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Journal of Orofacial Orthopedics / Fortschritte der Kieferorthopädie
Official Journal of the German Orthodontic Society / Offizielle Zeitschrift der Deutschen Gesellschaft für Kieferorthopädie

ISSN 1434-5293
Volume 81
Number 2

J Orofac Orthop (2020) 81:142-149
DOI 10.1007/s00056-019-00212-7

Springer

J Orofac Orthop (2020) 81:142–149
https://doi.org/10.1007/s00056-019-00212-7

ORIGINAL ARTICLE

Quad-helix compression to decompensate molar inclination prior to skeletal expansion

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Received: 18 March 2019 / Accepted: 28 November 2019 / Published online: 31 January 2020

Abstract

Objectives To demonstrate that patients without posterior crossbite (PCB) but with maxillary transverse deficiency, not previously observed due to an increased curve of Wilson, can benefit from the same palatal expansion as patients with PCB, after correction of the buccal inclination.

Materials and methods A total of 41 patients presenting a maxillary skeletal transverse deficiency were treated: 26 without PCB and 15 with PCB. In the non-PCB group, quad-helix compression was followed by a Hyrax expander (QH+HY), whereas the PCB group only underwent Hyrax expander treatment (HY). The maxillary intercanine, interpremolar, intermolar widths (cusp tips and gingival level) and molar inclination were measured at baseline and at the end of treatment in both groups.

Results No significant differences were found between groups at the end of treatment, and no PCBs remained. The same maxillary expansion was achieved in the QH+HY and HY groups in the region of the canines, at both the gingival (3.4 ± 2.0 vs. 3.4 ± 2.7 mm; $P = 0.999$) and cusp tip levels (4.5 ± 3.1 vs. 3.8 ± 2.2 mm; $P = 0.981$). The molar inclination in the QH+HY group decreased, while there was a slight increase in the HY group (–6.50° ± 5.34° vs. 2.3° ± 4.1°; $P < 0.001$).

Conclusions Some patients with maxillary transverse deficiency do not present with PCB, due to an increased curve of Wilson. However, these patients require skeletal expansion similar to that of patients with a bilateral PCB. The curve of Wilson should be flattened prior to expansion in order to increase the amount of maxillary skeletal expansion.

Keywords Rapid maxillary expansion · Dentoalveolar compensation · Maxillary expansion · Posterior crossbite · Hyrax

Quad-Helix-Kompression zur Dekompensation der Molarenneigung vor der skelettalen Expansion

Zusammenfassung

Ziele Es sollte gezeigt werden, dass Patienten ohne posterioren Kreuzbiss (PCB), aber mit einem transversalen Defizit im Oberkiefer, welches zuvor aufgrund einer verstärkten Wilson-Kurve kaschiert wurde, nach Korrektur der bukkalen Molarenneigung von der gleichen Gaumennahterweiterung profitieren können wie Patienten mit PCB.

Material und Methoden Insgesamt wurden 41 Patienten mit einem transversalen Defizit behandelt: 26 ohne PCB und 15 mit PCB. In der Nicht-PCB-Gruppe folgte auf die Quad-Helix-Kompression eine Behandlung mit dem Hyrax-Expander (QH+HY), während in der PCB-Gruppe nur die Hyrax-Expanderbehandlung (HY) durchgeführt wurde. Die oberen interkaninen, interprämolaren und intermolaren Breiten (Höckerspitzen und Zahnfleischniveau) sowie die Molarenneigung wurden in beiden Gruppen zu Beginn und am Ende der Behandlung gemessen.

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Ergebnisse Am Ende der Behandlung wurden keine signifikanten Unterschiede zwischen den Gruppen festgestellt, und es gab keine PCBs mehr. In den Gruppen QH+HY und HY wurde im Bereich der Eckzähne sowohl auf Höhe der Gingiva (3,4 ± 2,0 vs. 3,4 ± 2,7 mm; $p = 0{,}999$) als auch auf der der Höckerspitze (4,5 ± 3,1 vs. 3,8 ± 2,2 mm; $p = 0{,}981$) die gleiche maxilläre Expansion erreicht. Die Molarenneigung in der QH+HY-Gruppe nahm ab, während in der HY-Gruppe ein leichter Anstieg zu beobachten war (–6,50° ± 5,34° vs. 2,3° ± 4,1°; $p < 0{,}001$).

Schlussfolgerungen Einige Patienten mit transversalem Defizit im Oberkiefer weisen aufgrund einer verstärkten Wilson-Kurve keine PCB auf. Diese Patienten benötigen jedoch eine skelettale Erweiterung, die derjenigen von Patienten mit beidseitiger PCB ähnelt. Die Wilson-Kurve sollte vor Expansion abgeflacht werden, um das Ausmaß der skelettalen Expansion im Oberkiefer zu erhöhen.

Schlüsselwörter Schnelle Gaumennahterweiterung · Dentoalveoläre Kompensation · Maxilläre Expansion · Posteriorer Kreuzbiss · Hyrax

Introduction

Maxillary skeletal transverse deficiencies can create clinical, aesthetic and functional problems in both the maxilla and mandible. The most common manifestation is posterior crossbite (PCB) [1–3].

When an underlying skeletal deficiency is diagnosed and PCB is present, rapid maxillary expansion (RME) is often the treatment of choice [4, 5]. One of the most common appliances used is the four-band appliance (molars and premolars) with a midline screw (Hyrax). A large amount of the transverse movement is largely due to orthodontic tipping (49%) accompanied by opening of the suture (38%) and alveolar bending (13%) [4].

Nevertheless, patients with maxillary transverse deficiency can also present without PCB. In these cases, transverse deficiency is masked by dentoalveolar compensation of the molars as a result of buccal tipping (increased curve of Wilson across the maxillary molars), so that they are often seen as not requiring expansion. However, in patients with underlying skeletal transverse deficiency masked by increased molar inclination, RME is often still required [6]. If Hyrax treatment is performed without previous molar decompensation, iatrogenic effects such as molar tipping may develop, moving molars though the buccal plate of the maxilla or increasing the risk of causing a scissor bite (Fig. 1; [6, 7]).

The advantage of correcting molar inclination prior to expansion is that the molars are in the correct position within the dentoalveolar base. A modified quad-helix device allows up-righting the molars using a cross constriction force limited to only the first permanent maxillary molars [8, 9].

The main objective of the present study was to demonstrate that quad-helix compression (QH) followed by the application of a Hyrax expander (HY) in patients with maxillary skeletal transverse deficiency but not PCB, due to an increased curve of Wilson, could result in a final maxillary width and molar inclination similar to that achieved in patients with PCB treated with only a HY.

Materials and methods

This was an observational prospective study. Consecutive patients presenting a maxillary skeletal transverse deficiency in an initial orthodontic evaluation performed between 2009 and 2011 were included and followed until 2016. The patients were divided into two groups: (1) the presence of bilateral PCB, corrected with a HY or (2) the absence of PCB, treated with decompensation of the molars via quad-helix compression followed HY (QH+HY). The selection criteria are shown in Table 1. The protocol was approved by the Clinical Research Ethics Committee of Aragón (Spain) and was conducted in accordance with the Declaration of Helsinki. All the patients included provided informed consent to participate in the study.

Patients in the HY group underwent a treatment protocol with a four-band HY (Hyrax® Dentaurum, Ispringen, Germany). Activation was begun at the first day of treatment, followed by 1 activation once a day (0.20 mm). Patients were followed up twice a month for 3 months [10]. After achieving the required expansion, the HY was left in situ for 3–6 months.

In the QH+HY group, a removable modified quad-helix was used (MIA Mobile Intraoral Arch System, 3M Unitek, Neuss, Germany). The long arms contacting premolars were removed and the remaining quad-helix was compressed until the posterior helices were touching. The anterior region of the quad-helix was heated, and the quad-helix retained its new compressed form. Compression force was created by inserting the loops into the palatal tubes. Assessment was carried out every 2 weeks until correct inclination of the molars was achieved, and a PCB was created. Treatment was continued for these patients using the same protocol as for the HY group (Fig. 2).

Sociodemographic data were recorded, and measurements were taken from pre- (T1) and posttreatment (T2) plaster models of the maxillary dentition (Fig. 3):

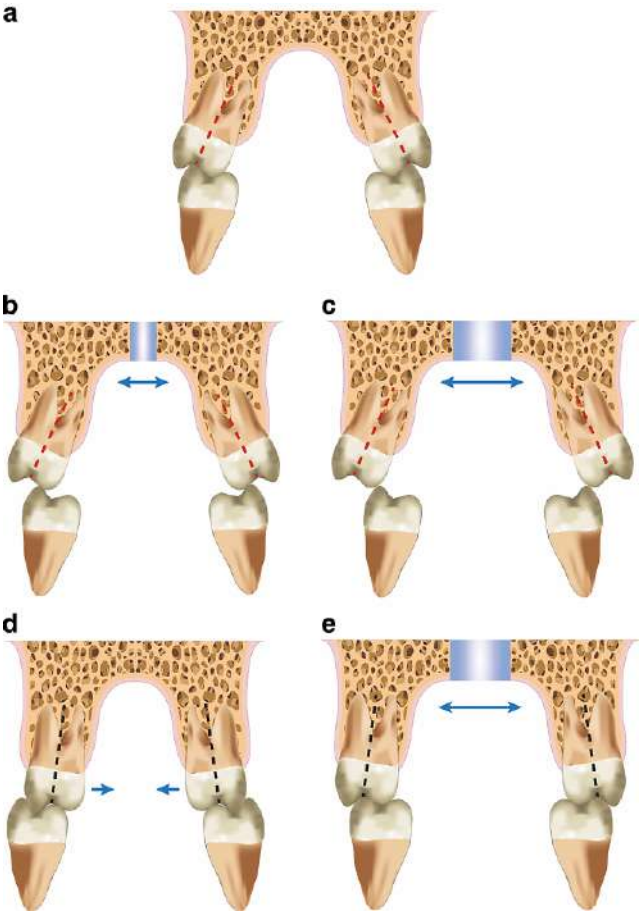

Fig. 1 **a** Initial occlusion of a patient from the QH+HY (quad-helix compression followed by a Hyrax expander) group, in which the maxillary skeletal transverse deficiency is camouflaged by the increased curve of Wilson of the molars. **b** If the inclination of molars had not been decompensated and directly treated the transverse deficiency with a Hyrax expander, the amount of expansion would have been limited. **c** If skeletal transversal deficiency had been completely corrected by expansion, a scissor bite would have been created. **d** If molar inclination had been decreased in these patients with quad-helix compression, according to the skeletal transversal deficiency, a crossbite would have been created. **e** If a previous decompensation is achieved, the total of the skeletal transversal deficiency can be corrected with a correct final transversal relationship

Abb. 1 **a** Initialokklusion eines Patienten der QH+HY-Gruppe (Quad-Helix-Kompression gefolgt von einem Hyrax-Expander), wo das transversale Defizit durch eine verstärkte Wilson-Kurve im Molarenbereich maskiert wird. **b** Wäre die Neigung der Molaren nicht dekompensiert und das transversale Defizitdirekt mit einem Hyrax-Expander behandelt worden, wäre der Umfang der skelettalen Expansion begrenzt gewesen. **c** Wäre das skelettale transversale Defizit durch Expansion vollständig korrigiert worden, wäre ein Scherenbiss entstanden. **d** Wäre bei diesen Patienten mit Quad-Helix-Kompression entsprechend dem skelettalen Transversalmangel die molare Neigung verringert worden, wäre ein Kreuzbiss entstanden. **e** Durch eine vorherige dentale Dekompensation kann das gesamte skelettale Defizit mit einer korrekten endgültigen Transversalbeziehung korrigiert werden

Table 1 Sample selection criteria
Tab. 1 Auswahlkriterien für Stichproben

Inclusion criteria for HY group	Bilateral PCB in CR
	Clinical evidence of maxillary transverse deficiency (constricted dental arch form or skeletal maxillary width assessment)
Inclusion criteria for QH+HY group	No PCB in CR
	Clinical evidence of maxillary transverse deficiency at canine level (triangular arch form or skeletal maxillary width assessment)
	Dental cast assessment confirming molars tipped buccally ≥10° in each molar
Exclusion criteria for HY and QH+HY group	Patients under 6.5 years of age or over 15.5 years of age
	Presence of mandibular transverse deficiency or overexpansion
	Presence of excessive mandibular dentoalveolar compensations
	Fusion of the midline suture
	Unilateral PCB
	Scissor bite
	Severe skeletal discrepancy malocclusion in the sagittal plane
	Transverse discrepancy with a cleft

CR centric relation, *HY* Hyrax, *QH+HY* quad-helix+Hyrax, *PCB* posterior crossbite

- Arch widths: measured at the mid-point of the gingival margin of each tooth and from the mesiobuccal cusp on each tooth. The measurements were taken using a two-point compass, and the distance was recorded in millimeters (mm) (Fig. 3a).
- Molar inclination: taken from the occlusal plane set at 0 degrees (°). A flat plane was placed on cusp tips across the whole arch. The dental surveyor (050310 Mestra, Talleres Mestraitua S.L., Bilbao, Spain) was adjusted until 0° was shown on a digital protractor (mini digital 1.6″ LCD 360-Degree Protractor Inclinometer Angle Meter (Z-036, ZnDiy de BRY)). This position was locked on the dental surveyor. A new plane was constructed involving only the molar mesiobuccal and mesiopalatal cusp tips. The digital protractor was then placed on the molar plane and the digital reading recorded (Fig. 3b).

One operator (C.L.) performed all the measurements.

Sample size

Sample size calculation was performed according to the outcome "changes in arch widths". Previous studies have shown that expansion after applying a conventional expander treatment is around 2.5 mm (standard deviation [SD] 4.5 mm) [11]. Accepting an alpha risk of 5% and a beta risk of 10% in a two-sided test, it was calculated that a total of

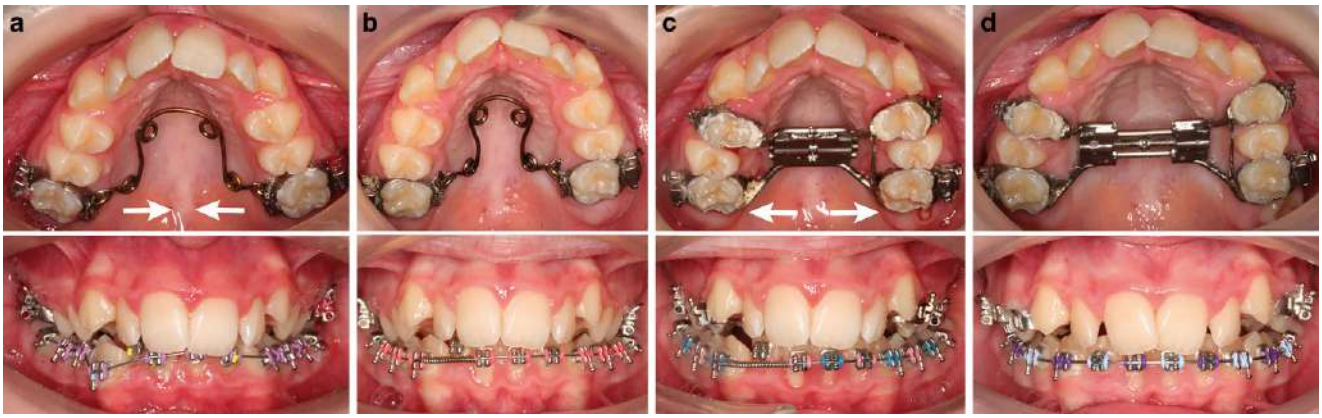

Fig. 2 Treatment sequence of quad-helix compression followed by Hyrax expansion. **a** Quad-helix compression in situ. **b** Completed molar correction. **c** Hyrax expander in situ preexpansion. **d** Hyrax expander in situ postexpansion
Abb. 2 Behandlungssequenz der Quad-Helix-Kompression gefolgt von der Hyrax-Expansion. **a** Quad-Helix-Kompression in situ. **b** Abgeschlossene Molarenkorrektur. **c** Hyrax-Expander in situ vor der Expansion. **d** Hyrax-Expander in situ nach der Expansion

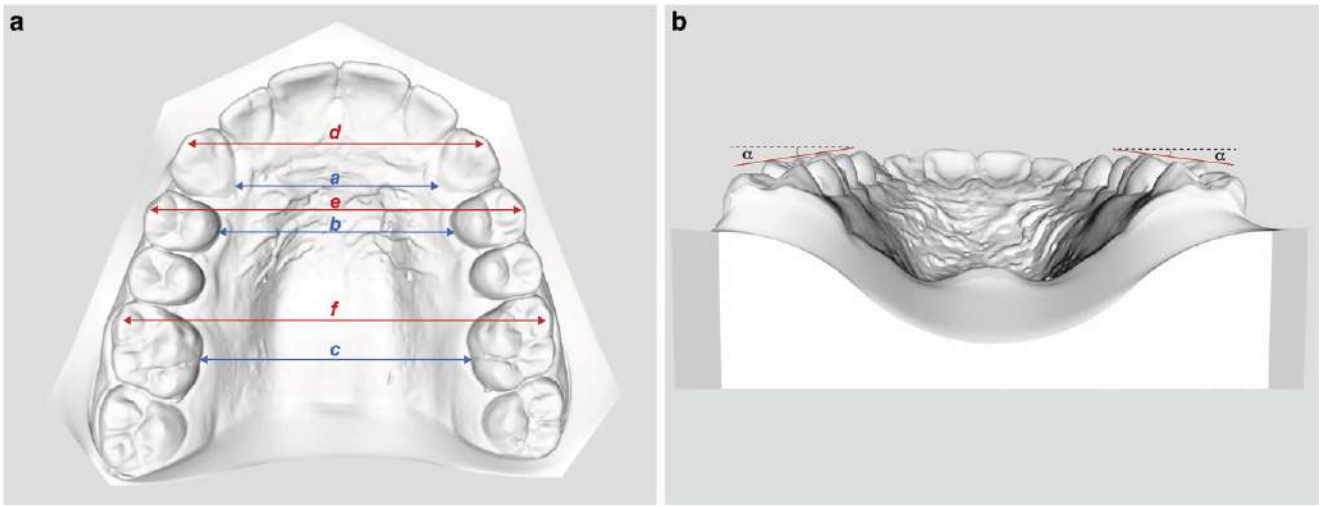

Fig. 3 Points of reference of maxillary widths and molar inclination on plaster models: **a** intercanine (*a* and *d*), interpremolar (*b* and *e*), and intermolar (*c* and *f*) maxillary widths at the gingival level and at the cusp tip level, respectively. **b** Angle (α) measurement for the molar inclination (curve of Wilson)
Abb. 3 Referenzpunkte für Oberkieferbreite und Molarenneigung auf den Gipsmodellen: **a** interkanine- (*a* und *d*), interprämolare- (*b* und *e*) und intermolare (*c* und *f*) Oberkieferbreite auf Gingiva- bzw. auf Höckerspitzenniveau. **b** Winkelmessung (α) der Molarenneigung (Wilson-Kurve)

41 subjects should be included in this study, considering a drop-out rate of 15%.

A total of 41 individuals presenting a maxillary skeletal transverse deficiency were included in the study (15 underwent HY and 26 QH+HY).

Statistical analysis

Comparisons between groups were performed using the χ^2 test to compare categorical variables (Fisher test if expected frequencies were <5) and the Student's *t*-test or analysis of variance (Mann–Whitney U test if not normal distribution) for quantitative variables (arch width and molar inclination).

Differences in molar inclination (posttreatment value minus the pretreatment value) were compared between groups using the Student's *t*-test. Pre- and posttreatment changes in each study group were evaluated using a paired-samples Student's *t*-test. Finally, adjusted multivariate linear regression analysis was performed for the main outcome.

Intraoperator reliability was evaluated by duplicating measurements on 10 plaster casts from T1 and T2 samples. The intraclass coefficient (ICC) was calculated for molar inclination measurements and maxillary widths at two different levels. Analysis was conducted using SPSS V23 (Chicago, IL, USA).

Table 2 Intermaxillary widths and molar inclination during follow-up
Tab. 2 Intermaxilläre Breiten und Molarenneigung in der Follow-up-Phase

Variables	Pretreatment			Posttreatment			Differences		
	HY group (SD) ($N=15$)	QH+HY group (SD) ($N=26$)	P value[a]	HY group (SD) ($N=15$)	QH+HY group (SD) ($N=26$)	P value[b]	HY (SD) (T2–T1)	QH+HY (SD) (T2–T1)	P value[c]
Gingival level (mm)									
Intercanine widths	23.0 (2.8)	23.1 (3.3)	0.727	26.4 (2.4)	26.4 (2.0)	0.679	3.4 (2.7)	3.4 (2.0)	0.999
Interpremolar widths	23.8 (2.4)	22.2 (1.7)	**0.032**	29.1 (3.9)	28.8 (1.6)	0.841	5.3 (2.2)	6.6 (2.1)	**0.049**
Intermolar widths	30.2 (1.1)	32.9 (2.2)	**0.002**	34.8 (4.3)	34.5 (2.4)	0.602	4.6 (2.0)	1.6 (1.8)	**<0.001**
Cusp tip level (mm)									
Intercanine widths	29.5 (3.1)	29.6 (2.6)	0.905	33.5 (2.9)	34.1 (1.7)	0.809	3.8 (2.2)	4.5 (3.1)	0.981
Interpremolar widths	36.3 (2.5)	35.4 (2.2)	0.277	42.2 (4.3)	43.5 (1.6)	0.429	5.9 (2.5)	8.0 (2.5)	**0.017**
Intermolar widths	44.9 (3.1)	48.0 (2.4)	**0.001**	51.1 (3.9)	52.2 (1.6)	0.301	6.2 (2.9)	4.2 (1.9)	**0.009**
Inclination (°)[d]	10.2 (4.9)	16.4 (3.7)	**<0.001**	12.5 (4.6)	9.9 (3.4)	0.072	2.3 (4.1)	–6.5 (5.3)	**<0.001**

T1 pretreatment visit, *T2* posttreatment visit, *SD* standard deviation
[a]Mann–Whitney U test between groups at T1
[b]Mann–Whitney U test between groups at T2
[c]Mann–Whitney U test for differences T2–T1 between groups
[d]Molar inclination mean using right and left values

Results

The mean age of the patients was 10.9 ± 2.1 years, and 73.2% were female. Twenty-one patients (51.2%) were managed with orthodontic interceptive treatment as their transversal malocclusion needed to be solved before their dentition development was completed.

The two study groups presented a similar age (9.78 ± 2.4 years in the HY group and 11.2 ± 1.9 years in the QH+HY group, $P=0.091$) and a similar distribution of gender ($P=0.986$). No differences were found in the percentages of orthodontic interceptive treatment between the two groups (66.7% in the HY and 42.3% in the QH+HY group, $P=0.131$). However, treatment duration was longer in the QH+HY group (18.3 ± 5.4 vs. 10.9 ± 7.7 months, respectively; $P=0.002$).

Pre- and posttreatment measurements according to study group

No statistically significant differences were observed between the HY and QH+HY groups for pretreatment intercanine widths at either the gingival level or the cusp tip level and for interpremolar width at the cusp tip level. However, there were differences for the interpremolar width at the gingival level (23.8 mm ± 2.4 mm vs. 22.2 mm ± 1.7 mm, respectively $P=0.032$) and for the intermolar width at the gingival level (30.2 mm ± 4.1 mm vs. 32.9 mm ± 2.2 mm, $P=0.002$) and at the cusp tip level (44.9 mm ± 3.1 mm vs. 47.9 mm ± 2.4 mm, $P=0.001$). Molar inclination was significantly greater in the QH+HY compared to the HY group at the start of treatment (16.4° ± 3.7° vs. 10.2° ± 4.9°, respectively $P<0.001$).

There were no statistically significant differences between groups at T2 for the 6 width measurements and for molar inclination (Table 2).

Intergroup comparisons: changes between groups from T1 to T2

Changes from T1 to T2 were calculated and compared between groups. No significant differences were found for the intercanine width (gingiva level $P=0.999$; cusp tip level $P=0.981$). Interpremolar changes at the gingiva ($P=0.049$) and at the cusp tip levels ($P=0.017$) were greater in the QH+HY group. By contrast, the intermolar width changes at the gingival ($P<0.001$) and at the cusp tip levels ($P<0.001$) were greater in the HY group. There was a reduction in molar inclination in the QH+HY group, while a slight increase was observed in the HY group (–6.50° ± 5.34° vs. 2.3° ± 4.1°; respectively, $P<0.001$) (Table 2).

The multivariate regression model for differences in molar inclination showed that the QH+HY group was independently related to less molar inclination compared to the HY

Table 3 Multivariate linear regression model for molar inclination (°)
Tab. 3 Multivariates lineares Regressionsmodell für die Molarenneigung (°)

Variable	Beta coefficient	95% CI	*P*-value
QH+HY vs. HY group	–9.215	–13.17 to –5.258	<0.001
Duration of treatment (months)	0.143	–0.271 to 0.557	0.489
Interceptive vs. final treatment	–2.644	–7.935 to 2.646	0.318

HY Hyrax, *QH+HY* quad-helix followed by a Hyrax, *CI* confidence interval

group (beta: –9.215, 95% confidence interval [CI] –13.17 to –5.258, respectively, $P<0.001$) (Table 3).

Intragroup comparisons: changes between groups from T1 to T2 (T2-T1)

The intercanine, interpremolar and intermolar changes were significant for both the QH+HY and the HY group (all $P<0.002$). The changes in molar inclination were significant in the QH+HY group (16.4° ± 3.7° to 9.9° ± 3.4°, $P<0.001$), while no differences were found in the HY group (10.2° ± 4.9° to 12.5° ± 4.6°, $P=0.069$). Correction of the transversal deficiency was achieved in all the patients, and no scissor bites were created.

Overall, there was excellent reproducibility with an intraobserver ICC score for single measures of 0.998 for molar inclination angles and 0.99 for maxillary widths.

Discussion

No differences were observed in intercanine widths between the two groups at baseline, followed by a very similar amount of expansion of the anterior region of the maxilla at the end of treatment. In addition, there were no significant differences in the results of the 6 widths measurements and molar inclinations between the two groups at T2, taking into account that the QH+HY group did not initially present PCB. These results demonstrate the presence of maxillary skeletal transverse deficiency in a series of patients (QH+HY) in whom it is camouflaged by a higher molar inclination. This accentuated curve of Wilson is what produced different values for the initial intermolar widths between the two groups.

The normal molar inclination in relation to the occlusal plane is about 97–98° (since the measurements in this study were performed in relation to the molar crown surface, for comparisons we had to add 90° to our values for baseline measurements) [3, 12, 13]. However, the molar inclination may sometimes increase to compensate for the maxillary skeletal deficiency, resulting in a transverse relationship without PCB [3, 13]. This confirms that while PCB is not seen clinically, maxillary transverse deficiency may still be present. Nonetheless, despite the absence of PCB, these patients are candidates for RME after eliminating molar buccal compensations [6].

Although the QH+HY group showed a significantly greater molar inclination at the initiation of treatment, these patients showed a decrease of 6.5° in molar inclination, which increased 2.3° in the HY group. The final values observed in each group were similar to those reported in the literature for normal inclination (4.73° ± 3.74°) [14–17]. The slight increase in the HY group is less than the values described in the literature, with means ranging from 2.5 to 20° [11, 18–23]. This may be because the HY group did not include subjects with an increased molar inclination. Studies reporting higher results may have placed expansion appliances in patients who already had maxillary buccal molar tipping as part of the malocclusion. The resulting side effect could be further tipping and bite opening [6]. However, taking into account the development of bone-borne expanders, future studies are needed to compare the results of arch width and dental tipping obtained with this device with those achieved in the present study [24].

According to McNamara [25], maxillary constriction should be treated with orthopedic expansion when the maxillary intermolar width is ≤30 mm. This condition was only present in the HY group at the beginning of the study because of the increased curve of Wilson in the QH+HY group. On the contrary, initial intercanine widths were similar in both groups (23 mm). This measurement showed that an anterior maxillary transverse deficiency was present at baseline in all of the 41 patients and was confirmed later on as similar expansion was required in both groups to achieve a correct transversal relationship. No significant differences were found in any of the 6 maxillary widths recorded at the end of treatment. Future studies should be aimed at recording the maxillary width of molars at the interim point of correction with quad-helix compression.

Orthodontists assume that dentoalveolar compensations should be managed before orthognathic surgery. However, in patients who require RME, skeletal movements are typically performed without prior dentoalveolar decompensation. Our study demonstrates the presence of maxillary transverse deficiency in patients without PCB, making it recommendable to correct dentoalveolar compensation before proceeding to maxillary expansion in order to control the final molar inclination. From a cost–benefit point of view, QH+HY patients had to have two different devices with a slight increase in treatment time. However, they benefited from an improvement in esthetics as well adequate skeletal expansion which allowed better placement of the

dentition and roots, decreasing the risk of the roots being positioned through the buccal or lingual plate [7]. In addition, in a study evaluating the long-term changes in arch dimensions after RME, McNamara et al. [20] observed that skeletal expansion was especially stable.

The scanning of models offers a way of obtaining digital measurements. However, this has not shown to be superior to manual methods taken with digital appliances [26]. Cone-beam computed tomography (CBCT) is the gold standard for accurate anatomical measurements, providing a more comprehensive understanding of transverse problems by providing cross-sectional molar images that can be measured. At the start of this study, not all patients required a CBCT scan as part of their orthodontic diagnosis. Our method showed good reproducibility for measurements, with an ICC of 99% for both the molar inclination and the maxillary widths.

This study has some limitations. It was an observational study since patients with overcompensated molars might result in an increased risk for the formation of recessions, thus, limiting the amount of expansion that is feasible. Further on, overexpansion may result in a scissor bite in patients with the HY-only treatment. Despite the small sample size, strict selection criteria were used for population selection, and the analyses showed enough power to detect significant differences for the main outcomes. Nonetheless, longitudinal studies with a larger sample size are needed to confirm our findings.

Conclusion

Patients presenting an increased curve of Wilson at the first molars may have an underlying maxillary skeletal transverse deficiency, despite the absence of an initial PCB. Previous treatment with compression by a quad-helix improved the inclination of the first molars, allowing a greater degree of expansion with a Hyrax appliance in the second phase. This decreased the risk for further tipping or causing a scissor bite, and provided an amount of expansion similar to that in patients diagnosed with an initial PCB. Subsequent expansion was required in all cases and correct transverse relationships were achieved.

Acknowledgements The authors would like to thank all the staff member at the Lorente Clinic Zaragoza (Spain) for their administrative and clinical support. The authors also would like to thank Drs. Paula Murray, Manuel Lahoz and Federico Hernández-Alfaro for their guidance and support.

Compliance with ethical guidelines

Conflict of interest C. Lorente, P. Lorente, M. Perez-Vela, C. Esquinas and T. Lorente declare that they have no competing interests. This was not an industry-supported study.

Ethical standards The Clinical Research Ethics Committee of Aragón (Spain) approved the protocols of this study (No. CP02/2016). Informed consent was obtained from all individual participants included in the study.

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