**. Methods:** Forty patients were randomized into two groups. Group HH was composed by patients with Class III malocclusions treated with a hybrid hyrax expander with two miniscrews in the maxilla and two miniscrews in the anterior region of the mandible. Class III elastics were used from the maxillary first molar to the mandibular miniscrews until anterior crossbite correction or a maximum 12 months of treatment. The group CH was treated with a similar protocol except for the conventional Hyrax expander in the maxilla. Cone-beam computed tomography exams and digital dental models were obtained before expansion (T1) and after treatment (T2). The primary outcomes included the sagittal skeletal effects produced with treatment. The secondary outcomes included the upper airway changes and transversal changes in the maxillary structures. Intergroup comparison was performed using t tests and Mann-Whitney U tests ($p<0.05$). **Results:** The final sample comprised 18 subjects (8 female, 10 male; initial age of 10.80 years) in Group HH and 14 subjects (6 female, 8 male; initial age of 11.44 years) in Group CH. A greater increase in maxillomandibular skeletal relationship and maxillary length was observed for the HH group. Both groups presented similar skeletal vertical and orthodontic outcomes after maxillary protraction. The oropharynx and the most constricted area of oropharynx increased similarly in both groups. Significantly greater increases in the nasal cavity width and buccal alveolar crest width were found for group HH. The maxillary interpremolar distance showed a greater increase in group CH. **Conclusions:** Miniscrew-anchored maxillary protraction using hybrid expanders produced greater orthopedic effects with better control of dental side effects and constitute an alternative for growing Class III malocclusion patients. No differences in upper airway changes were observed using maxillary protraction anchored on hybrid or conventional hyrax expanders.

Keywords: Orthodontics, Interceptive. Malocclusion, Angle Class III. Palatal expansion technique. Airway Management. Imaging, Three-Dimensional.

RESUMO

Introdução: O objetivo deste ensaio clínico randomizado foi comparar os efeitos dentoesqueléticos e das vias aéreas superiores após a protração maxilar ancorada em mini-implantes usando expansor híbridos e hyrax convencional em indivíduos em crescimento com má oclusão de Classe III. **Métodos:** Quarenta pacientes foram randomizados em dois grupos. O grupo HH foi composto por pacientes com má oclusão de Classe III tratados com um expansor híbrido com dois mini-implantes na maxila e dois mini-implantes na região anterior da mandíbula. Elásticos de Classe III foram utilizados conectando os primeiros molares superiores e os mini-implantes mandibulares até a correção da mordida cruzada anterior ou um período máximo de 12 meses de tratamento. O grupo CH foi tratado com um protocolo semelhante, exceto pelo uso do expansor hyrax convencional na maxila. Tomografias computadorizadas de feixe cônico foram obtidas ao início (T1) e final do tratamento (T2). Os desfechos primários incluíram os efeitos esqueléticos sagitais. Os desfechos secundários incluíram alterações nas vias aéreas superiores e alterações transversais nas estruturas maxilares. A comparação intergrupos foi realizada usando teste *t* independente e teste Mann-Whitney U ($p<0.05$). **Resultados:** A amostra final foi composta por 18 indivíduos (8 mulheres, 10 homens; idade inicial de 10,80 anos) no Grupo HH e 14 indivíduos (6 mulheres, 8 homens; idade inicial de 11,44 anos) no Grupo CH. Um aumento significantemente maior na relação esquelética maxilomandibular e no comprimento maxilar foi observado no grupo HH. Ambos os grupos apresentaram alterações verticais e ortodônticos semelhantes após a protração maxilar. A orofaringe e a área mais constrita da orofaringe aumentaram de maneira semelhante nos dois grupos. Aumentos significativamente maiores na largura da cavidade nasal e na largura da crista alveolar vestibular foram encontrados para o grupo HH. A distância inter pré-molares superiores mostrou um aumento significantemente maior no grupo CH. **Conclusões:** A protração maxilar ancorada em mini-implantes utilizando expansor híbrido produziu maiores efeitos ortopédicos com melhor controle dos efeitos dentários colaterais e constitui uma opção de tratamento para os pacientes com má oclusão de Classe III em crescimento. Não foram observadas diferenças significantes nas alterações das vias aéreas superiores usando a protração maxilar ancorada no expansor híbrido ou convencional.

Palavras-chave: Ortodontia Interceptora. Má Oclusão de Angle Classe III. Técnica de Expansão Palatina. Manuseio das Vias Aéreas. Imagem Tridimensional.

LIST OF FIGURES

ARTICLE 1

ARTICLE 2

ARTICLE 3

LIST OF TABLES

ARTICLE 1

ARTICLE 2

ARTICLE 3

LIST OF ABBREVIATIONS AND ACRONYMS

HH	Hybrid Hyrax
CH	Conventional Hyrax
CBCT	Cone beam computed tomography
MAMP	Miniscrew-anchored maxillary protraction
T1	Timing 1
T2	Timing 2
RCT	Randomized clinical trial
BAMP	Bone-anchored maxillary protraction
MARPE	Miniscrew supported rapid palatal expansion
OP	Oropharynx
MinAx	Most constricted axial area
6-6 width	Intermolar width
5-5 width	Inter- second premolars width
4-4 width	Inter- first premolars width
3-3 width	Intercanine width
ICC	Intraclass correlation coefficient
SD	Standard deviation
CI	Confidence interval
Diff	Difference
FAPESP	São Paulo Research Foundation
CAPES	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (in portuguese)
CONSORT	Consolidated Standards of Reporting Trials

TABLE OF CONTENTS

1 INTRODUCTION

1 INTRODUCTION

Class III malocclusion treatment in growing patients is challenging. Maxillary retrusion, mandibular prognatism, or the combination of both are the main causes of this malocclusion.[1] The facemask therapy associated with RME is the gold standard protocol for Class III malocclusion in early stages. Previous studies demonstrated that the treatment of Class III malocclusion with face mask and RME in the early mixed dentition results in more favorable craniofacial changes than the treatment in the late mixed dentition.[2] The late-treatment group showed no significant improvement in maxillary growth when compared to the early-treatment group.[2] In the late mixed dentition and permanent dentition, facemask therapy promotes only limited maxillary advancement while considerable amount of dentoalveolar effects including the mesial movement of maxillary posterior teeth is observed.[2,3]

A new Class III orthopedic approach using miniplates as anchorage reported an efficient maxillary protraction in the late mixed dentition and early permanent dentition (10-14 years).[4] Bone-anchored maxillary protraction (BAMP) uses Class III elastics attached to miniplates installed on the infra-zygomatic maxillary crest and between canines and lateral incisors at the mandible, bilaterally.[4,5] The authors reported a whole maxillary bone advancement as a result of treatment, once that the pterygomaxillary fissure and the orbital ridge moved forward as well.

A BAMP-derived therapy was recently described using a hybrid hyrax as anchorage in the maxilla and modified miniplates in the mandible.[6] Miniscrew-assisted rapid palatal expansion (MARPE) and hybrid hyrax are a simple modification of the conventional RME appliance which incorporated miniscrews to ensure expansion.[7-14] Another derivation of BAMP therapy could replace the mandibular miniplates for miniscrews.[15] Miniscrew-anchored maxillary protraction (MAMP) uses a hybrid hyrax in the maxilla and mandibular miniscrews to anchor Class III elastics.[15] Improvements in the maxillary structures and facial convexity was observed after MAMP therapy.[15] Also, in order to simplify a conventional expander could be used in the maxillary arch.

Currently, cone beam computed tomography (CBCT) have been widely used to three-dimensionally assess the dentoskeletal and upper airway changes. CBCT offers

the advantages of volumetric rather than linear measurements and distortion-free measurements.[16,17] Increases in the nasopharynx and velopharynx was found in the volume of growing patients with Class III malocclusion when compared to untreated Class III patients.[16] Also using CBCT, an increase in airway volume and oropharyngeal dimensions was found for subjects treated with BAMP therapy.[17] Airway changes after MAMP therapy in growing patients was not previously reported in the literature.

2 ARTICLES

2 ARTICLES

The articles presented in this Thesis were written according to the CONSORT 2010 checklist and the *American Journal of Orthodontics and Dentofacial Orthopedics* instructions and guidelines for article submission.

- **ARTICLE 1** - Dentoskeletal comparison of miniscrew-anchored maxillary protraction with hybrid and conventional hyrax expanders: a randomized clinical trial

- **ARTICLE 2** - Upper airway changes in miniscrew-anchored maxillary protraction with hybrid and hyrax expanders: a randomized clinical trial

- **ARTICLE 3** - Orthopedic outcomes of hybrid and conventional hyrax expanders: secondary data analysis from a randomized clinical trial

2.1 ARTICLE 1

Dentoskeletal comparison of miniscrew-anchored maxillary protraction with hybrid and conventional hyrax expanders: a randomized clinical trial

ABSTRACT

Introduction: The aim of this randomized clinical trial was to compare the orthopedic and orthodontic outcomes of miniscrew-anchored maxillary protraction using hybrid and conventional hyrax expanders in growing Class III subjects**.** **Methods:** Forty patients were randomized into two groups. Group HH was composed by patients with Class III malocclusions in the late mixed or early permanent dentition treated with a hybrid hyrax expander with two miniscrews in the maxilla and two miniscrews in the anterior region of the mandible. Class III elastics were used from the maxillary first molars to the mandibular miniscrews placed between permanent canines and first premolars. Group CH was composed by patients treated with a similar protocol except for the use of a conventional hyrax expander in the maxilla. The primary outcomes included the sagittal skeletal effects produced with treatment. Allocation was performed with a simple randomization process. Intergroup comparison was performed using t tests ($p<5\%$). **Results:** The final sample comprised 18 subjects (8 female, 10 male; initial age of 10.80 years) in Group HH and 14 subjects (6 female, 8 male; initial age of 11.44 years) in Group CH. A greater increase in maxillomandibular skeletal relationship and maxillary length was observed for the HH group. Both groups presented similar skeletal vertical outcomes after maxillary protraction. The orthodontic effects were similar between groups. Group HH and CH produce a 2.99 and 2.03 overjet correction ($p=0.202$), respectively. **Conclusions:** Miniscrew-anchored maxillary protraction using hybrid expanders produced a greater maxillary length increase and constitute an alternative for growing Class III malocclusion patients. **Registration:** The trial was registered at ClinicalTrials.gov, under the identifier NCT03712007. **Protocol:** This trial protocol was not published.

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KEYWORDS: Orthodontics, Interceptive; Malocclusion, Angle Class III; Palatal expansion technique.

INTRODUCTION

Innovations in Class III malocclusion orthopedic interventions were remarkable in the last decade. Facemask therapy constitutes the standard protocol to treat growing Class III malocclusion with maxillary deficiency.[1] Maxillary protraction with facemask therapy produces a combination of skeletal and dental effects.[2] A forward and downward movement of maxilla, an extrusion of posterior maxillary teeth and a counter-clockwise rotation of the palatal plane can be observed after facemask therapy.[2] As consequence the mandible rotates toward inferior and posterior increasing the lower anterior facial height.[2] Baccetti et al.[3] compared the outcomes of facemask therapy in two age groups of growing Class III malocclusion. The early-treatment group (mean age of 6.9 years) showed significant forward movement of the maxillary structures when compared to an untreated Class III malocclusion sample.[3] Conversely, the late-treatment group (mean age of 10.3 years) have not produced significant changes in the maxilla position after treatment when compared to the untreated sample.[3] Theses founds are in concordance with previously studies that report more favorable effects of facemask therapy in younger age groups.[2,4,5]

A new protocol for treating growing Class III malocclusion using skeletal anchorage was described by De Clerck et al.[6] Bone-anchored maxillary protraction (BAMP) uses Class III elastics attached to titanium miniplates on the infra-zygomatic maxillary crests and between the mandibular canines and lateral incisors, bilaterally.[6] BAMP produced favorable skeletal effects in late treatment groups (mean age of 11.10 years).[6-8] A mean maxillary advancement of 3.5mm with minimal undesirable dentoalveolar effects were found using BAMP therapy.[6,8]

BAMP derived therapies were later described for Class III patients in the late mixed or early permanent dentition. Wilmes et al.[9] used a hybrid hyrax expander as anchorage in the maxilla and modified miniplates in the mandible in order to anchor Class III elastics in young patients (mean age of 10.6 years).[9] Recently, Miranda et al.[10] described a miniscrew-anchored maxillary protraction (MAMP) protocol using a hybrid hyrax in the maxilla and two miniscrews in the mandible. MAMP produced a maxillary protraction with an adequate overjet correction.[10]

Specific objectives and hypotheses

The aim of this study was to compare the dentoskeletal effects of miniscrew-anchored maxillary protraction using hybrid and conventional hyrax expanders. The

null hypothesis was that maxillary protraction with hybrid and conventional hyrax expanders present similar orthopedic and orthodontic changes.

METHODS

Trial design and any changes after trial commencement

This study is a single center randomized clinical trial (RCT), with two parallel arms and a 1:1 allocation ratio. Changes in participants number were performed after trial commencement and were described in the flow chart (Fig 1). This clinical trial was register under the number NCT03712007 at Clinicaltrials.gov.

The study followed the Consolidated Standards of Reporting Trials guidelines (CONSORT).[11] The study was approved by the Ethics in Research Committee of Bauru Dental School, University of São Paulo, Brazil (protocol number 67610717.7.0000.5417). All participants and parents signed the written informed consent before treatment.

Participants, eligibility criteria and settings

The individuals were recruited in the Orthodontic Clinic, Bauru Dental School, University of São Paulo, from July of 2017 to March of 2018. The sample consisted of 40 Class III malocclusion individuals with age ranging from 9 to 13 years of age. The eligibility criteria included: (1) both sexes; (2) late mixed or early permanent dentition; (3) skeletal Class III malocclusion with maxillary deficiency (Wits appraisal of less than -1mm); (4) anterior crossbite or incisor edge-to-edge relationship. Exclusion criteria included individuals with history of previous orthodontic treatment, non-erupted mandibular permanent canines, special need or syndromic individuals.

Interventions

Group HH was composed by growing Class III malocclusion patients treated with miniscrew-anchored maxillary protraction anchored in a hybrid expander (Fig 2). The therapy consisted of a hybrid hyrax (Fig 2A) in the maxilla and two mandibular miniscrews positioned distally to the permanent canines, bilaterally (Fig 2). A pre-manufactured hybrid expander (Peclab, Belo Horizonte, Brazil) was supported by bands in the maxillary first permanent molars and two miniscrew placed in the anterior region of the palate in a parasutural position (Fig 2A). The miniscrews with 1.8 mm diameter, 7 mm length and 4 mm transmucosal length were installed in the screw slots

after expander bond (Fig 2A). In the mandible, two miniscrews with 1.6 mm diameter, 6 mm length and 1 mm transmucosal length were placed on the buccal aspect between the permanent canines and first premolars at the level of the mucogingival junction (Fig 2B).

Group CH was composed by growing Class III malocclusion patients treated with a similar protocol of group HH except for the use of conventional Hyrax expander as anchorage for Class III elastics in the maxilla (Fig 3).

The screw activation protocol and Class III elastics were similar for both groups. The expander screw was activated 1/4 turn twice a day for 14 days, achieving 5.6mm of expansion. In the maxillary molar bands, distal hooks of 1mm-round-stainless steel wire were soldered to accommodate the Class III elastics and provide a more horizontal force. The Class III elastics were used from the maxillary molar distal hooks to the mandibular miniscrews (Figs 2 and 3). Traction started with a load of 150g/side in the first month and 250g/side in the following period. Patients were instructed to wear the elastics full time, changing them every morning and night.[6] Composite build-ups on the occlusal aspect of mandibular permanent first molars were used to open the bite during maxillary protraction (Figs 2 and 3).

Patients and parents were oriented to maintain an adequate level of oral hygiene during treatment. Peri-implantar chlorhexidine gel (2%) was prescribed twice a day after oral hygiene during active treatment. Maxillary protraction was maintained for a mean of 11.3 and 11.0 months for the experimental and control groups, respectively (Table I). After appliance removal, a chin cup was recommended nighttime as active retention.

Cone-beam computed tomography (CBCT) was obtained before (T1) and after therapy (T2) with the i-CAT 3-dimensional system (Imaging Sciences International, Hatfield, PA, USA). The protocol of 120 kV, 23.87 mA, 13cm-FOV and a voxel size of 0.25 mm was used. All CBCT data were exported in DICOM format (Digital Imaging and Communications in Medicine) to Dolphin 3D Imaging 11.5 software (Patterson Dental Supply, Inc., Chatsworth, CA, USA). The head orientation was standardized in the right sagittal view positioning the Frankfurt plane parallel to the horizontal plane; in the frontal view, the orbital plane was positioned parallel the horizontal plane; and in the axial view, the midsagittal plane was passing on the anterior and posterior nasal spine.

Outcomes (primary and secondary) and any changes after trial commencement

The primary outcomes were the sagittal skeletal effects. The secondary outcomes were the therapy vertical effects and dental changes. Reformatted lateral cephalometric images were obtained using Dolphin 3D Imaging 11.5 software (Patterson Dental Supply, Inc., Chatsworth, CA, USA). A cephalometric analysis with 19 linear and angular variables was assessed with Dolphin 3D Imaging 11.5 software (Patterson Dental Supply, Inc., Chatsworth, CA, USA)

Sample size calculation

Sample size was calculated in order to provide a power of 80%, an alpha error of 5%, a minimum intergroup difference of 2 mm. Considering the standard deviation of 1.4 mm for maxillary length (CoA) changes,[7] a sample of nine patients was required for each group.

Interim analyses and stopping guidelines

Not applicable.

Randomization (random number generation, allocation concealment, implementation)

Randomization process was performed in the Randomization.com website (http://www.randomization.com). Allocation concealment corresponded to opaque, sealed and sequenced numbered envelopes. Each envelope contained the group name according to the randomization sequence.[12] A different operator was responsible for randomization sequence generation, allocation concealment and process.

The allocation process started after recruitment for the patients who met the inclusion criteria and signed the informed consent. Before opening the envelope, the name of patient and date of allocation were irreversible identified in the external surface. Inside each envelope, a card containing the group name was found. During treatment, undesirable dental effects in the maxillary arch were observed in group CH. For ethical reasons, the treatment in group CH was interrupted after 11 months of trial commencement and before appliance installation in the last 5 volunteers.

Blinding

CBCT scans were unidentified before assessment. Only simple blinding was accomplished considering both operator and patient were aware of the type of treatment performed.

Statistical analysis

After 1-month period, 30% of the sample were randomly selected for remeasurement by the same examiner. The reliability of repeated measures was assessed by the intraclass correlation coefficient (ICC) and Bland-Altman limit of agreement.

Kolmogorov-Smirnov test was used to verify normal distribution. Intergroup comparisons were performed using t tests. When normal distribution was absent, Mann-Whitney U test was used. Statistical analyses were performed using the SPSS Statistical Software Package (Version 21.0; SPSS, Chicago, IL, USA). A significance level of 5% was regarded.

RESULTS

Participant flow

Twenty patients were allocated in Group HH. One patient interrupted treatment and one was excluded due to palatal miniscrew instability during the active expansion period. The final sample of Group HH comprised 18 individuals (8 female and 10 male) with a mean initial age of 10.80 years. The mean treatment time for group HH was 11.38 months.

Twenty individuals were allocated to Group CH. However, the last 5 participants were no treated due the observation of collateral effects during the therapy in 2 out of 15 patients that were in treatment. These side effects were an extreme mesial movement of posterior teeth and maxillary canine buccal displacement. After allocation, one patient interrupted treatment. The final sample of group CH comprised 14 individuals (6 female and 8 male) with a mean age of 11.44 years. Mean treatment time was 11 months. Figure 1 shows participant flow chart.

Baseline data

Similar sex distribution, initial age and treatment time were found for both groups (Table I). Initial cephalometric variables were similar for both groups except the SNA angle that was greater to group HH (Table II).

Number analyzed for each outcome, estimation and precision, subgroup analyses

Good reproducibility of repeated measurements was found for all variables (ICC varying from 0.770 to 0.989). The variable with the greatest limits of agreement was the nasolabial angle (-9.96 and 13.87) and the variable with the smallest was the overbite (-1.62 and 1.27).

Group HH showed a greater increase in the maxillary length and a greater improvement in the maxillomandibular relationship (Table III). Both groups presented similar vertical skeletal effects. No intergroup differences were observed for maxillary and mandibular incisor inclination, overjet, overbite and molar relation (Table III).

The success rate for palatal miniscrews in group HH was 97.36% (1 out of 38). The instability/loss rate of mandibular miniscrews in groups HH and CH was 15.78% and 17.85%, respectively.

Harms

Patients compliance with Class III elastics was extremely necessary for successful results. No-compliant patients presented moderate to unsatisfactory results. The treatment was performed until the anterior crossbite correction or conduct for a maximum of twelve months period.

When mandibular miniscrews were instable before anterior crossbite correction, a replacement was performed after two weeks in the same region with a 30º screw inclination.

Negative overjet was still present after the intervention in 5.5% and 28.5% of group HH and CH, respectively. A compensatory orthodontic treatment or orthognathic surgery were considered as an alternative treatment option for patients that did not achieve overjet correction after maxillary protraction.

DISCUSSION

Main findings in the context of the existing evidence and interpretation

This is the first RCT comparing the dentoskeletal effects of two protocols of miniscrew-anchored maxillary protraction in growing Class III individuals. MAMP is a BAMP-derived therapy replacing miniplates by miniscrews. The miniscrews are simpler to be placed and removed compared to miniplates. Additionally, the miniscrews are orthodontic-friendly not requiring the maxillofacial surgeon. In this study, reformatted lateral cephalometric images were obtained from the CBCT exams for performing a dentoskeletal appraisal of MAMP protocol. CBCT three-dimensional images were used for planning miniscrew installation in T1 and for planning comprehensive orthodontic treatment in T2. Additionally, the airway changes were analyzed in a previous study.

Both groups HH and CH showed adequate sagittal skeletal changes after maxillary protraction. An increase of 1.92mm and 1.45mm in Wits appraisal was found for group HH and CH, respectively. The ANB angle showed a significant increase in both groups (1.83º and 1.1º). Previous studies using miniplates as skeletal anchorage reported successfully maxillary advancement.[7,8,13] Our results showed smaller skeletal changes when compared to BAMP therapy, which showed an improvement of 5.9mm in Wits appraisal after treatment.[7,8] In BAMP therapy, the protraction forces are applied directly in the maxillary bone and at the level of the maxillary center of resistence.[6] On the other hand, MAMP therapy use an indirect anchorage on the hybrid hyrax and the protraction forces are applied below the maxillary center of resistance (Fig 2A). A previous study reported a 3.8 mm increase in Wits appraisal and a 3.4 degrees increase in ANB angle after a facemask maxillary protraction anchored on the hybrid hyrax.[13] Patients included in the study were younger (mean initial age of 9.5 years)[13] than patients treated with MAMP therapy in groups HH and CH (10.8 years and 11.44 years, respectively). In addition, the force applied with facemask (400g/side) was greater than the force applied with Class III elastics (250g/side).[13]

Group HH showed a greater increase in the maxillary length and maxillomandibular relationship than group CH (Table III). Group HH had skeletal anchorage in both jaws. The hybrid hyrax probably had an important role in the amount of maxillary advancement achieved in group HH. In Group CH, the dental anchorage in the maxilla led to unpredictable amount of dental side effects especially in patients with vertical growth pattern. Group HH also showed a greater frequency of overjet

correction (95%) after 1 year of treatment. In group CH, a negative overjet remained in 28% of the patients.

The mandible remained sagitally stable in both groups (Table III). As expected, MAMP therapy with a hybrid or conventional hyrax led to minimal mandibular changes. On the other hand, a slight restraining effect on mandibular growth was observed after BAMP therapy.[8] Similar vertical skeletal effects were observed in both groups with a mandibular plane rotating back and downward. (Table III). These results are similar to facemask therapy that produced a clockwise rotation of the mandibular plane.[7] Conversely, a counterclockwise rotation (1º) of the mandibular plane were observed after BAMP therapy.

Dental changes were similar in group HH and CH (Table III). Changes in the maxillary incisor inclination was negligible in both groups. This similarity between groups was not expected due to different type of anchorage in the maxilla. Group CH clinically displayed a mesial migration of the posterior teeth, a decrease in the arch perimeter leading to a maxillary canine crowding. Maxillary incisor inclination was not affected by the aforementioned side effects. Changes in mandibular incisor inclination were variable and similar between groups. BAMP produced a labial inclination of mandibular incisors due to overjet correction.[8] On the other hand, facemask therapy produced a lingual tipping of mandibular incisors due the presence of chin cup.[1,2,5,7] In the hybrid hyrax group, mandibular incisors inclination remained stable during treatment.

Similar increases in the overjet and molar relation were found for both groups (Table III). Group HH showed a 2.99 mm increase in overjet and group CH had a 2.03 mm overjet increase (Table III). BAMP therapy produced a 3.7 mm increase in overjet after one year of treatment.[8] The molar relationship improved similarly in both groups (Table III). BAMP therapy produced a significant improvement of the molar relationship after treatment.[8] A previous study using facemask therapy also showed a significant improvement in the molar relationship after treatment.[5] However, a smaller increase in molar relationship was observed after facemask therapy when compared to BAMP therapy.[7]

As expected, palatal miniscrews showed a high success rate (97.36%). High stability rates were previously reported for miniscrews inserted on the palatal mucosa.[14,15] However, mandibular miniscrews presented higher instability rates when compared to maxillary miniscrews.[16] Our findings showed a greater instability of the

mandibular miniscrews than palatal miniscrews. The mandibular miniscrews were placed between the permanent canines and first premolars, bilaterally, using the mucogingival junction as reference. Some patients presented a limited amount of keratinized mucosa, which forced an apical displacement of the miniscrews. Miniscrews delivered in movable mucosa are less stable than those installed in keratinized mucosa.[17] In order to overcome these complications, patients in both groups were instructed to maintain a high level of oral hygiene and perimplant 2% chlorhexidine gel was prescribed during treatment. In BAMP therapy, miniplates presented high stability rates during treatment and can be maintained for the retention period.[6] In MAMP therapy, the miniscrews need to be removed after treatment and the retention may require a different approach as a chin cup.

In conclusion, MAMP therapy using the hybrid hyrax demonstrated a greater maxillary protraction and less dental side effects than the protocol using conventional hyrax expander. Future three-dimensional analysis should be performed to compare the midface protraction and condyle/glenoid fossa between MAMP and BAMP.

Limitations

A limitation of the present study was the patient assignment interruption performed in group CH, which led to a smaller sample size in this group. However, the ethical aspects were more relevant when extreme dental side effects were observed in the conventional hyrax group. Another limitation was that only bidimensional analysis were performed to compare the dentoskeletal effects changes promoted by MAMP therapy in both groups. Future studies should be conducted to demonstrate three-dimensional maxillary changes of MAMP therapy with hybrid expanders in comparison with BAMP therapy.

CONCLUSIONS

The null hypothesis was rejected. Miniscrew-anchored maxillary protraction associated with hybrid expanders promoted a greater increase of the maxillary length and a greater improvement in the maxillomandibular relationship in Class III growing patients compared to the same protocol using conventional hyrax expanders.

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FIGURE LEGENDS

Fig 1. CONSORT flow chart.

Fig 2. Miniscrew-anchored maxillary protraction using the hybrid hyrax

Fig 3. Miniscrew-anchored maxillary protraction using the conventional hyrax.

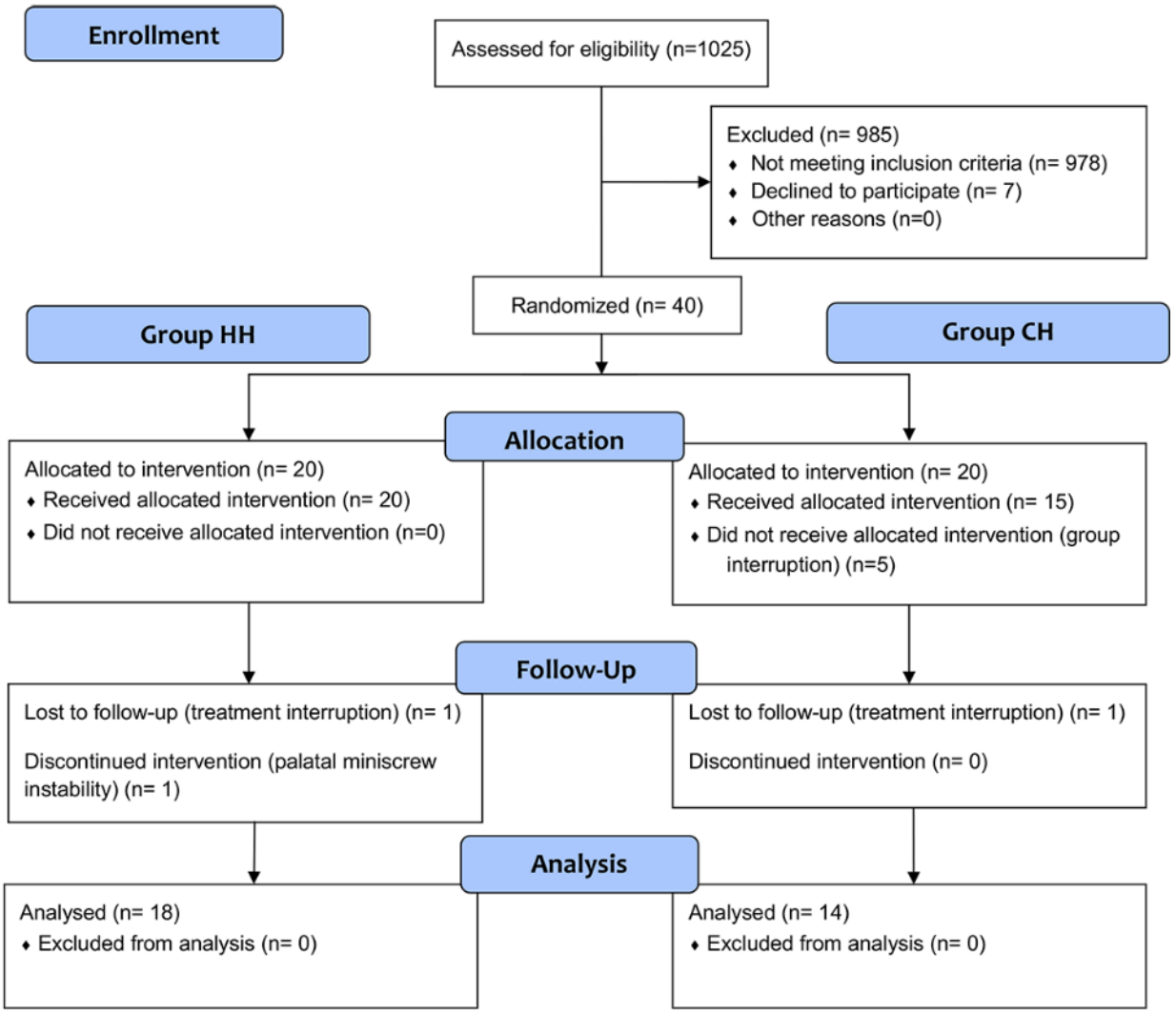
Enrollment
Assessed for eligibility (n=1025)
Excluded (n= 985)
Not meeting inclusion criteria (n= 978)
Declined to participate (n= 7)
Other reasons (n=0)
Randomized (n= 40)
Group HH
Group CH
Allocation
Allocated to intervention (n= 20)
Received allocated intervention (n= 20)
Did not receive allocated intervention (n=0)
Allocated to intervention (n= 20)
Received allocated intervention (n= 15)
Did not receive allocated intervention (group interruption) (n=5)
Follow-Up
Lost to follow-up (treatment interruption) (n= 1)
Discontinued intervention (palatal miniscrew instability) (n= 1)
Lost to follow-up (treatment interruption) (n= 1)
Discontinued intervention (n= 0)
Analysis
Analysed (n= 18)
Excluded from analysis (n= 0)
Analysed (n= 14)
Excluded from analysis (n= 0)

Fig 1.

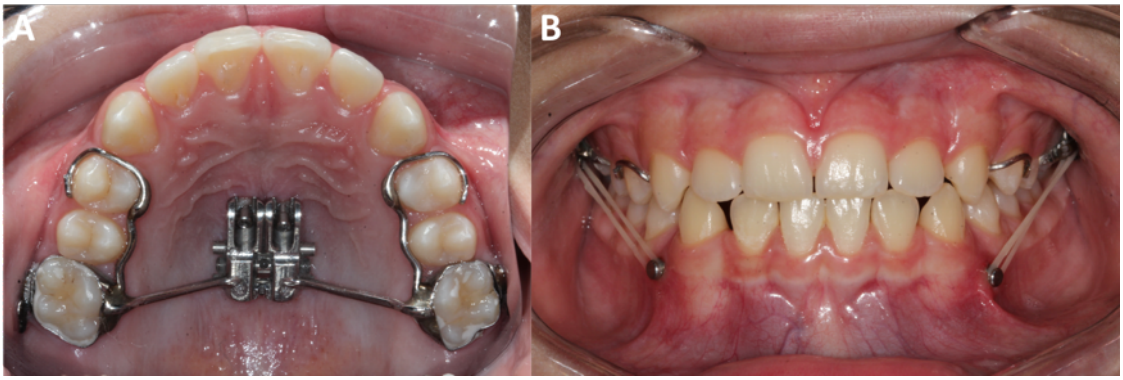

Fig 2.

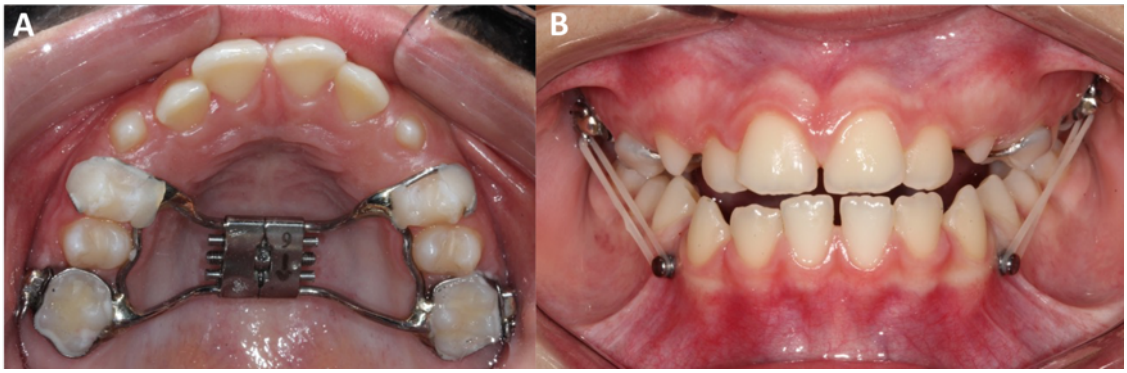

Fig 3.

Table I. Baseline characteristics of the groups and treatment time.

Variable	***Group HH***	***Group CH***	***P value****
Sex, n			
Female	8	6	0.928
Male	10	8	
Total, n	18	14	
Mean initial age, y (SD)	10.80 (1.04)	11.44 (1.26)	0.102
Treatment time, m (SD)	11.38 (3.98)	11.00 (3.78)	0.782

Chi-square test (sex); t test (age and treatment time).

Table II. Intergroup comparisons of the starting forms (t test and Mann-Whitney U test).

Variable	***Group HH*** Mean (SD)	***Group CH*** Mean (SD)	***95% CI Lower, Upper***	***P value****
Sagittal skeletal				
SNA (º)	85.30 (4.71)	81.99 (3.35)	0.27, 6.35	0.034*
SNB (º)	84.20 (3.25)	81.72 (3.47)	-0.18, 5.15	0.067
ANB (º)	0.57 (2.35)	-0.04 (1.71)	-1.02, 2.26	0.447
Wits (mm)	-5.25 (2.07)	-5.61 (3.02)	-1.67, 2.40	0.715
Mx/Md diff (mm)	26.03 (3.33)	28.20 (4.34)	-5.22, 0.89	0.157
Co-A (mm)	79.11 (4.44)	76.57 (5.67)	-1.10, 6.19	0.165
Co-Gn (mm)	110.05 (6.98)	110.33 (10.52)	-7.31, 6.74	0.933
Co-Go (mm)	47.74 (3.85)	50.81 (5.31)	-6.73, 0.58	0.096
Na-AP (º)	177.43 (7.23)	178.56 (3.75)	-5.75, 3.49	0.618
Vertical skeletal				
Occ Plane to FH (º)	6.80 (3.29)	6.72 (4.97)	-2.82, 2.98	0.957
Palatal plane to FH (º)	-1.05 (3.25)	-2.67 (3.66)	-0.87, 4.12	0.194
FMA (MP – FH) (º)	25.59 (4.56)	25.43 (4.37)	-3.38, 3.71	0.926
Co-Go-Me (º)	124.96 (6.04)	125.53 (5.68)	-5.23, 4.08	0.802
ANS-Me (mm)	58.39 (6.02)	61.26 (6.62)	-7.88, 2.13	0.248
Teeth				
U1-palatal plane (º)	23.72 (2.98)	24.76 (3.80)	-3.48, 1.40	0.392
IMPA (º)	90.81 (6.40)	90.83 (7.81)	-5.66, 5.62	0.993
Overjet (mm)	-1.12 (2.18)	-0.40 (2.19)	-2.45, 1.01	0.401
Overbite (mm)	1.65 (2.69)	0.50 (1.71)	-0.66, 2.94	0.204
Molar Relation (mm)	-3.28 (2.45)	-2.47 (2.34)	-2.55, 0.94	0.251ψ

*Statistically significant at $P<0.05$; t test; ψ Mann-Whitney U test.

Table III. Intergroup comparisons of treatment changes (t test and Mann-Whitney U test).

Variable	***Group HH*** Mean changes (SD)	***Group CH*** Mean changes (SD)	***Diff*** Mean	***95% CI*** ***Lower, Upper***	***P value****
Sagittal skeletal					
SNA (º)	1.47 (1.41)	0.76 (1.29)	0.71	-0.27, 1.70	0.151
SNB (º)	-0.15 (1.64)	-0.36 (1.31)	0.21	-0.99, 1.38	0.736
ANB (º)	1.83 (1.69)	1.15 (1.52)	0.68	-0.61, 1.95	0.295
Wits (mm)	1.92 (2.48)	1.45 (2.05)	0.47	-1.35, 2.27	0.606
Mx/Md diff (mm)	-1.04 (2.64)	-0.11 (1.56)	-0.93	-2.67, 0.80	0.048*ψ
Co-A (mm)	1.95 (1.65)	0.71 (1.69)	1.24	0.01, 2.44	0.048*
Co-Gn (mm)	1.85 (2.89)	0.6 (2.66)	1.25	-0.95, 3.46	0.252
Co-Go (mm)	0.78 (2.80)	-1.65 (3.56)	2.43	-0.10, 4.96	0.059
Na-AP (º)	-3.46 (3.96)	-2.08 (3.00)	-1.38	-4.18, 1.42	0.321
Vertical skeletal					
Occ Plane to FH (º)	0.21 (2.01)	-0.54 (1.56)	0.75	-0.68, 2.18	0.325ψ
Palatal plane to FH (º)	-0.40 (2.07)	-0.46 (1.52)	0.06	-1.29, 1.40	0.932
FMA (MP – FH) (º)	0.95 (1.81)	1.07 (1.99)	-0.12	-1.62, 1.39	0.650ψ
Co-Go-Me (º)	0.44 (2.83)	-1.37 (2.21)	1.81	-0.20, 3.84	0.077
ANS-Me (mm)	1.01 (1.64)	1.01 (1.42)	0	-1.21, 1.23	0.991
Teeth					
U1-palatal plane (º)	-0.40 (1.00)	0.19 (0.73)	-0.59	-1.24, 0.05	0.073
IMPA (º)	0.26 (3.74)	-1.71 (2.56)	1.97	-0.58, 4.53	0.125
Overjet (mm)	2.99 (2.27)	2.03 (2.54)	0.96	-0.94, 2.88	0.202ψ
Overbite (mm)	-1.09 (2.01)	-0.64 (1.35)	-0.45	-1.80, 0.94	0.523
Molar Relation (mm)	2.3 (1.99)	2.47 (2.72)	-0.17	-1.88, 1.52	0.896ψ

*Statistically significant at $P<0.05$; t test; ψ Mann-Whitney U test.

2.2 ARTICLE 2

Upper airway changes in miniscrew-anchored maxillary protraction with hybrid and hyrax expanders: a randomized clinical trial

ABSTRACT

Introduction: The aim of this study was to compare the upper airway space changes after miniscrew-anchored maxillary protraction with hybrid and conventional hyrax expanders. **Methods:** The sample comprised 40 Class III growing patients that were randomized into two groups of miniscrew-anchored maxillary protraction. The group HH was treated a hybrid hyrax appliance in the maxilla and two miniscrews distally to the canines in the mandible. Class III elastics were used from the maxillary first molar to the mandibular miniscrews until anterior crossbite correction. The group CH was treated with a similar protocol except for the conventional hyrax expander in the maxilla. CBCT was obtained before (T1) and after 12 months of therapy (T2). The shape and size of upper airway were assessed. Intergroup comparisons were performed using independent t tests ($p<0.05$). **Results:** The group HH was composed by 13 patients (6 female, 7 male) with a mean age of 10.42 years. The group CH was composed by 15 patients (5 female, 7 male) with a mean age of 11.38 years. Good reproducibility was found for all measurements. Anteroposterior and transversal increases of complete upper airway were found for both groups. The oropharynx and the most constricted area increased similarly in both groups. **Conclusions:** Maxillary protraction using miniscrews as anchorage produced an increase in the upper airways. No differences in upper airway changes were observed using protraction anchored on hybrid or conventional hyrax expanders. **Registration:** The trial was registered at ClinicalTrials.gov, under the identifier NCT03712007. **Protocol:** This trial protocol was not published.

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KEYWORDS

Orthodontics, Interceptive; Orthodontic appliance; Palatal expansion technique; Airway Management; Imaging, Three-Dimensional.

INTRODUCTION

Skeletal discrepancies and maxillary deficiency can influence the airway space volume and morphology.[1] The airway space is divided into a nasopharynx, oropharynx, and hypopharynx all related to several structures of the face.[2] In Class III growing patients, orthopedic maxillary protraction cause not only skeletal changes but also modifications in the adjacent soft tissue as the airway.[2-5]

Several studies investigated the effects of maxillary protraction on pharyngeal airway dimension showed conflicting results.[3,6,7] The effects of maxillary protraction using facemask therapy on the upper airway was evaluated using the cephalometric radiographs in a sample of Class III malocclusion patients with 10.3 years of age.[8] The results indicated that the maxillary protraction increased the naso and oropharynx after treatment.[8] Previous studies using conventional 2D evaluation found that facemask therapy associated with RME caused a pharyngeal airway increase.[4,5,8,9] On the other hand, previous studies reported that the nasopharyngeal and oropharyngeal airway dimensions remained unchanged after maxillary protraction.[7,9] A recent meta-analysis found that facemask therapy associated with RME increase the upper airway space changes in children or young adolescents.[4] However, authors reported that 2D cephalometric radiography might not completely reflect the exact changes in the pharyngeal airway space.[4]

Most of the previous studies evaluated the changes of the upper airway using cephalometric radiography. 2D cephalometric radiography may limit the accuracy of the measurements of upper airway.[10-12] Currently, cone beam computed tomography (CBCT) have been widely used to assess the upper airway shape and volume.[3,13-15] CBCT offers the advantages of volumetric rather than linear measurements, distortion-free measurements, and measurements that are independent of head positioning.[3,14] Chen et al. [3] used CBCT in order to evaluate changes of upper airway after maxillary protraction with facemasks. An increase was found in the volume of nasopharynx and oropharynx of growing patients with Class III malocclusion when compared to untreated Class III patients.[3] Nguyen et al. [14], using CBCT, showed an increase in airway volume and oropharyngeal dimensions in subjects treated with bone anchored maxillary protraction (BAMP). BAMP is an innovative treatment modality that uses miniplates to anchor Class III elastics and correct the maxillary deficiency.[16,17] Miniscrew-anchored maxillary protraction (MAMP) is a BAMP- derived therapy that replace the mandibular miniplates for miniscrews. The MAMP therapy seems to be an

effective treatment alternative for Class III malocclusion correction in growing patients. However, no previous studies evaluated the effect of MAMP therapy on the upper airway volume and morphology.

Specific objectives and hypotheses

The aim of this study was to compare the upper airway changes after miniscrew-anchored maxillary protraction with hybrid and hyrax expanders. The null hypothesis is that miniscrew-anchored maxillary protraction with hybrid and hyrax expanders have similar upper airway changes after treatment.

METHODS

Trial design and any changes after trial commencement

This study was a single center randomized clinical trial with two parallel arms and a 1:1 allocation ratio. Changes in participants number were performed after trial commencement and were described below (Fig 1). This clinical trial was registered under the number NCT03712007 at Clinicaltrials.gov.

The study followed the Consolidated Standards of Reporting Trials guidelines (CONSORT).[18] The study was approved by the Ethics in Research Committee of Bauru Dental School, University of São Paulo, Brazil (protocol number 67610717.7.0000.5417) where patients were treated by the same orthodontist (FM). The airway evaluation was performed at the Department of Orthodontics of Case Western Reserve University, Cleveland, Ohio, USA. All patients and parents signed the written informed consent before treatment.

Participants, eligibility criteria and settings

The individuals were recruited in the Orthodontic Clinic of Bauru Dental School, University of São Paulo, from July 2017 to March 2018. The sample consisted of 40 individuals with Class III malocclusion from 9 to 13 years of age. The eligibility criteria were: (1) both sexes; (2) late mixed or early permanent dentition; (3) skeletal Class III malocclusion with maxillary deficiency (Wits appraisal of -1mm or less); (4) anterior crossbite or incisor edge-to-edge relationship. Exclusion criteria were individuals with history of previous orthodontic treatment, non-erupted mandibular permanent canines and individuals with special needs or syndromes.

Interventions

The two treatment groups differ in the maxillary anchorage strategy. The group HH was treated with miniscrew-anchored maxillary protraction therapy anchored in a hybrid expander.[19] A hybrid expander was used in the maxilla (Fig. 2A) and two mandibular miniscrews were positioned distal to the permanent canines, bilaterally (Fig. 2A). Patients were instructed to wear full time Class III elastics connecting the maxillary first molar hooks to the mandibular miniscrews (Fig. 2A). The group CH was treated with a similar protocol using conventional hyrax expander instead of hybrid expanders (Fig. 2B). Parents were oriented to activate the expander screw 1/4 turn twice a day for 14 days, achieving 5.6mm of expansion. Traction started with a load of 150g/side in the first month and 250g/side in the following period. Class III elastics were changed twice a day in the morning and night.[17] The elastics were used until reaching an overjet correction or until a maximum of 12 months of treatment. Active treatment time was a mean of 11.30 (SD 4.58) and 10.83 (SD 4.08) months in the group HH and CH, respectively (Table I). After appliance removal, a chin cup was used during the night as active retention.

Cone-beam computed tomography (CBCT) was obtained before (T1) and after treatment (T2), using the i-CAT 3-dimensional system (Imaging Sciences International, Hatfield, PA, USA) with a protocol of 13cm-FOV, 120 kV, 23.87 mA and a voxel size of 0.25 mm. All CBCT data were exported in DICOM format (Digital Imaging and Communications in Medicine) to Dolphin 3D Imaging 11.5 software (Patterson Dental Supply, Inc., Chatsworth, CA, USA). The head orientation was standardized in the sagittal view, positioning the Frankfort plane with the horizontal plane (considering the right side); in the frontal view, leveling the orbital plane with the horizontal plane; and in the axial view, positioning the midsagittal plane passing on the anterior and posterior nasal spine.

Outcomes and any changes after trial commencement

The primary outcomes were dentoskeletal and airway changes produced by maxillary protraction. Dentoskeletal outcomes were evaluated in another study. Group HH and CH displayed significantly different Co-A changes of 1.95 and 0.71, respectively. The SNA angle change was 1.47 and 0.76 in group HH and CH ($p=0.151$), respectively.

The primary outcomes of this study were the shape and volume analysis performed by innovative open source softwares. Semiautomatic airway segmentations were performed in the ITK-SNAP software (http://www.itksnap.org). The palatal plane was used as the upper limit of oropharynx (OP) (Fig 3). A parallel line passing in the antero-inferior border of the third cervical vertebrae (C3) was used as lower limit of the OP (Fig 3). The upper airway volume was generated after segmentation. To ensure a spherical topology, the constructed airways models were processed to avoid spicules and holes in the model.[20] The epiglotic vallecula was excluded.[21] The shape analysis was performed in 3D Slicer (www.slicer.org) via the SlicerSALT project (salt.slicer.org, Vicory et al 2018).[22] Parametric surface models were created for each segmented airway (Figs 4 and 5). The mean latitude axis and minimum axial area was found for each model. The minimum axial area (minAx) was considered the most constricted axial area in the oropharyngeal. Surface superimpositions and color maps were generated to visually compare the changes between T1 and T2 (Figs 6 and 7).

The secondary outcomes included the changes in the volume of oropharynx (OP) and minimum axial area (minAx) calculated using Dolphin 3D Imaging 11.5 software (Patterson Dental Supply, Inc., Chatsworth, CA, USA). The OP volume was defined using the same anatomic boundaries of the shape analysis. The threshold sensitivity was individualized for each scan.

Sample size calculation

The sample size calculation considered maxillary anteroposterior changes described in a previous study. Sample size was calculated in order to provide 80% of test power, at a significance level of 0.05. With a minimum intergroup difference of 2 mm and a standard deviation of 1.4 mm in maxillary length (CoA),[16] a sample of nine patients was required for each group.

Interim analyses and stopping guidelines

Not applicable.

Randomization (random number generation, allocation concealment, implementation)

Randomization, envelopes concealment and allocation were performed by different operators. Randomization was performed electronically in the

Randomization.com website (http://www.randomization.com). Opaque, sealed and numbered envelopes containing the group name were made according to the sequence generated by the randomization.[23]

The allocation process started after recruitment and the signed informed consent was obtained. The name of patient and date of allocation were identified in the external surface of the envelopes. After that, the envelope was opened to verify to which group the patient was allocated. During treatment, undesirable dental effects in the maxillary arch were observed in the group CH. For ethical reasons, the group CH treatment was interrupted after 11 months of treatment and before installation in the last 5 individuals.

Blinding

To avoid bias all CBCT scans were unidentified before assessment, achieving a simple blinding. Double blinding was not accomplished considering that both operator and patient were aware of the type of treatment performed.

Statistical analysis

Repeated measurements on 30% randomly selected patients were performed after 1 month by the same examiner. The intraclass correlation coefficient (ICC) and Bland-Altman limits of agreement were used to assess the reliability of repeated measures and the correlation between softwares.

Normal distribution was verified by Kolmogorov-Smirnov test. Intergroup comparison was evaluated using t tests. A significance level of 5% was regarded for all tests. Statistical analyses were performed with SPSS Statistical Software Package (Version 21.0; SPSS, Chicago, IL, USA).

RESULTS

Participant flow

Forty individuals were selected and agreed to participate in this trial. Twenty individuals were allocated to the group HH. After the trial commencement one patient quit and another was excluded due to palatal miniscrew instability. Eighteen individuals were treated in group HH. Before CBCT upper airway analysis, five patients had to be excluded due to unsuitability of CBCT scan (teeth were not in occlusion). The final

sample in the group HH comprised 13 individuals with a mean age of 10.42 years (6 female and 7 male).

Fifteen patients were treated in the group CH. One patient interrupted treatment and two were excluded due to unsuitability of CBCT scan (teeth were not in occlusion). The final sample of the group CH comprised 12 individuals with a mean age of 11.38 years (5 female and 7 male). Figure 1 shows the complete participant flow chart.

Baseline data

The demographic characteristics of each group are presented in Table I. Both groups presented similar sex distribution and treatment time. The group CH presented a slight greater initial age.

Baseline characteristics are presented in Table II. Similar upper airway size was observed in both groups.

Number analyzed for each outcome, estimation and precision, subgroup analyses

In the intraexaminer analysis, ICC varied from 0.808 to 0.997 showing good to excellent agreement of the measurements. ICC showed a high correlation for both minimum axial area and volume measurements between the softwares (Table III).

The oropharynx volume and minimum axial area showed similar increases in both groups (Table IV). Figure 7 shows individual treatment changes in the upper airway illustrated using color maps. Both transversal and anteroposterior changes were observed in both groups (Fig 7).

Harms

The frequency of instability of mandibular miniscrews in the groups HH and CH were 15.7% and 17.8%, respectively. When mandibular miniscrews were unstable before anterior crossbite correction they were replaced after two weeks in the same region with 30º inclination. The instability of palatal miniscrews was 2.6%.

Treatments were performed until the anterior crossbite correction or after 12 months of therapy. Patient compliance was very important for successful outcomes. No-compliant patients presented poor results, however they were also considered in the final analysis.

DISCUSSION

Main findings in the context of the existing evidence and interpretation

In the past decade, there was a markedly increase in volumetric airway analyses and obstructive sleep apnea (OSA) assessment.[24] Previous studies showed that maxillary protraction increased the upper airway volume and most constricted area.[3,4,9,14,25] The airway volumetric increase after maxillary advancement can benefit the OSA management in growing subjects.[26] This study compared three-dimensionally the upper airway space between two different protocols of miniscrew-anchored maxillary protraction in growing Class III malocclusion patients.

An adequate reproducibility of volumetric measurements was found for all measurements. These results are in accordance with previous studies demonstrating that CBCT is a reliable tool for measuring the upper airway volume.[27,28] The threshold sensitivity influence in OP volume.[29] A fixed threshold interval selection produced different segmentation and volume measurements when comparing different softwares.[29] In this study, the threshold sensitivity was individualized for each scan showing an adequate reproducibility for the OP measurements (ICC varying from 0.985 to 0.986). CBCT accuracy and reliability for upper airway analyses showed conflicting results in previous studies.[15,27,29,30] CBCT allows a static rather than dynamic examination of the airway.[15] During the exam, some factors as the respiratory phase, CBCT definition, mandible and head position needs to be controlled.[28,31] Variability in the dimensions and shape of the airway can occur when the CBCT is acquire with no standardization. On the other hand, CBCT is considered an easy access and low-cost tool to assess the airway volume.[28] CBCT has the possibility to define the boundaries and segment the soft tissue and airway spaces accurately.[27,28]

In this study, two different methods were used to assess the upper airway. The first analysis included the ITKSNAP for performing a semi-automatic segmentation and volume assessment followed by the SPHARM-PDM module in the SlicerSalt software that performed an upper airway model shape analysis. Although this first analysis is time consuming, the softwares are open access. The second method of analyzing the upper airways was Dolphin3D software that presented a highly intuitive interface even though consists in a high-cost commercial software. A good correlation was found when comparing the two softwares (Table III). A previous study reported good correlation between three different commercial softwares for upper airway assessments with semi-automatic segmentations (Dolphin3D, InVivoDental and

OnDemand3D).[27] However, the accuracy was considered poor when comparing automatic and manual segmentation softwares.[27] The ITKSNAP + SPHARM-PDM and Dolphin3D upper airway analysis were also previously compared.[21] A good reproducibility was reported for both intra and inter examiner correlations.[21] No differences were reported between the three-dimensional volumetric assessments between these softwares.[21]

Miniscrew-anchored maxillary protraction produced similar increases in the upper airway volume after treatment with hybrid and conventional hyrax expanders (Table IV). Anteroposterior increases were observed in the oropharynx after treatment (Fig 7). One of the possible explanations was the orthopedic maxillary advancement produced by MAMP therapy. The correlation between maxillary protraction and the increase in the upper airway dimension was previously reported.[2] Additionally, significant increases on the pharyngeal airway dimensions were reported after facemask therapy.[4,8,32] On the other hand, Baccetti et al.[9] found no changes in the sagittal airway dimension after facemask therapy.

The oropharynx also showed an increase in the transversal dimension after treatment (Fig 7). The increase in the transversal dimension might be correlated with maxillary expansion performed before maxillary protraction. Increases in the airway dimensions after maxillary expansion were previously reported.[4,33,34] Additionally, craniofacial growth might have been contributed to sagittal and transversal increase of the upper airways. [13,34-36]

The minimum axial area corresponds to the most constricted axial area in the oropharynx and it is one of the most important changes to be assessed in the upper airway studies.[26,37] Determining the minimum axial area can help to locate the exact location of the airway obstruction, which can benefit the treatment plan of OSA patients.[37,38] In our study, both groups showed similar increases in the minimum axial area after treatment (Table IV). The maxillary advancement may be the main cause for the change in the airway most constricted area. Differently than our findings, no differences were reported for the minimum axial area after BAMP therapy.[15] Class III malocclusion patients diagnosed with obstructive sleep apnea can benefit from treatment with maxillary protraction using both hybrid and conventional hyrax.

Limitations

Our study main limitation is the absence of an untreated Class III malocclusion control group for growth comparisons. However, maintaining a Class III population without treatment would be unethical. The number of patient exclusion due to CBCT quality decreasing the sample size was also a limitation of this study. However, the remained sample size was enough to demonstrate volume and shape changes in study groups.

CONCLUSIONS

Maxillary protraction using miniscrews as anchorage produced an increase in the upper airways. The null hypothesis was accepted. No differences in upper airway changes were observed using protraction anchored on hybrid or conventional hyrax expanders.

ACKNOWLEDGMENTS

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FIGURE LEGENDS

Fig 1. CONSORT flow chart.

Fig 2. MAMP therapy in group HH and group CH.

Fig 3. Oropharynx morphologic limits.

Fig 4. Before (grey) and after (red) parametric surface models of the oropharynx created by the SPHARM-PDM software for group HH.

Fig 5. Before (grey) and after (red) parametric surface models of the oropharynx created by the SPHARM-PDM software for group CH.

Fig 6. Surface superimpositions from before (grey) and after (red) parametric surface models of the oropharynx created by the SPHARM-PDM software for the experimental and control groups.

Fig 7. Color maps illustrating the changes produced by the experimental and control group in the oropharynx. Red indicates the most affected regions and green the less affected.

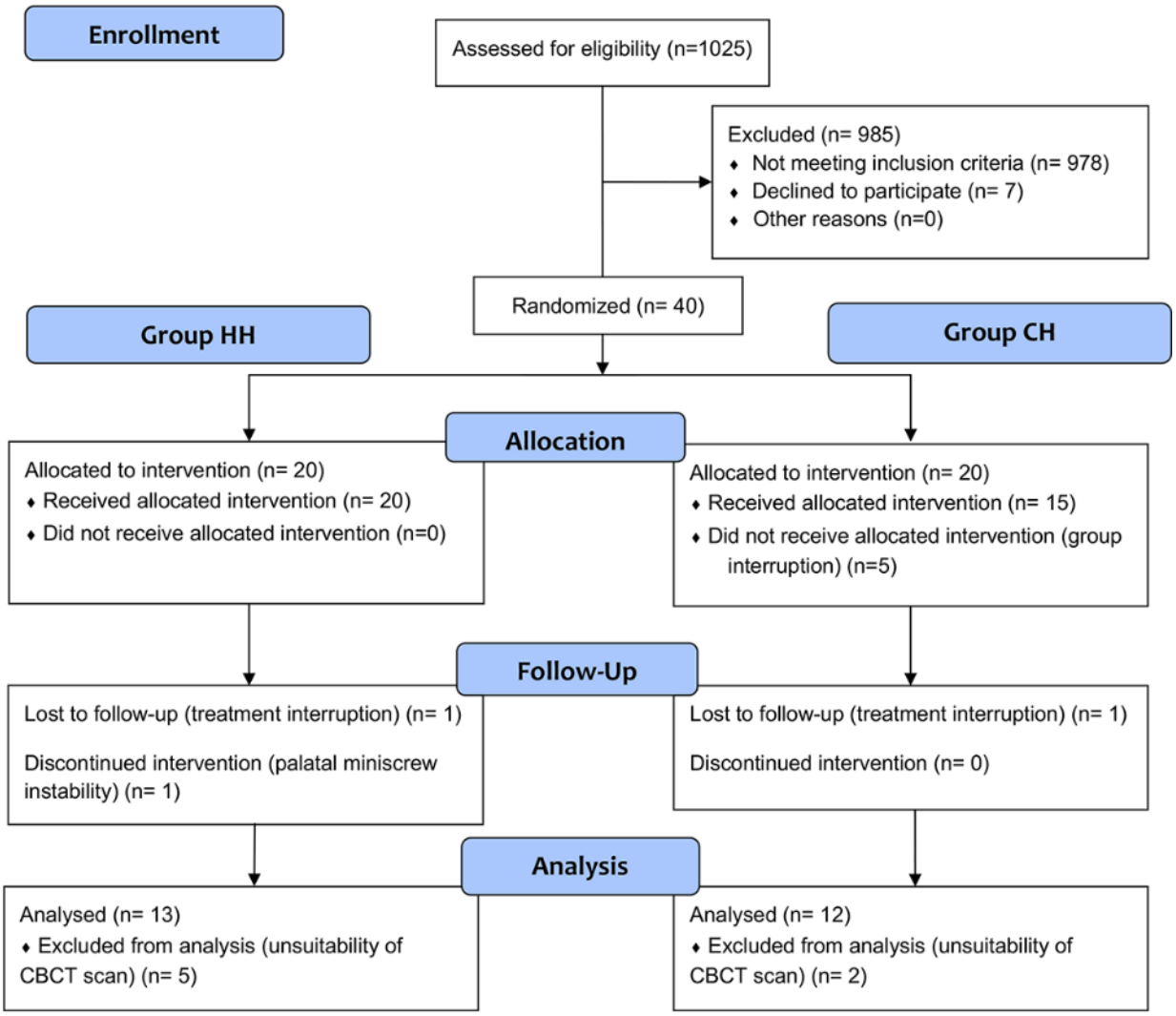

Enrollment
Assessed for eligibility (n=1025)
Excluded (n= 985)
Not meeting inclusion criteria (n= 978)
Declined to participate (n= 7)
Other reasons (n=0)
Randomized (n= 40)
Group HH
Group CH
Allocation
Allocated to intervention (n= 20)
Received allocated intervention (n= 20)
Did not receive allocated intervention (n=0)
Allocated to intervention (n= 20)
Received allocated intervention (n= 15)
Did not receive allocated intervention (group interruption) (n=5)
Follow-Up
Lost to follow-up (treatment interruption) (n= 1)
Discontinued intervention (palatal miniscrew instability) (n= 1)
Lost to follow-up (treatment interruption) (n= 1)
Discontinued intervention (n= 0)
Analysis
Analysed (n= 13)
Excluded from analysis (unsuitability of CBCT scan) (n= 5)
Analysed (n= 12)
Excluded from analysis (unsuitability of CBCT scan) (n= 2)

Fig 1.

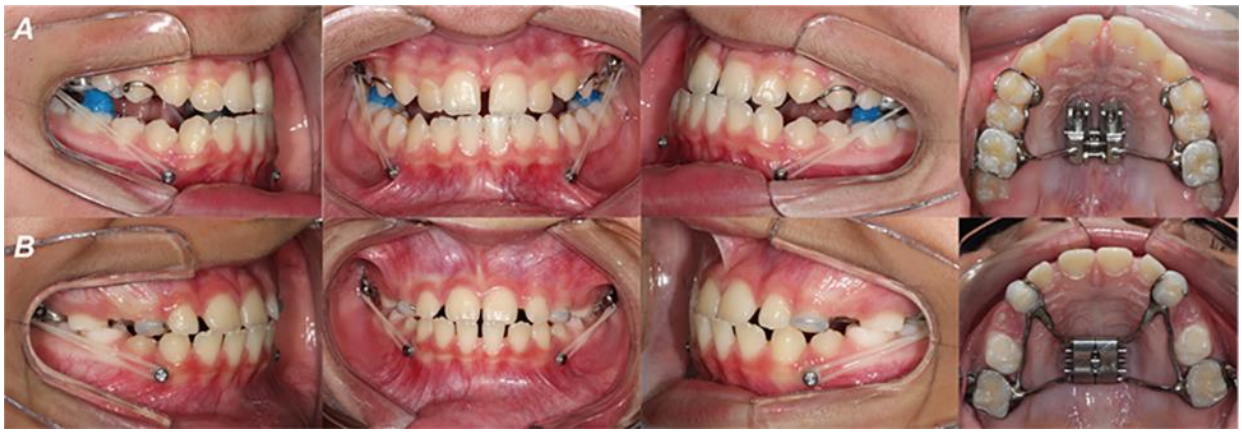


Fig 2.

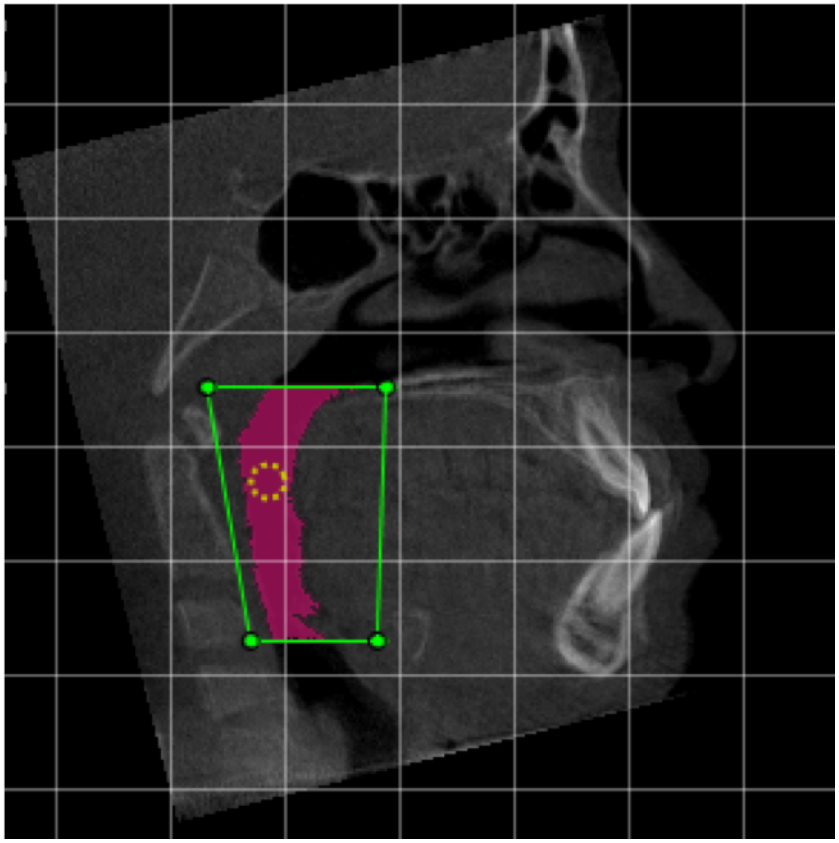


Fig 3.

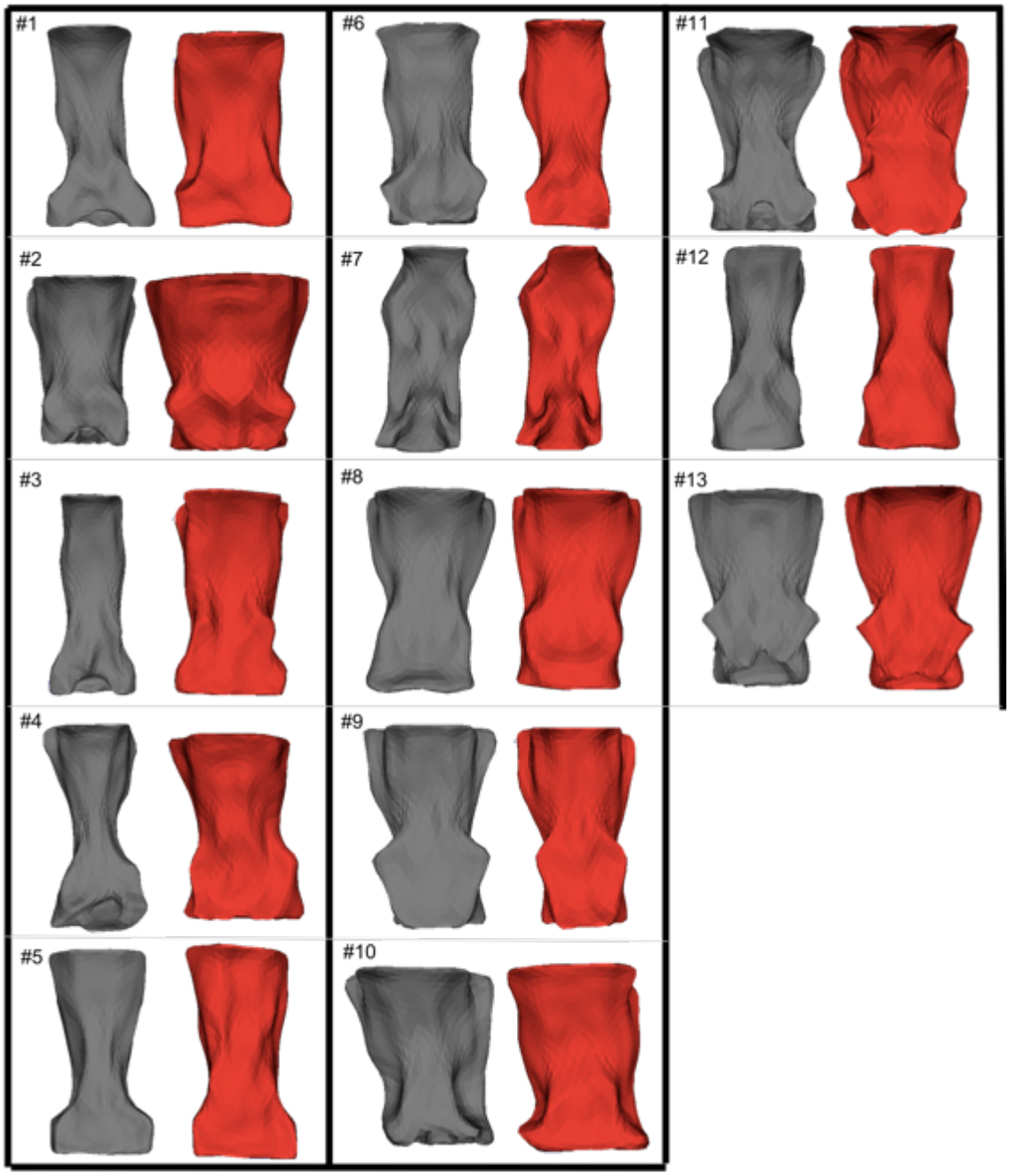
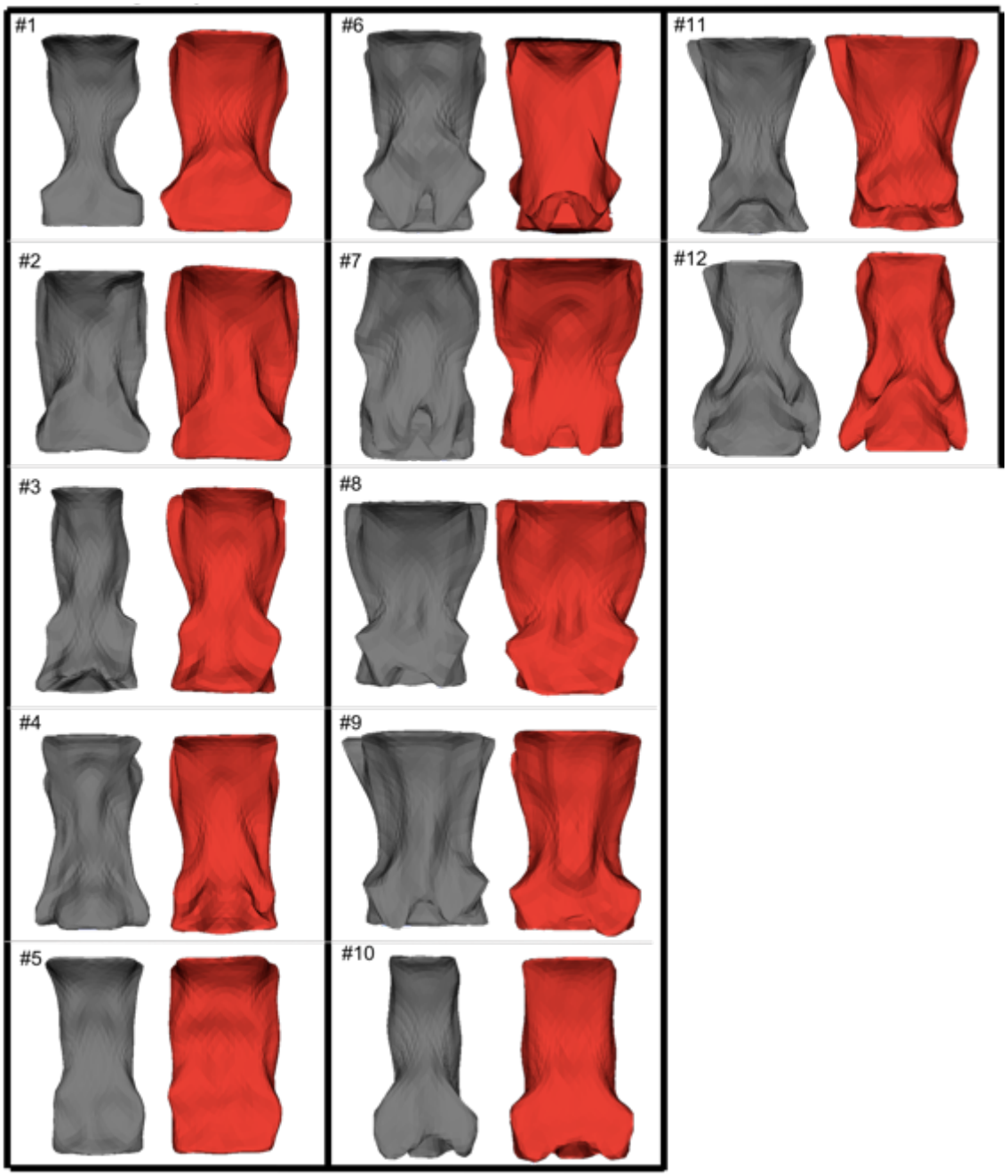


Fig 4.



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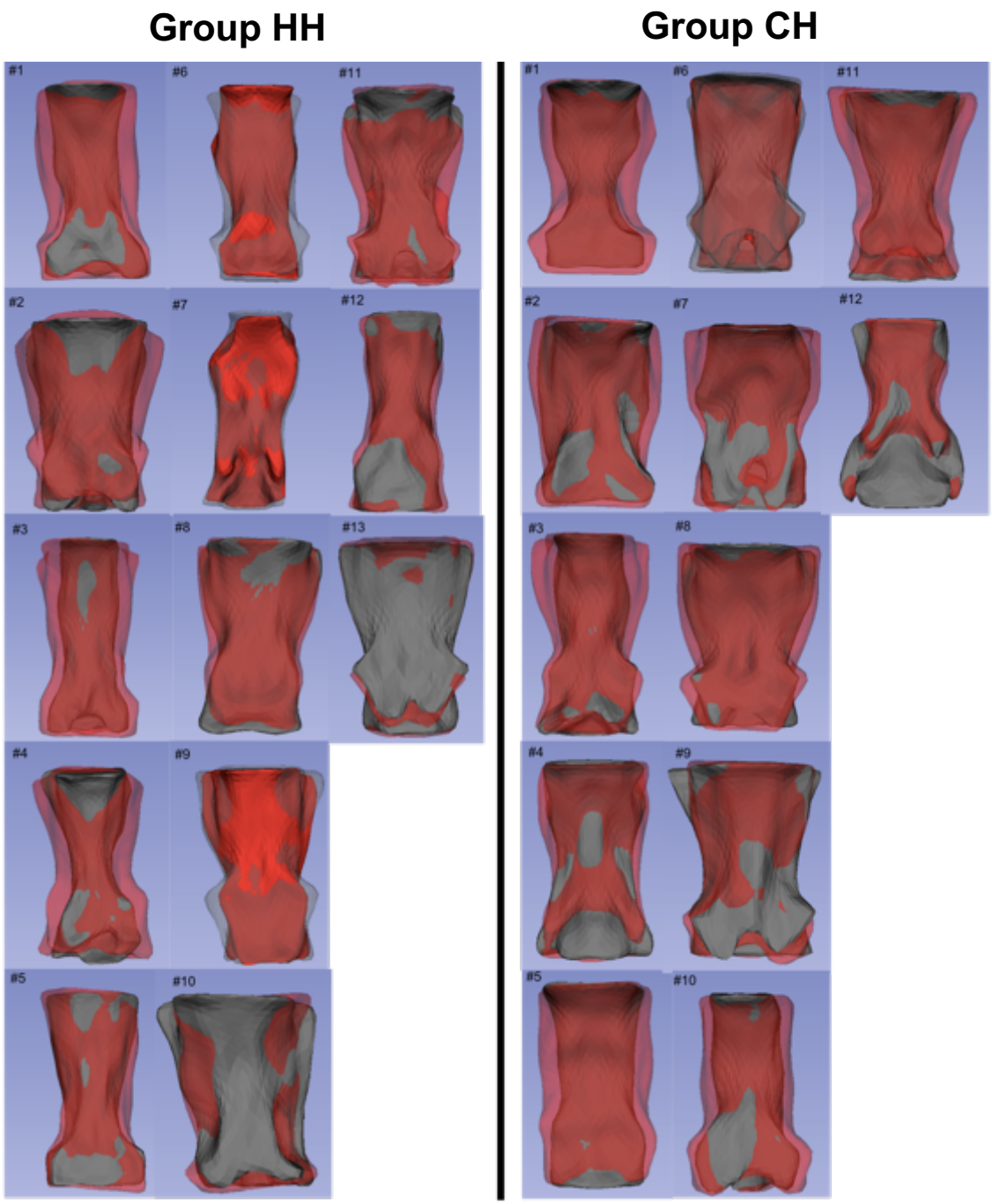

Fig 6.

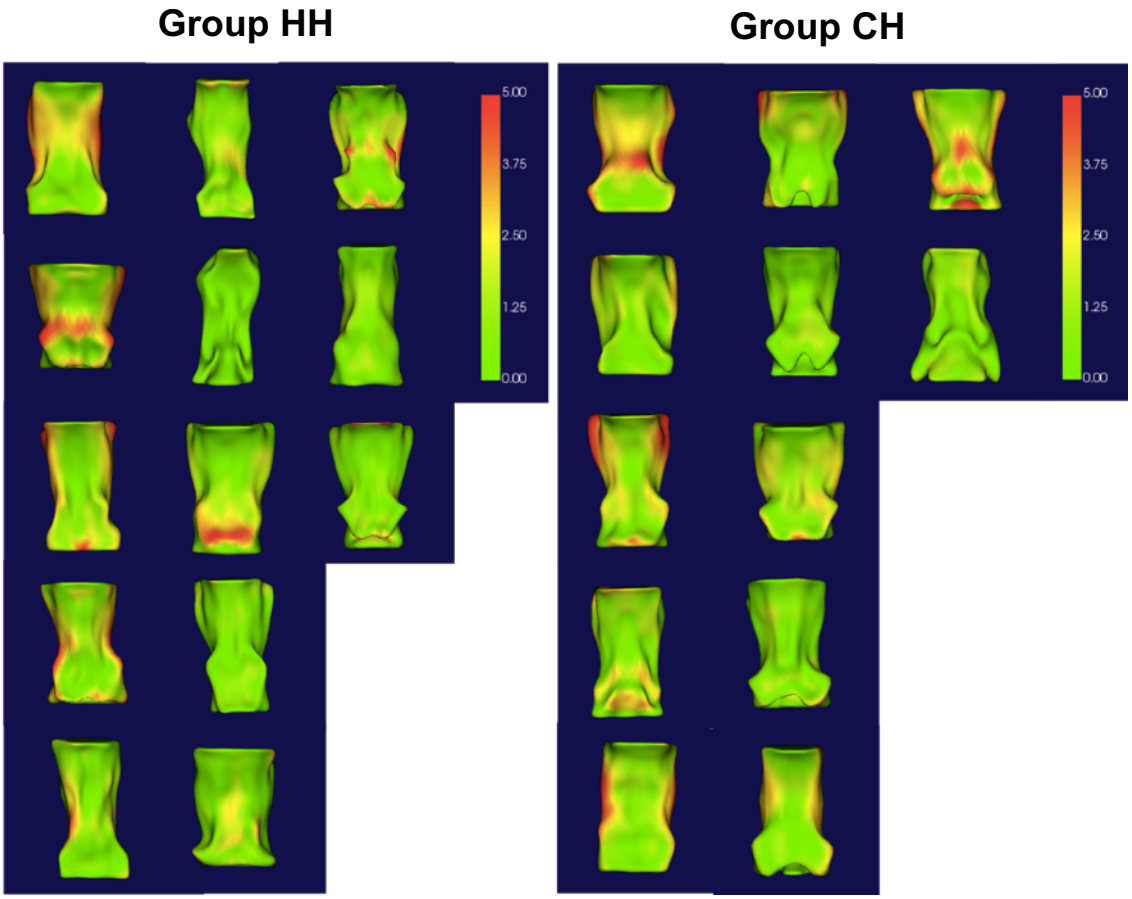

Fig 7.

Table I. Baseline characteristics of the groups and treatment time.

Variable	*Group HH*	*Group CH*	*P value**
Sex, n			
Female	6	5	0.821
Male	7	7	
Total, n	13	12	
Mean age, y (SD)	10.42 (0.85)	11.38 (1.26)	0.036*
Treatment time, m (SD)	11.30 (4.58)	10.83 (4.08)	0.788

Chi-square test (sex); t test (age and treatment time).

Table II. Intergroup comparisons of the starting forms (t test).

Variable	***Group HH*** Mean (SD)	***Group CH*** Mean (SD)	***95% CI*** ***Lower, Upper***	***P value****
SPHARM + ITK				
minAx (mm^2)	172.28 (81.14)	164.44 (66.04)	-71.70, 44.33	0.630
OP Volume (mm^3)	11352.73 (5948.01)	10289.02 (3015.69)	-2928.75, 5056.17	0.586
DolphinD				
minAx (mm^2)	156.00 (61.52)	176.25 (67.19)	-73.50, 33.00	0.440
OP Volume (mm^3)	12196.38 (6427.15)	11429.92 (3233.14)	-3500.71, 5033.65	0.714

*Statistically significant at $P<0.05$; t test.

Table III. Softwares comparison with intraclass correlation coefficients (ICC) and Bland-Altman limits of agreement (95% LoA).

Variable	***SPHARM + ITK*** Mean (SD)	***Dolphin3D*** Mean (SD)	***Diff*** Mean (SD)	***ICC***	***Bland-Altman 95% LoA***	
					Lower	***Upper***
minAx (mm^2)	213.92 (94.64)	210.37 (83.74)	3.55 (36.45)	0.918	-74.98	67.89
OP Volume (mm^3)	13575.05 (6922.24)	15048.42 (7337.12)	1473.37 (1123.68)	0.967	-729.04	3675.79

Table IV. Intergroup comparisons of treatment changes (t test).

Variable	***Group HH*** Mean changes (SD)	***Group CH*** Mean changes (SD)	***Diff*** Mean	***95% CI*** ***Lower, Upper***	***P value****
SPHARM + ITK					
minAx (mm^2)	51.27 (81.06)	64.96 (53.09)	-13.69	-71.70, 44.33	0.630
OP Volume (mm^3)	2034.86 (3713.09)	4018.94 (4078.82)	-1984.08	-5286.24, 1318.08	0.226
Dolphin3D					
minAx (mm^2)	52.00 (72.41)	55.25 (74.74)	-3.25	-64.15, 57.65	0.913
OP Volume (mm^3)	3518.31 (5140.97)	3701.00 (4031.23)	-182.69	-4028.04, 3662.65	0.923

*Statistically significant at $P<0.05$; t test.

2.3 ARTICLE 3

Orthopedic outcomes of hybrid and conventional hyrax expanders: secondary data analysis from a randomized clinical trial

ABSTRACT

Introduction: The aim of this study was to compare the effects of the hybrid and conventional hyrax expanders in growing subjects**. Methods:** Group HH was composed by patients in treated with the hybrid hyrax expander with two miniscrews. Group CH comprised patients treated with conventional hyrax expanders. CBCT exams and digital dental models were obtained before expansion (T1) and 11-month post-expansion (T2). The primary outcomes included the orthopedic transversal effects of expansion. The secondary outcomes comprised the dental effects of rapid maxillary expansion. A simple randomization process was used. Intergroup comparison was performed using t tests (p<5%). **Results:** Forty patients were randomized into two groups. The final sample comprised 18 subjects (8 female, 10 male; initial age of 10.8 years) in the group HH and 14 subjects (6 female, 8 male; initial age of 11.4 years) in the group CH. Significantly greater increases in the nasal cavity width and buccal alveolar crest width were found for the hybrid hyrax group. The maxillary interpremolar distance showed a greater increase in the conventional hyrax group. No intergroup differences were observed for arch shape changes. **Conclusions:** The hybrid hyrax expander produced greater increases in the nasal cavity width and buccal alveolar crest width. The group CH showed a greater increase in the maxillary interpremolar width. No differences were observed for the intermolar width, intercanine width, arch length and arch perimeter. Arch size and shape showed similar changes between groups. **Registration:** The trial was registered at ClinicalTrials.gov, under the identifier NCT03712007. **Protocol:** This trial protocol was not published.

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KEYWORDS

Orthodontics, Interceptive; Orthodontic appliance; Palatal expansion technique; Dental models; Imaging, Three-Dimensional.

INTRODUCTION

Rapid maxillary expansion (RME) is indicated for treating maxillary constrictions. The orthopedic opening of the midpalatal suture represents the main effect of RME procedure.[1] Conventional expanders are commonly used for RME.[2] Recently, innovative expanders using skeletal anchorage for performing RME procedure were described.[3,4] Is there an increase in the orthopedic effect of RME by incorporating skeletal anchorage to conventional expanders?

The first report of skeletal-anchored RME was in a 14-year old female adolescent and used two small implants in the palate.[5] Lee et al. were the first to use miniscrew-supported RME procedure.[3] Using four palatal miniscrews as anchorage, an increase of 8.3 mm and 2.4 mm was obtained in the intermolar distance and in maxillary bone base in a young adult patient.[3] Miniscrew-anchored rapid palatal expansion (MARPE) seems to extend the age limit for RME.[3,6-8] A previous study using a MARPE in a sample of 69 adult patients with a mean age of 20.9 years showed a success rate of 86.96% in the opening of the midpalatal suture.[7] An increase in the maxillary width of 2.11 mm was found after MARPE.[7] The nasal cavity width and intermolar width also showed significant increases of 1.07 mm and 8.32 mm after expansion, respectively.[7] Both skeletal and dental changes remained stable during the mean follow-up period of 30.2 months.[7] Additionally, an instability rate of 5.0% was found for the palatal miniscrews and 13.0% showed clinically acceptable mobility after expansion.[7]

A hybrid hyrax was reported for growing patients by Wilmes et al.[4] The hybrid hyrax was anchored both on the maxillary permanent first molars and on two parasutural miniscrews in the anterior region of the palate.[4] The use of a hybrid hyrax was indicated as anchorage for maxillary protraction with facemask therapy.[9-11] A previous study compared the periodontal and skeletal effects produced by the RME using a hybrid and conventional hyrax expanders in adolescent patients in the permanent dentition.[12] Similar skeletal effects were found in both groups.[12] The hyrax expander produced greater increases in the interpremolar distances compared to the hybrid expanders.[12] An increase in the palatal bone thickness and a decrease in the buccal bone thickness of anchorage maxillary first molars were found for both expanders.[12] A greater decrease of the buccal bone plate of first premolars was found for the conventional hyrax expanders when compared to hybrid expanders.[12]

The orthopedic outcomes of miniscrew-supported maxillary expanders were more extensively studied in adult patients. The literature is limited regarding the dentoskeletal effects of the hybrid expander in growing patients. A previous study compared the dentoskeletal and periodontal effects of the hybrid and conventional hyrax expanders, however a small sample size and the amount of screw activation was not standardized.[12] Further studies are necessary to more extensively compare the orthopedic effects produced by the hybrid and conventional hyrax expander in growing individuals.

Specific objectives and hypotheses

The aim of this study was to compare the orthopedic outcomes of hybrid and conventional hyrax expanders in growing patients. The null hypothesis was that the dentoskeletal effects produced by both expanders are similar.

METHODS

Trial design and any changes after trial commencement

This study was a secondary data analysis from a previous single center randomized clinical trial. Two parallel arms and a 1:1 allocation ratio was used. Changes in participant number were made after trial commencement and were described below (Fig 1).

The study followed the Consolidated Standards of Reporting Trials guidelines (CONSORT).[13] The study was approved by the Ethics in Research Committee of Bauru Dental School, University of São Paulo, Brazil (protocol number 67610717.7.0000.5417). All patients and parents signed the written informed consent before treatment.

Participants, eligibility criteria and settings

The individuals were recruited in the Clinic of Orthodontics of Bauru Dental School, University of São Paulo, from July 2017 to March 2018. The sample consisted of 40 individuals with posterior crossbites and age varying from 9 to 13 years. The eligibility criteria included: (1) both sexes; (2) late mixed or early permanent dentition: and (3) Class I and Class III malocclusions. Exclusion criteria included individuals with history of previous orthodontic treatment, patients with special need or syndromes.

Interventions

Group HH was treated with a pre-manufactured 9-mm hybrid hyrax expander (Peclab, Belo Horizonte, Brazil). The expander was inserted posteriorly to the third palatal rugae, supported by bands in the maxillary first permanent molars and 1-mm distant from the palatal surface (Fig 2A). Two parasutural miniscrews of 1.8 mm diameter, 7 mm length and 4 mm transmucosal length were installed in the expander slots (Fig 2A). The miniscrews were installed under local anesthesia, using a contra-angle implant driver with maximum insertion torque of 35Ncm and 30 rotation/minute. Miniscrews were installed with an approximately 45º inclination relative to the occlusal plane, following the expander slot chamfer (Fig 3).

In Group CH, rapid maxillary expander was performed using a conventional hyrax expander (Fig 2B). Bands in the maxillary first permanent molars and bonded C shape clasps in the maxillary canines or premolars were used to support the expander (Fig 2B). In both groups, the expander screw was activated 1/4 turn twice a day for 14 days, achieving 5.6mm of expansion. After the active phase, expanders were maintained in the oral cavity for 11 months as a retention until a bone-anchored maxillary protraction therapy was performed for a previous study. The treatment time was 11.38 and 11.00 months for the experimental and control groups, respectively (Table I).

Cone-beam computed tomography (CBCT) and digital dental models were obtained before expansion (T1) and after the expander removal (T2). CBCT scans were obtained using the i-CAT 3-dimensional system (Imaging Sciences International, Hatfield, PA, USA) with a protocol of 120 kV, 23.87 mA, 13cm-FOV and a voxel size of 0.25 mm. The head orientation was standardized in the sagittal view, positioning the palatal plane parallel to the horizontal plane; in the frontal view, leveling the orbital plane parallel to the horizontal plane; and in the axial view, positioning the vertical plane simultaneously on the anterior and posterior nasal spine.

Outcomes (primary and secondary) and any changes after trial commencement

The primary outcomes of this study included the dentoskeletal changes of RME measured on CBCT scans. A coronal section passing through the center of the palatal root of the right maxillary permanent first molar was used to evaluate the transversal measurements. The variables illustrated in Figure 4A were measured using the Nemoscan software (Nemotec, Madrid, Spain).

The secondary outcomes included the maxillary dental arch dimensions measured on digital dental models (Fig 4B). The arch widths (at the molars, premolars and canines), arch length and arch perimeter were evaluated using the OrthoAnalyzer 3D software (3Shape A/S, Copenhagen, Denmark). Arch size and shape were measured using the softwares Stratovan Checkpoint (Stratovan Corporation, Davis, CA, USA) and MorphoJ (Klingenberg Lab, Manchester, UK) according to a previous study (Figs 4C and 5).[14] Digital dental models were imported into the Stratovan Checkpoint software (Stratovan Corporation, Davis, CA, USA). Fourteen landmarks were placed in both T1 and T2 dental models (Fig 6). The landmark coordinates (x and z) were imported into the MorphoJ software (Klingenberg Lab, Manchester, UK). The arch size was calculated by using the centroid size of each dental arch in T1 and T2. Generalized Procrustes Analysis was used to calculate the mean arch shape in each time point and the interphase arch shape changes.

Sample size calculation

Sample size calculation was performed in order to provide 80% of test power, a significance level of 0.05, a standard deviation of 1.18 mm for maxillary width[15] and a minimum intergroup difference of 2.0 mm. A sample of eight patients was required for each group.

Interim analyses and stopping guidelines

Not applicable.

Randomization (random number generation, allocation concealment, implementation)

Randomization was performed electronically using the Randomization.com website (http://www.randomization.com). Opaque, sealed and numbered envelopes containing the group name were organized according to the sequence generated by the randomization.[16]

The allocation was performed by identifying the name of patient and date of allocation in the external surface of the envelopes. After that, the envelope was opened to verify to which group the patient was assigned. Different operators performed the randomization, envelopes concealment and allocation.

Blinding

All CBCT scans were unidentified before assessment to avoid bias. Only a simple blinding was performed, once both operator and patient were aware of the type of treatment performed.

Statistical analysis

After 1 month, the same operator (F.M) randomly selected and remeasured 30% of the sample. The intraclass correlation coefficient (ICC) was used to assess reliability of repeated measures.

Normal distribution was verified by Kolmogorov-Smirnov test. Independent t test was used for intergroup comparisons. Mann-Whitney U test were used to the variables that did not have normal distribution. A significance level of 5% was regarded for all tests. Statistical analyses were performed with SPSS Statistical Software Package (Version 21.0; SPSS, Chicago, IL, USA).

RESULTS

Participant flow

Forty growing individuals agreed to participate of the trial. Twenty patients were allocated in Group HH. One patient interrupted treatment and one was excluded due to palatal miniscrew instability. The final sample of Group HH comprised 18 individuals (8 female; 10 male) with a mean age of mean age of 10.80 years. The total treatment time was 11.38 months.

Fifteen individuals were allocated in the group CH. Five were not allocated due to group interruption related to side effects observed during maxillary protraction in the original RCT. One patient quitted treatment. The final sample of the group CH comprised 14 individuals with a mean age of 11.44 years (6 female and 8 male) and 11 months of treatment time. Figure 1 contains the completed participants' flow chart.

Baseline data

Similar characteristics regarding sex, initial age and treatment time were found in both groups (Table I).

Intergroup differences were found for 3 out of 13 variables in T1 (Table II). Group HH presented slightly greater transversal dimensions before treatment compared to Group CH.

Number analyzed for each outcome, estimation and precision, subgroup analyses

ICC varied from 0.883 to 0.999 for all the transversal measurements, showing good reproducibility. Landmarks assigned for arch shape analysis demonstrated an ICC varying from 0.745 to 0.999.

All patients from both groups demonstrated a midpalatal suture split during RME. A significantly greater increase in the nasal cavity width and buccal alveolar crest width was found for the hybrid expander (Table III).

The maxillary interpremolar distance showed a greater increase in the conventional hyrax expander group (Table III). No intergroup differences were found for the intermolar, intercanines, arch length and perimeter (Table III). Arch size presented similar increases after treatment in both groups (Table III). Both type of expanders produced a similar arch shape change after RME (Fig 5).

Harms

One out of 38 palatal miniscrews were lost in Group HH. A 97.36% stability rate was found for palatal miniscrews. One patient was excluded from the sample after palatal miniscrew instability.

Another patient from Group HH still demonstrated a posterior crossbite after expander removal in T2 and a quad-helix appliance was recommended before comprehensive orthodontic treatment.

DISCUSSION

Main findings in the context of the existing evidence and interpretation

This study aimed to compare the orthopedic effects of rapid maxillary expansion with a hybrid and conventional hyrax expander in growing patients. Both CBCT and digital dental models provides accurate information regarding the dentoskeletal effects produced by RME.[17-22] Good reproducibility was found for dimensional measurements in both type of three-dimensional images (ICC ranging from 0.883 to 0.999). Previous studies also reported good reproducibility for measures performed in digital dental models.[21,23] In agreement, a previous study also reported excellent intraexaminer reproducibility by assessing the bone morphology in CBCT with different voxel sizes.[24] A previous study also reported good intraexaminer reproducibility for transverse dimensions of the maxilla measured after RME in CBCT.[25]

The hybrid expander is an innovative treatment option for maxillary constriction, which incorporated miniscrews to the expansion procedure.[3,4,7] In adult patients, a greater bone resistance to midpalatal suture opening requires four miniscrews as anchorage.[3,7,26,27] On the other hand, in the late mixed and early permanent dentition, only two anterior miniscrews were necessary to open the midpalatal suture (Fig 2A). In this study, midline diastema and radiologic suture opening was observed for all patients from both groups. Previous studies demonstrated high stability rates for the palatal miniscrews.[7,28] Only one out 38 palatal miniscrews was lost during maxillary expansion. In agreement with our findings, a sample of 69 adult patients treated with MARPE showed a stability rate of 95% for palatal miniscrews.[7] The palate is a very suitable place to receive miniscrews with high stability rates, supporting heavier forces from RME.[28] The possible explanation are the favorable bone quality and quantity and the presence of extensive keratinized mucosa in the paramedian anterior palate.[29,30] Additionally, a previous study demonstrated that stability is increased by splitting two miniscrews in the palate.[28,31]

A greater increase in the nasal cavity width was found for the hybrid hyrax expander (2.26mm) compared to conventional expanders (1.11mm). The hypothesis is that the palatal miniscrews transfer the expansion forces to higher maxillary levels increasing the orthopedic outcome of RME in the nasal cavity. Previous studies have demonstrated an increase of nasal cavity width varying from 1.2 to 2.73 mm after conventional rapid maxillary expansion.[12,25,32] A previous study in adolescents corroborates our findings demonstrating a greater increase in the nasal cavity width with a bone-borne expander compared to a conventional tooth-borne expander.[32] On the other hand, a previous study demonstrated similar increases in the nasal cavity width after expansion using hybrid and hyrax expanders in growing individuals.[12] The possible explanation for these divergences was that in the study by Gunyuz Tokly et al. the amount of screw expansion was not standardized between groups and cusp tip relationship was individually used as a reference to determine the amount of expansion.[12] Considering the ratio between nasal cavity increase and the amount of screw activation, the Hybrid and conventional expanders demonstrated an orthopedic effect of approximately 40% and 20%, respectively.

The buccal alveolar crest width also showed a greater increase after treatment in group HH compared to group CH (Table III). During the expansion active phase, hybrid expanders usually demonstrated a slight posterior divergence of the screw

hingers (Fig.2A) due to the expansion limitation caused by the skeletal anterior anchorage. As consequence, the expansion force might have a greater impact on the dentoalveolar region of maxillary first molars. Another assumption is that first molar eruption is restrained during the hybrid hyrax is in the oral cavity. A relative intrusion of maxillary first molars were observed in subjects of Group HH. This side effects could have collaborated to increase the molar intercrestal distance.

All maxillary dental arch width increased similarly in both groups with the exception of the inter-first premolar distance that showed a greater increase in the conventional hyrax group (Table III). These outcomes were expected since the hybrid expander might transfer less force to first premolars due the anterior palatal miniscrews. In addition, the C shape clasps of first premolar in the hybrid expander were not bonded. These results are consistent with a greater decrease in the buccal bone plate of first premolars in conventional hyrax expanders compared to hybrid expanders observed in a previous study.[12] The arch shape changes observed in Figure 5 confirm the aforementioned findings. Observe that premolar region demonstrated a greater expansion in the conventional hyrax expander group (Fig 5B) compared to hybrid hyrax group (Fig 5B), although both groups have demonstrated a significant arch shape change (Fig 5C and D). Arch size also increased similarly in both groups. A previous study has reported that hyrax expander has not produced an arch shape change.[14] However, the study was conducted in patients with bilateral complete cleft lip and palate, which might explain these divergencies.

Limitations

The hybrid expander promoted a greater orthopedic outcome at the level of the nasal cavity than conventional hyrax expanders. One limitation of our study was the lack of a nasal airflow analysis. Considering the nasal cavity width changes, future studies should evaluate the influence of hybrid hyrax expanders in the respiratory function of patients with oral breathing and sleep apnea.

In all, while the functional outcomes of hybrid expanders are unknown, the indication of skeletal anchored maxillary expansion in growing patients should be restricted for subjects with deficient dental anchorage for conventional expanders (oligodontia and tooth transition); patients with periodontal bone deficiencies on the anchorage teeth; and as anchorage for bone protraction in Class III patients.

CONCLUSIONS

- Hybrid hyrax expander produced a greater increase in the nasal cavity width compared to conventional hyrax expanders.
- Inter-first premolar width had a greater increase after RME with conventional hyrax expanders.
- Arch size and shape changes were similar for both type of expanders.

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FIGURE LEGENDS

Fig 1. CONSORT flow chart**.**

Fig 2. A: Hybrid hyrax expander before and after RME. B: Conventional hyrax expander before and after RME.

Fig 3. Miniscrews installed with a 45º inclination in the paramedian anterior palate in a subject using the hybrid expander.

Fig 4. A: Coronal slice showing the transversal measurements: nasal cavity width, first molars palatal root distance, maxillary width, palatal alveolar crest width, buccal alveolar crest width and arch width. B: Transversal measurements performed in the digital dental models. C: Landmarks used for arch shape analysis.

Fig 5. A: Intergroup comparison of pre-expansion arch shape. B: Intergroup comparison of post-expansion arch shape. C-D: Arch shape before (black line) and after expansion (red line) in the hybrid (C) and conventional hyrax (D) groups.

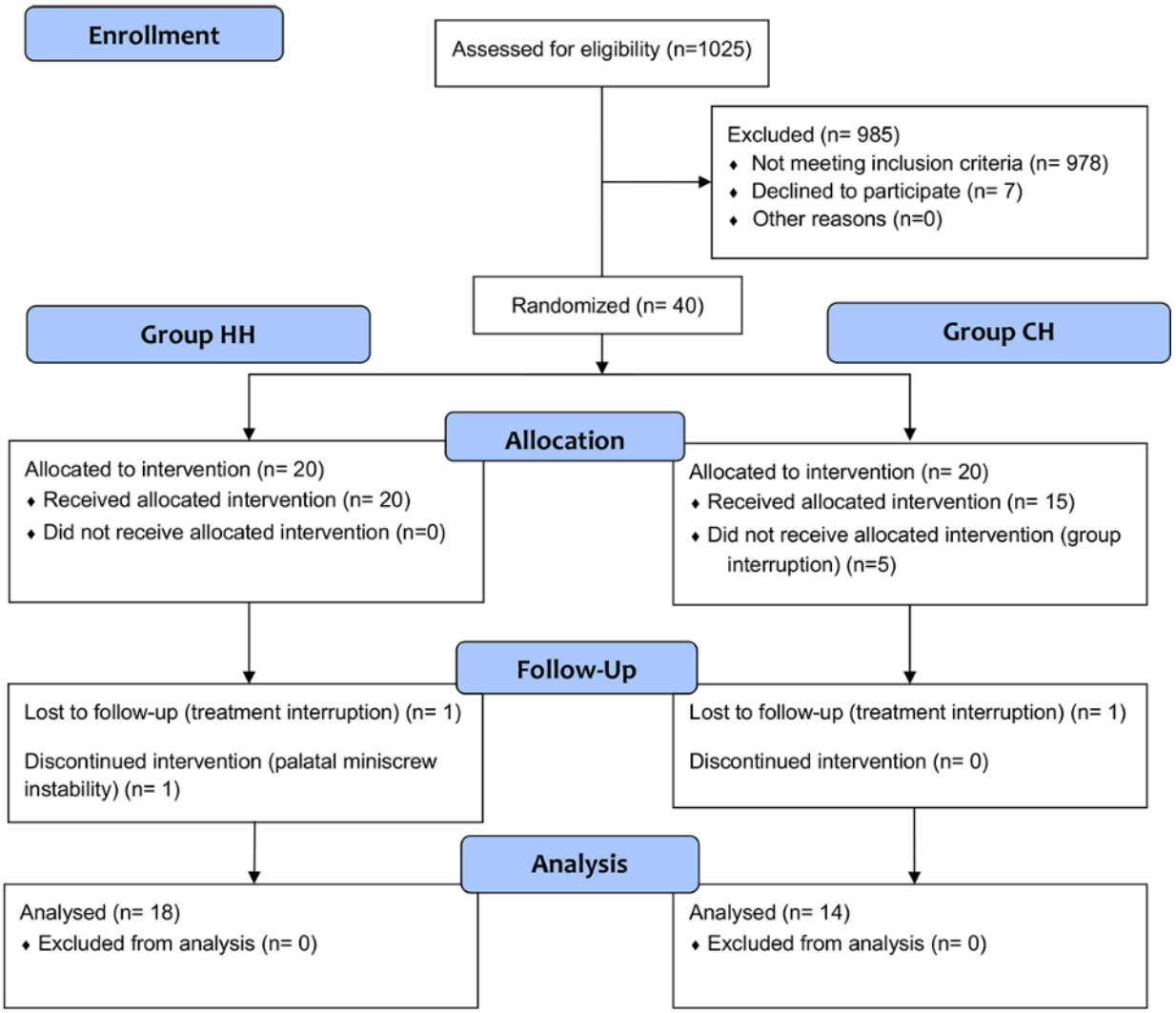
Enrollment
Assessed for eligibility (n=1025)
Excluded (n= 985)
Not meeting inclusion criteria (n= 978)
Declined to participate (n= 7)
Other reasons (n=0)
Randomized (n= 40)
Group HH
Group CH
Allocation
Allocated to intervention (n= 20)
Received allocated intervention (n= 20)
Did not receive allocated intervention (n=0)
Allocated to intervention (n= 20)
Received allocated intervention (n= 15)
Did not receive allocated intervention (group interruption) (n=5)
Follow-Up
Lost to follow-up (treatment interruption) (n= 1)
Discontinued intervention (palatal miniscrew instability) (n= 1)
Lost to follow-up (treatment interruption) (n= 1)
Discontinued intervention (n= 0)
Analysis
Analysed (n= 18)
Excluded from analysis (n= 0)
Analysed (n= 14)
Excluded from analysis (n= 0)

Fig 1.

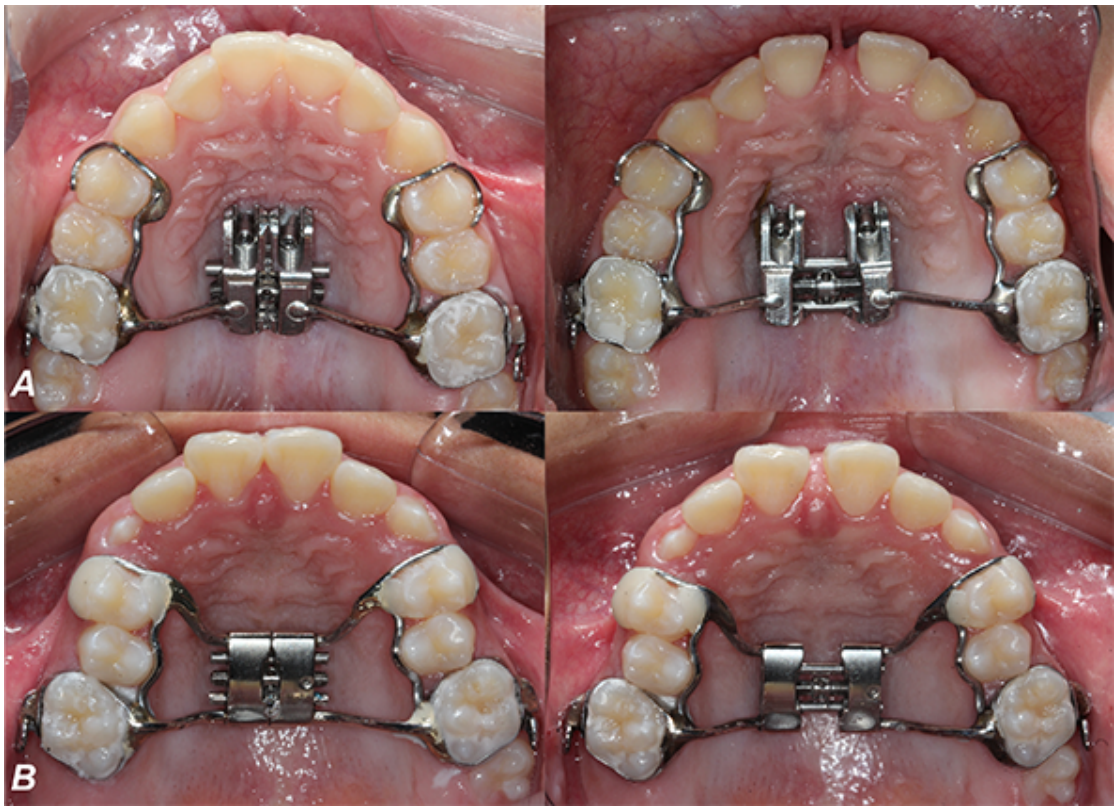

Fig 2.

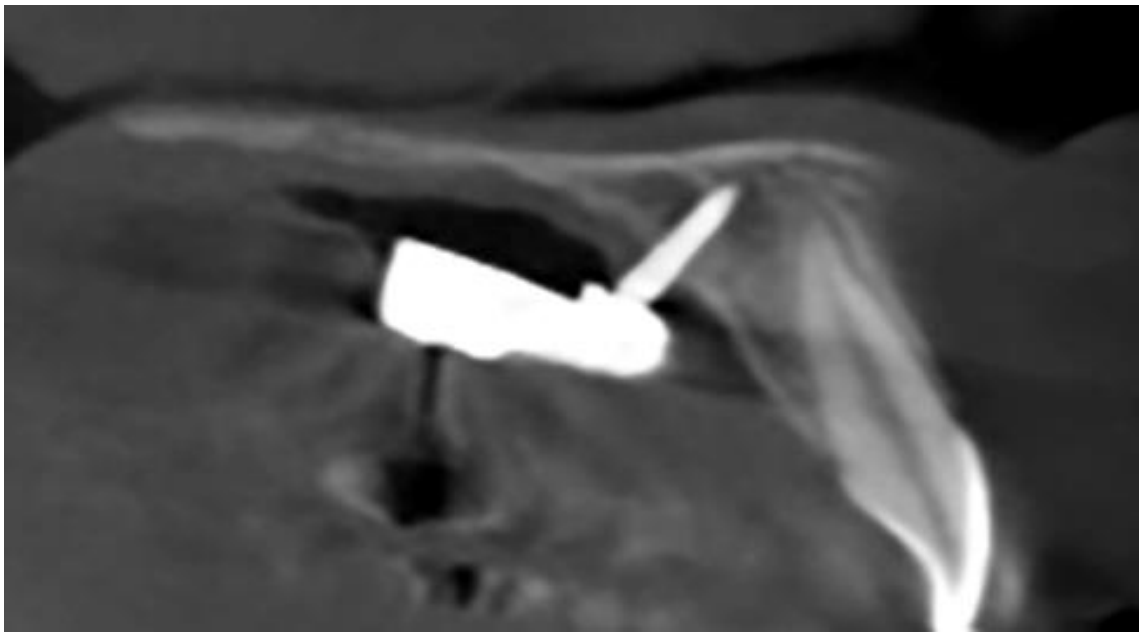

Fig 3.

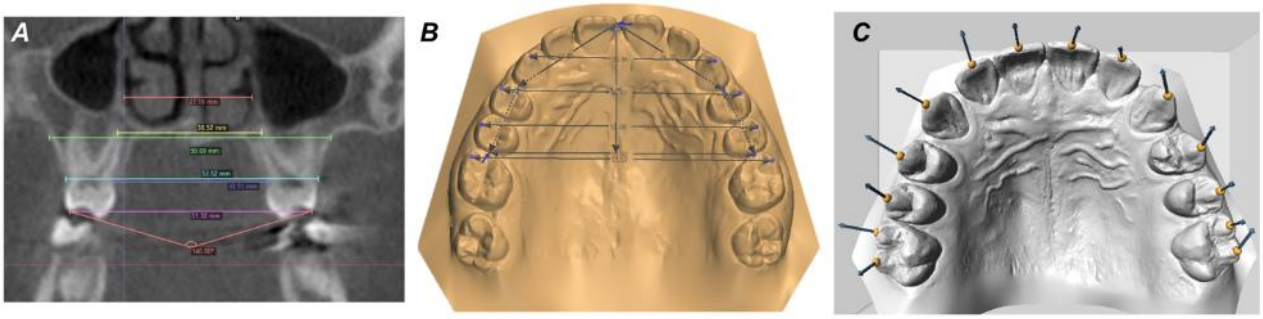

Fig 4.

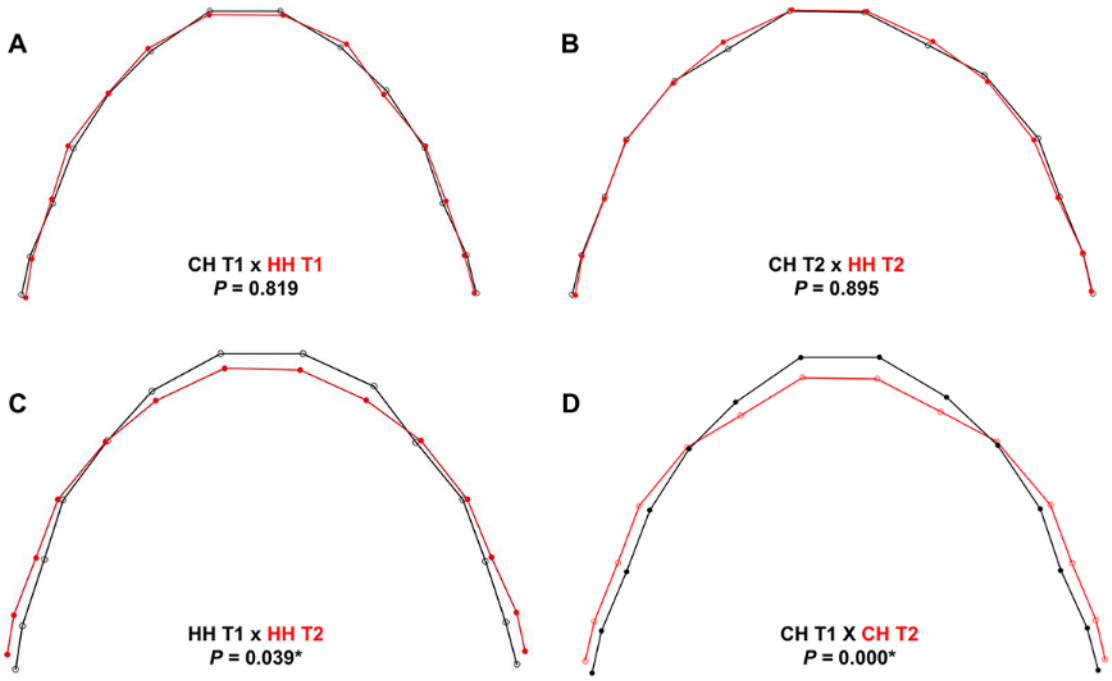
A
CH T1 x HH T1
P = 0.819
B
CH T2 x HH T2
P = 0.895
C
HH T1 x HH T2
P = 0.039*
D
CH T1 X CH T2
P = 0.000*

Fig 5.

Table I. Baseline characteristics of the groups and treatment time.

Variable	*Group HH*	*Group CH*	*P value**
Sex, n			
Female	8	6	0.928
Male	10	8	
Total, n	18	14	
Mean age, y (SD)	10.80 (1.04)	11.44 (1.26)	0.102
Treatment time, m (SD)	11.38 (3.98)	11.00 (3.78)	0.782

Chi-square test (sex); t test (age and treatment time).

Table II. Intergroup comparisons of the starting forms (t test and Mann-Whitney U test).

Variable	***Group HH*** Mean (SD)	***Group CH*** Mean (SD)	***95% CI Lower, Upper***	***P value****
Transversal distances (mm)				
Nasal cavity width	28.81 (2.35)	28.33 (2.18)	-1.18, 2.14	0.561
Palatal root distance width	34.56 (2.86)	31.65 (3.31)	0.64, 5.18	0.021*ψ
Maxillary width	64.64 (3.47)	62.59 (4.85)	-0.96, 5.05	0.175
Palatal alveolar crest width	36.32 (2.66)	33.94 (3.97)	-0.06, 4.83	0.056
Buccal alveolar crest width	59.94 (3.40)	57.08 (3.86)	-0.19, 5.52	0.036*
Arch width	57.02 (3.12)	54.69 (4.32)	-0.41, 5.07	0.093
Dental model analysis (mm)				
6-6 width	55.35 (3.27)	52.59 (4.77)	-0.31, 5.82	0.077
5-5 width	50.47 (2.95)	47.57 (5.12)	-0.25, 6.05	0.070
4-4 width	45.61 (2.72)	42.63 (3.86)	0.36, 5.58	0.027*
3-3 width	36.83 (2.66)	34.78 (3.00)	-0.99, 5.08	0.170
Arch length	29.09 (3.00)	27.66 (2.80)	-0.80, 3.66	0.201
Arch perimeter	77.64 (5.03)	75.02 (5.52)	-1.75, 7.00	0.228
Arch size				
Maxillary Arch Size	91.96 (5.54)	91.09 (5.86)	-4.00, 5.74	0.716

*Statistically significant at $P<0.05$; t test; ψ P values for Mann-Whitney U test.

Table III. Intergroup treatment changes comparison (t test and Mann-Whitney U test).

Variable	***Group HH*** Mean (SD)	***Group CH*** Mean (SD)	***Difference*** Mean	***95% CI*** ***Lower, Upper***	***P value****
Transversal distances (mm)					
Nasal cavity width	2.26 (1.17)	1.11 (0.95)	1.15	0.36, 1.94	0.005*
Palatal root distance width	3.52 (1.04)	2.83 (1.34)	0.69	-0.19, 1.55	0.128ψ
Maxillary width	1.82 (1.47)	0.99 (0.84)	0.83	-0.07, 1.73	0.071
Palatal alveolar crest width	3.67 (1.26)	3.02 (1.24)	0.65	-0.28, 1.57	0.166
Buccal alveolar crest width	3.22 (1.55)	2.03 (1023)	1.19	0.13, 2.22	0.028*
Arch width	2.89 (1.40)	2.67 (1.22)	0.22	-0.75, 1.20	0.641
Dental model analysis (mm)					
6-6 width	3.5 (1.24)	3.47 (1.21)	0.03	-0.90, 0.97	0.941
5-5 width	3.18 (2.12)	4.23 (1.23)	-1.05	-2.46, 0.36	0.138
4-4 width	2.62 (1.76)	4.07 (1.19)	-1.45	-2.67, -0.21	0.023*
3-3 width	0.94 (1.12)	0.54 (1.55)	0.4	-1.03, 1.83	0.559
Arch length	-1.94 (1.36)	-2.2 (1.68)	0.26	-0.89, 1.41	0.648
Arch perimeter	0.11 (2.31)	-0.51 (1.70)	0.62	-1.10, 2.34	0.501ψ
Arch size					
Maxillary Arch Size	3.62 (2.48)	3.30 (1.92)	0.32	-1.65, 2.31	0.737

*Statistically significant at $P<0.05$; t test; ψ P values for Mann-Whitney U test.

3 DISCUSSION

3 DISCUSSION

MAMP therapy is a simpler treatment option for Class III malocclusion treatment in the late mixed and early permanent dentition.[15] MAMP is a BAMP-derived therapy that replaces the titanium miniplates for miniscrews. Miniscrews are more Orthodontic-friendly with a lower cost, less invasive technique, smaller size and are easier to place than miniplates. Conversely, miniplates presents higher stability rates and produces larger amounts of orthopedic effects.[4,18]

In our study, maxillary length and maxillomandibular relationship showed significant changes between groups. The hybrid expander group showed a greater increase in the maxillary length and greater improvement in the maxillomandibular relationship. These findings are in accordance with post-BAMP therapy findings.[4,18,19] The authors reported a whole maxillary bone advancement as a result of treatment with BAMP therapy.[19] Also, a posterior positional relocation of the condyle and anteriorly reoriented direction of growth of the condyle was found for BAMP therapy.[20] MAMP therapy produces more moderate orthopedic maxillary advancement than BAMP, once that miniscrews are enabling only an indirect anchorage to the maxillary structures.

Both groups presented similar dental effects and vertical control after maxillary protraction anchored in hybrid and conventional hyrax expanders. Our findings differ from post-facemask therapy studies.[3,21,22] Facemask therapy produces a forward and downward movement of maxilla, an extrusion of posterior maxillary teeth and a counter-clockwise rotation of the palatal plane after treatment.[3,21,22] Negligible changes were observed for dental and vertical skeletal changes after MAMP therapy using both expanders. The findings for BAMP therapy were strictly skeletal with no involvement of dental structures after treatment.[18]

Currently, the volumetric airway analyses and obstructive sleep apnea (OSA) assessment have been widely studied.[23] In our study, both groups presented similar increases in the oropharynx and most constricted axial area after maxillary protraction. There is a high correlation between maxillary protraction and the increase in the upper airway dimension after treatment.[24] Additionally, maxillary expansion promotes larger

increases in the airway dimensions after treatment.[25-27] The maxillary advancement produced by MAMP therapy may benefit Class III malocclusion individuals with OSA.

The dentoskeletal outcomes produced by both expanders were also compared. The hybrid expander produced a greater increase in the nasal cavity width and maxillary buccal alveolar crest width. Additionally, the conventional expander produced a greater increase in the interpremolar distance. Increases in the nasal cavity width and maxillary width were previously reported after expansion with a hybrid hyrax in adolescent patients.[12,28] The hypothesis is that miniscrews ensure the expansion procedure and produces more effective orthopedic forces. The conventional hyrax expander also showed a greater increase in the interpremolar distance. This is in accordance with previous findings that showed a buccal tipping of first premolar after maxillary expansion.[29,30]

MAMP therapy anchored in a hybrid expander showed more efficient orthopedic outcomes, better control of dental side effects and similar increases in the airway volume after treatment. MAMP therapy with a hybrid expander seems to be a good alternative option for treating growing Class III malocclusion.

4 FINAL CONSIDERATIONS

4 FINAL CONSIDERATIONS

Miniscrew-anchored maxillary protraction using the hybrid expander in the maxilla is an alternative option for growing Class III malocclusion individuals. The hybrid expander anchoring the maxillary protraction promoted greater dentoskeletal effects in both sagittal and transversal dimensions with better control of dental side effects than the conventional hyrax expander. No differences in upper airway changes were observed using maxillary protraction anchored on hybrid or conventional hyrax expanders.

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APPENDIX

APPENDIX A – Declaration of exclusive use of the article 1 in thesis

DECLARATION OF EXCLUSIVE USE OF THE ARTICLE IN DISSERTATION/THESIS

We hereby declare that we are aware of the article “Dentoskeletal comparison of miniscrew-anchored maxillary protraction with hybrid and conventional hyrax expanders: a randomized clinical trial” will be included in the Thesis of the student Felicia Miranda and may not be used in other works of Graduate Programs at the Bauru School of Dentistry, University of São Paulo.

Bauru, February 26th of 2020.

Felicia Miranda _____

Author Signature

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Daniela Garib _____

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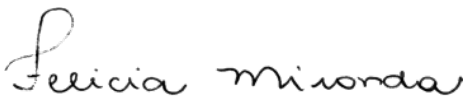

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_Daniela Garib_____ _____
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ANNEX

ANNEX A – Research Institutional Board approval, protocol number 2.112.065 (1/4)

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PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Comparação de dois protocolos de protração ortopédica da maxila por meio de ancoragem esquelética: ensaio clínico randomizado

Pesquisador: Felicia Miranda

Área Temática:

Versão: 2

CAAE: 67610717.7.0000.5417

Instituição Proponente: Universidade de São Paulo - Faculdade de Odontologia de Bauru

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.112.065

Apresentação do Projeto:

Respectivo projeto de pesquisa tem como objetivo comparar as alterações esqueléticas e dentoalveolares produzidas por dois protocolos de protração maxilar ancorada em mini-implantes. Será um estudo clínico randomizado, composto por 2 grupos, no qual serão selecionados 40 indivíduos, de ambos os sexos, idades variando entre 9 e 13 anos, com má oclusão esquelética de Classe III e caninos inferiores já irrompidos. O grupo 1 será composto por 20 indivíduos tratados com elástico de Classe III ancorados em um expansor maxilar com ancoragem dentoesquelética e em 2 mini-implantes mandibulares. O grupo 2 será composto por 20 indivíduos tratados com elástico de Classe III ancorados em um expansor maxilar dentossuportado e em mini-implantes mandibulares. Serão obtidos os modelos dentários e tomografias computadorizadas cone -beam no início e final do tratamento. Além disso, serão obtidas radiografias oclusais e modelos parciais (de canino a canino) antes e imediatamente após a expansão. Nos modelos dentários serão analisadas as variáveis: distância intercaninos e intermolares, largura, perímetro e comprimento do arco, inclinação dos dentes posteriores e caninos, overjet e overbite. Serão realizadas análises cefalométricas convencionais bidimensionais e a análise cefalométrica tridimensional por meio da sobreposição das estruturas da base do crânio para avaliar os efeitos na maxila e osso zigomático, nas suturas circunmaxilares, na

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ANNEX A – Research Institutional Board approval, protocol number 2.112.065 (2/4)

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Continuação do Parecer: 2.112.065

mandíbula, nos côndilos e nas fossas glenóides. Nas radiografias oclusais e modelos dentários será avaliada a quantidade de expansão promovida pelos dois protocolos de expansão maxilar. O teste t pareado será utilizado na comparação intragrupo, enquanto o teste t independente será utilizado na comparação intergrupo. Será adotado um nível de significância de 5%.

Objetivo da Pesquisa:

O objetivo desse estudo clínico randomizado será avaliar os efeitos da protração maxilar ancorada em miniimplantes.

Avaliação dos Riscos e Benefícios:

Riscos:

Os riscos promovidos são baixos e em sua maioria estão associados as complicações dos mini-implantes, dentre elas podemos citar: instabilidade primária (o que acarreta na necessidade de nova instalação), mucosite perimplantar, instabilidade tardia, fratura do mini-implante. A expansão rápida da maxila é um procedimento muito consagrado na Ortodontia, com riscos baixíssimos durante sua aplicação. Os pacientes serão orientados sobre o desconforto que a ativação do parafuso expansor pode causar. Além disso, é esperado a abertura de um diastema entre os incisivos superiores devido a abertura da sutura palatina mediana. Por se tratar de uma mecânica Ortodontia removível, um outro risco seria a falta de colaboração do paciente no uso dos elásticos o que colocaria em risco o sucesso da terapia.

Benefícios:

Os resultados desse estudo contribuirão para elucidar as alterações promovidas por dois novos protocolos de protração maxilar ancoradas em mini-implantes. Conhecer os efeitos de um método mais fácil e eficiente de protração maxilar, ancorada em mini-implantes, propiciará um melhor e mais prático protocolo de tratamento ortopédico para as más oclusões de Classe III esqueléticas. Para avaliação do efeito do tratamento, serão realizadas análises cefalométricas tridimensionais. A avaliação cefalométrica pelo método da sobreposição das estruturas da base do crânio permite vislumbrar os efeitos suscitados na maxila e osso zigomático, nas suturas circunmaxilares, na mandíbula, nos côndilos e nas fossas glenóides. A reconstrução da telerradiografia à partir da TCCB também será utilizada para realização da avaliação cefalométrica convencional bidimensional, antes e após o tratamento.Adicionalmente, os benefícios da tomografia para a amostra avaliada refere-se à possibilidade de vislumbrar as alterações como reabsorções condilares que seriam justificativa para não prolongar a mecânica em concomitância com a fase de ortodontia corretiva com aparelhos fixos. A tomografia ainda permitiria a visualização da ocorrência de

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ANNEX A – Research Institutional Board approval, protocol number 2.112.065 (3/4)

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Continuação do Parecer: 2.112.065

efeitos colaterais como a rotação ântero-medial dos segmentos maxilares e a espessura vestibulolingual do rebordo alveolar após a ERM, observada na TCCB final.

Comentários e Considerações sobre a Pesquisa:

Não há.

Considerações sobre os Termos de apresentação obrigatória:

Todos os documentos pertinentes foram apresentados, inclusive realizadas as alterações sugeridas no Termo de Assentimento.

Recomendações:

Não há.

Conclusões ou Pendências e Lista de Inadequações:

Respectivo projeto de pesquisa estava-se com pendência para adequação do termo de assentimento. A pesquisadora autora realizou todas as correções necessárias, assim, sou de parecer favorável à aprovação do projeto.

Considerações Finais a critério do CEP:

Esse projeto foi considerado APROVADO na reunião ordinária do CEP de 07.06.2017, com base nas normas éticas da Resolução CNS 466/12. Ao término da pesquisa o CEP-FOB/USP exige a apresentação de relatório final. Os relatórios parciais deverão estar de acordo com o cronograma e/ou parecer emitido pelo CEP. Alterações na metodologia, título, inclusão ou exclusão de autores, cronograma e quaisquer outras mudanças que sejam significativas deverão ser previamente comunicadas a este CEP sob risco de não aprovação do relatório final. Quando da apresentação deste, deverão ser incluídos todos os TCLEs e/ou termos de doação assinados e rubricados, se pertinentes.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_877265.pdf	17/05/2017 19:48:35		Aceito
Outros	Oficio_Pendencias.pdf	17/05/2017 19:46:35	Felicia Miranda	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	Termodeassentimento_Modificado.pdf	17/05/2017 19:45:26	Felicia Miranda	Aceito

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ANNEX A – Research Institutional Board approval, protocol number 2.112.065 (4/4)

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Continuação do Parecer: 2.112.065

Outros	QuestionarioTecnicodoPesquisadorResponsavel.pdf	20/04/2017 18:52:49	Felicia Miranda	Aceito
Declaração de Pesquisadores	DeclaracaodeCompromissodoPesquisadorResponsavel.pdf	20/04/2017 18:49:23	Felicia Miranda	Aceito
Declaração de Instituição e Infraestrutura	CARTADEENCAMINHAMENTO_TERMODEAQUIESCENCIA.pdf	20/04/2017 18:47:28	Felicia Miranda	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE_FELICIA.pdf	20/04/2017 13:14:54	Felicia Miranda	Aceito
Projeto Detalhado / Brochura Investigador	Projeto_Pesquisa_CEP_2017.pdf	20/04/2017 13:14:27	Felicia Miranda	Aceito
Folha de Rosto	Folha_de_rosto.pdf	20/04/2017 13:12:09	Felicia Miranda	Aceito

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

BAURU, 09 de Junho de 2017

Assinado por:
Ana Lúcia Pompéia Fraga de Almeida
(Coordenador)

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