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original article

Quality of occlusal outcome in adult patients with posterior crossbite treated with completely customized lingual appliances and CAD/CAM archwires for maxillary expansion and mandibular compression compared to adult Class I patients: A retrospective study

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Summary

Purpose > There is a lack of evidence regarding whether non-surgical crossbite correction leads to compromised occlusal outcomes. The aim of this study was to objectively evaluate the quality of the occlusal outcome and the transverse correction after non-surgical crossbite correction in adults compared to adult patients with no pretreatment crossbite.

Material and methods > This retrospective study included 80 adult patients treated consecutively with completely customized lingual appliances (CCLAs) between 2019 and 2021. Crossbite correction was performed with CAD/CAM expansion archwires in the maxilla and compression archwires in the mandible. Occlusal outcome was evaluated using the American Board of Orthodontics (ABO) Model Grading System (MGS), and transverse metric measurements were performed, both on plaster models before treatment (T1), on the set-up models (T2A) and after debonding (T2B).

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Results > From a total of 1098 patients debonded during the observation period, 40 patients (f/m 30/10, mean age 33.6 ± 10.9 years) with unilateral or bilateral crossbite were enrolled in the crossbite group. The matched non-crossbite control group consisted of 40 Class I patients (f/m 30/10, mean age 30.7 ± 9.1 years). No statistically significant difference was observed between the crossbite and non-crossbite groups regarding the total ABO score at T2B (20.7 vs. 18.8, $p > 0.05$), despite the malocclusion being significantly more severe in the crossbite group at T1 (68.1 vs. 41.0, $p < 0.001$). In both groups, 38 out of 40 patients (95%) would have passed the ABO examination (total score at T2B $\leq$ 25). All crossbites were completely corrected at T2B, with a mean total transverse correction of 6.7 ± 2.3 mm (3.2 ± 2.1 mm maxillary expansion, 3.5 ± 2.4 mm mandibular compression).

Conclusion > Non-surgical crossbite correction did not lead to compromised occlusal results. CCLAs in combination with CAD/CAM expansion and compression archwires can correct posterior crossbites successfully in adult patients. The final occlusal outcome can be of a similar high quality in crossbite and non-crossbite patients.

Introduction

Posterior crossbite is a common malocclusion caused by a transverse maxillo-mandibular discrepancy. It affects up to 15% of the adult European population [1]. The aetiology remains unclear and may involve a combination of skeletal, dentoalveolar and neuromuscular functional factors [2].

To date, the choice of the optimal treatment option for posterior crossbite in adults remains highly controversial. Surgically assisted rapid palatal expansion (SARPE) [3], segmental osteotomies (two/three-piece maxilla) [4], microimplant-assisted rapid palatal expansion (MARPE) [5], or nonsurgical palatal expansion [6] are commonly used to treat posterior crossbites in adults. It is apparent that these treatment options typically include various types of maxillary expansion to correct the maxillo-mandibular discrepancy [2], whereas mandibular arch modification is not common due to stability concerns [7]. However, the adaptation of the upper arch to a lower arch that is too wide may also be more prone to relapse [8,9].

Expert opinion suggests that transverse discrepancies of up to 5 mm can be corrected nonsurgically in adults [10]. Wiechmann described a novel concept for crossbite correction in both jaws using completely customized lingual appliances (CCLAs) and CAD/CAM expansion archwires in the maxilla and compression archwires in the mandible [11]. It has been shown that even larger amounts of transverse discrepancies in adults can be corrected nonsurgically with this concept when the correction is performed in both jaws with limited tipping of posterior teeth [12,13]. The main advantage of this approach is that it is the least invasive, as complications are common with surgical crossbite correction [14].

To date, there is a lack of evidence whether this treatment concept leads to compromised occlusal results. Recent studies have shown that high-quality occlusal results may be a favourable prognostic factor for long-term stability [15,16], and CCLAs are generally helpful in achieving these high-quality results [17–20]. Therefore, the aim of the present investigation was to objectively evaluate the quality of the occlusal outcome and interdigitation after nonsurgical crossbite correction in adults compared to adult patients with no pretreatment crossbite. The null hypothesis was tested that there is a statistically significant difference in the quality of the occlusal outcome after treatment between a crossbite group and non-crossbite group treated with CCLAs.

Material and methods

The approval for this retrospective cohort study was received from the ethical committee of the Hannover Medical School, Hannover, Germany (3151–2016).

A sample size calculation using G*Power 3.1 based on $\alpha = 0.05$ (two-sided) and power of $1 - \beta = 0.90$ was performed. Assuming a clinically meaningful group difference of 5 points in mean ABO total scores at debonding (T2B) (SD 5.71 points) [20], an effect size (Cohen's d) of 0.88 was calculated. These values suggested that each group required at least 30 participants.

Eligible for inclusion were patients, which were consecutively treated in one orthodontic specialist practice (Bad Essen, Germany) and were debonded between 2019 and 2021. Patients with major or generalized gingival recessions or poor bone support were not treated with this concept. All treatments were completed by orthodontic specialists with extensive experience in the use of CCLAs. Inclusion criteria were adult patients being 18 years of age or older at the beginning of the treatment who were treated with a CCLA in both arches (WIN appliance, DW Lingual Systems, Bad Essen, Germany). Patients with a known centric occlusion-centric relation discrepancy, planned extractions and space closure, dental bridges and implants, or a compromised treatment plan where the target set-up did not represent a Class I with a transverse normal occlusion were not included. All patients in this cohort were included consecutively to avoid selection bias, no patient was excluded because of compromised results, missing records (i.e. dental casts) or any other reason.

Two groups were defined: Group 1 with no crossbite, and Group 2 with a posterior uni- or bilateral crossbite. A crossbite was defined as at least 4 antagonist teeth in crossbite (more than edge to edge), from first premolar to second molar, on one side (*figure 1*) or both sides (*figure 2*).

FIGURE 1

Example of a 35-year-old patient presenting with unilateral crossbite at T1, corrected in both arches using a completely customized lingual appliance. CAD/CAM stainless steel archwires were used for upper expansion and lower compression. The unilateral crossbite was fully corrected at T2B.

FIGURE 2

Example of a 19-year-old female patient showing a bilateral crossbite at T1, due to a narrow upper arch and a too broad lower arch. The bilateral crossbite was totally corrected at T2B. The correction was conducted in both arches, with a completely customized lingual appliance combined with upper expansion and lower compression archwires.

FIGURE 3

Example of a 28-year-old female patient of the non-crossbite group, showing a class I malocclusion with crowding in both arches, corrected by a completely customized lingual appliance.

The non-crossbite patients (*figure 3*) were matched with the crossbite patients on age and sex to ensure even distribution in both groups. An ideal occlusion was designed using a plaster set-up, without overcorrection: maxillary expansion and mandibular compression were planned in the area of the crossbite for each case, to harmonize the shape of the upper and lower arches. The expansion and compression were conducted with 0.016×0.024 stainless steel ribbonwise archwires, with the amount of correction (1, 2 or 3 cm of upper expansion, and 1 or 2 cm of lower compression) decided by the orthodontist based on clinical observations on an individual basis, as described by Wiechmann [11]. No criss-cross interarch elastics were used during the treatments for the crossbite correction.

The seven measurements according to the American Board of Orthodontics Model Grading System (ABO MGS) were made on the plaster models before (T1) and after orthodontic treatment (T2B) as well as on the target set-up (T2A), as described in previous studies [19,20].

Along with the ABO MGS measurements (alignment and rotations, marginal ridges, buccolingual inclination, occlusal contacts, occlusal relationship, overjet, and interproximal contacts), the transverse dimension for each arch was measured in the area of the biggest transverse discrepancy, according to the methodology described by Wiechmann [11] (*tables I and II*).

The measurements were taken with the ABO measuring gauge for the ABO MGS criteria, and with a digital calliper for the millimetric transverse measurements. All measurements were taken by the same investigator (Y.J.) who had successfully completed the ABO calibration directed by the former ABO Director (P.F.). The ABO passing score was set to 25 penalty points. As in previous studies in which final occlusal outcomes were on plaster casts compared to an individual set-up, no radiographs were assessed for root parallelism [18–22].

Table I
Description of the measurements and intrarater reliability

Measurement	Description	ICC
Alignment	Assessment of tooth alignment. Incisal edges and lingual surfaces of maxillary anterior teeth, incisal edges and labial-incisal surfaces of mandibular anterior teeth, mesiodistal central grooves of posterior maxillary teeth and buccal cusps of posterior mandibular teeth should be in line.	0.998
Marginal ridges	Assessment of vertical positioning of posterior teeth. Marginal ridges of adjacent teeth should be at the same level.	0.890
Buccolingual inclination	Assessment of buccolingual inclination of posterior teeth. Upper and lower buccal and lingual cusps should be at the same height.	0.969
Occlusal contacts	Assessment of intercuspation of opposing teeth. The functioning cusps should be contacting the occlusal surfaces of opposing teeth.	0.990
Occlusal relationship	Assessment of anteroposterior position of posterior teeth. The occlusion should be an Angle Class I relationship.	0.999
Overjet	Assessment of anteroposterior relationship of anterior teeth and transverse relationship of posterior teeth. Anterior teeth should be in contact and posterior functioning cusps should be in the fossae of opposing teeth.	0.991
Interproximal contacts	Assessment of spacing within the dental arch. All teeth should be in contact with one another.	0.998
Total score	Sum of the grading scores for the above parameters. Total score should be as low as possible.	0.998
Upper arch width	Measurement of the arch width [mm] in the area of the largest transverse discrepancy.	0.997
Lower arch width	Measurement of the arch width [mm] in the area of the largest transverse discrepancy.	0.997

ICC < 0.5: poor reliability; 0.5 ≤ ICC < 0.75: moderate reliability; 0.75 ≤ ICC < 0.9: good reliability; ICC ≥ 0.9: excellent reliability.

Table II
Description of the calculated transverse distances

Measurement	Description
Maxillary expansion	Difference between upper arch width [mm] before (T1) and after treatment (T2B). + = expansion, − = compression.
Maxillary expansion setup	Difference between upper arch width [mm] on the setup (T2A) and after treatment (T2B). + = expansion, − = compression.
Mandibular compression	Difference between lower arch width [mm] before (T1) and after treatment (T2B). + = compression, − = expansion.
Mandibular compression setup	Difference between lower arch width [mm] on the setup (T2A) and after treatment (T2B). + = compression, − = expansion.
Total correction	Calculation [mm] of total transversal crossbite correction achieved (maxillary expansion + mandibular compression).
Total correction setup	Calculation [mm] of total transversal crossbite correction planned on the setup (maxillary expansion setup + mandibular compression setup).

Statistical analysis

Case-control matching was performed for age and sex. Ten percent of the sample (8 patients) were randomly selected and remeasured at least 2 weeks later by the principal investigator (Y.J.) to assess intrarater reliability. Intraclass correlation coefficient (ICC) estimates were calculated based on a single measurement, absolute-agreement, 2-way mixed effects model and interpreted according to Koo and Li 2016 [23]. Descriptive statistics were calculated for all variables using mean ± SD, 95% confidence intervals, minimum and maximum. Non-parametric tests were used since the data was not normally distributed, as assessed by the Shapiro–Wilk test

($p < 0.05$). Pairwise comparisons between the three time points (T1, T2A, T2B) were performed using Wilcoxon signed-rank tests. Mann–Whitney U tests were used to assess intergroup differences. The significance level was set to $\alpha = 5\%$, and a p-value < 0.05 was considered significant. No α-correction for multiple testing was performed due to the exploratory nature of the study. All statistical analyses were performed using SPSS Statistics 29 software (IBM Corp., Armonk, NY, USA).

Results

A total of 80 patients treated with the CCLA WIN were included in this study. Out of the 1098 patients debonded during the observation period, 40 patients with a posterior crossbite were included. Each group consisted of 40 patients (30 females, 10 males, representing 75% and 25% of the groups respectively), the mean age in the crossbite group was 33.6 ± 10.9 years, and 30.7 ± 9.1 years in the non-crossbite group. The mean treatment time in the crossbite group (2.1 ± 0.8 years) was significantly longer than in the non-crossbite group (1.3 ± 0.6 years). In the crossbite group, 15 patients (37.5%) showed a Class I malocclusion, 20 patients (50%) a Class II malocclusion, and 5 patients (12.5%) a Class III malocclusion. All 40 patients in the non-crossbite group showed a Class I malocclusion (*table III*). The intrarater reliability was excellent for all measurements (*table I*).

Descriptive statistics for the ABO MGS score and the metric measurements of the transverse dimension are shown in *tables IV, V, VI*. Boxplots of the ABO MGS score at the different timepoints and the individual target set-up as well as the metric measurements of the transverse dimension are displayed in *figures 4–7*. For all patients with a posterior crossbite at T1, this crossbite was corrected at T2B.

TABLE III
Baseline characteristics

Characteristic	Crossbite	Non-crossbite
Age (years) Mean ± SD (range)	33.6 ± 10.9 (18.0–61.2)	30.7 ± 9.1 (18.1–54.7)
Total treatment time (years)	2.1 ± 0.8 (0.8–4.8)	1.3 ± 0.6 (0.2–2.9)
Sex – Female *n* (%)	30 (75.0%)	30 (75.0%)
Sex – Male *n* (%)	10 (25.0%)	10 (25.0%)
Angle Class – Class I	15 (37.5%)	40 (100%)
Angle Class – Class II	20 (50%)	–
Angle Class – Class III	5 (12.5%)	–

ABO score

Assuming an ABO MGS passing threshold score of 25 penalty points or lower, all but one (27 penalty points, non-crossbite group) of the individual target set-ups (T2A) would meet ABO standards in both groups (*tables IV and V*, *figure 4*). Posttreatment (T2B), 38 out of 40 crossbite cases (95%) and 38 out of

TABLE IV
Descriptives and Wilcoxon signed-rank test statistics for the crossbite group

Variables	T1					T2A					T2B					Wilcoxon test	
																T1-T2B	T2A-T2B
	Mean	SD	95% CI	Min	Max	Mean	SD	95% CI	Min	Max	Mean	SD	95% CI	Min	Max	Sig	Sig
Total score	68.10	12.88	63.98–72.22	41	94	10.55	3.74	9.35–11.75	4	21	20.70	5.21	19.04–22.36	10	37	< 0.001*	< 0.001*
AR	27.25	7.50	24.85–29.65	11	42	0.90	1.08	0.55–1.25	0	4	3.85	2.32	3.11–4.59	0	11	< 0.001*	< 0.001*
MR	5.53	2.32	4.78–6.27	1	10	3.58	2.15	2.89–4.26	0	9	4.15	1.78	3.58–4.72	0	7	0.004*	0.121
BI	6.30	3.24	5.26–7.34	0	13	1.33	1.47	0.85–1.80	0	6	5.98	2.83	5.07–6.88	0	11	0.407	< 0.001*
OJ	14.58	5.63	12.78–16.37	4	27	0.50	1.11	0.15–0.85	0	5	1.95	1.68	1.41–2.49	0	7	< 0.001*	< 0.001*
OC	2.55	3.64	1.38–3.72	0	14	0.33	0.62	0.13–0.52	0	2	1.43	1.68	0.89–1.96	0	7	0.034*	< 0.001*
OR	10.07	4.89	8.51–11.64	0	20	3.98	2.68	3.12–4.83	0	11	3.23	2.70	2.36–4.09	0	13	< 0.001*	0.100
IC	1.83	3.62	0.67–2.98	0	15	0.00	0.00	0.00–0.00	0	0	0.13	0.34	0.02–0.23	0	1	0.005*	0.025*

SD: standard deviation; Sig: significance (P-value); AR: alignment; MR: marginal ridges; BI: buccolingual inclination; OJ: overjet; OC: occlusal contacts;OR: occlusal relationship; IC: interproximal contacts.
* < 0.05.

Table V
Descriptives and Wilcoxon signed-rank test statistics for the non-crossbite group

Variables	T1 Mean	T1 SD	T1 95% CI	T1 Min	T1 Max	T2A Mean	T2A SD	T2A 95% CI	T2A Min	T2A Max	T2B Mean	T2B SD	T2B 95% CI	T2B Min	T2B Max	Wilcoxon T1–T2B	Wilcoxon T2A–T2B
Total score	40.98	10.75	37.54–44.41	20	61	12.08	5.26	10.39–13.76	4	27	18.77	5.52	17.01–20.54	10	34	< 0.001*	< 0.001*
AR	22.90	6.85	20.71–25.09	10	39	2.05	2.50	1.25–2.85	0	12	4.83	2.39	4.06–5.59	1	12	< 0.001*	< 0.001*
MR	4.10	2.37	3.34–4.86	0	9	2.88	1.91	2.26–3.49	0	9	3.48	1.84	2.89–4.06	0	8	0.051	0.063
BI	4.28	2.66	3.42–5.13	0	11	2.15	2.42	1.37–2.93	0	10	4.28	2.59	3.45–5.10	0	11	0.883	< 0.001*
OJ	4.38	3.09	3.39–5.36	0	10	0.83	1.15	0.46–1.19	0	4	1.85	1.49	1.37–2.33	0	8	< 0.001*	< 0.001*
OC	1.55	2.43	0.77–2.33	0	13	1.45	1.99	0.81–2.09	0	8	1.53	2.05	0.87–2.18	0	9	0.866	0.390
OR	3.15	2.76	2.27–4.03	0	10	2.78	2.12	2.10–3.45	0	8	2.80	2.05	2.14–3.46	0	8	0.348	0.834
IC	0.65	1.70	0.11–1.19	0	9	0.00	0.00	0.00–0.00	0	0	0.03	0.16	−0.03 to 0.08	0	1	0.010*	0.317

SD: standard deviation; Sig: significance (*P*-value); AR: alignment; MR: marginal ridges; BI: buccolingual inclination; OJ: overjet; OC: occlusal contacts;OR: occlusal relationship; IC: interproximal contacts.
* < 0.05.

Table VI
Intergroup Mann–Whitney U test statistics

Variables	T1	T2A	T2B
	Sig	Sig	Sig
Total score	< 0.001*	0.220	0.056
AR	0.010*	0.006*	0.058
MR	0.012*	0.148	0.079
BI	0.004*	0.143	0.005*
OJ	< 0.001*	0.092	0.879
OC	0.314	0.002*	0.800
OR	< 0.001*	0.048*	0.849
IC	0.288	1.000	0.092

Sig: significance (*P*-value); AR: alignment; MR: marginal ridges; BI: buccolingual inclination; OJ: overjet; OC: occlusal contacts; OR: occlusal relationship; IC: interproximal contacts.
* < 0.05.

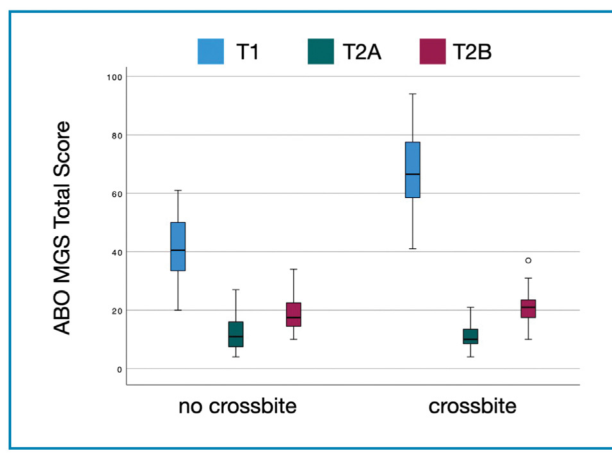

Figure 4
Boxplots of the ABO MGS Total Score before treatment (T1), for the setup (T2A), and after treatment (T2B)

40 non-crossbite cases (95%) would pass the defined threshold. The total ABO MGS score of the cases that would not have passed was 31/37 in the crossbite group and 30/34 in the non-crossbite group. In both groups, all ABO MGS categories improved from T1 to T2B. Therefore, the total score improved substantially in both groups with a mean reduction from 68.1 to 20.7 penalty points in the crossbite group and from 41.0 to 18.8 penalty points in the non-crossbite group (*tables IV and V*, *figure 4*). The intergroup comparison at T2B indicated no statistically significant difference between the two groups, neither for the total ABO MGS score nor for the different ABO MGS components, except for buccolingual inclination (*table VI*, *figure 4*).

Metric measurements

For patients with a posterior crossbite, the mean transverse correction obtained was 6.7 ± 2.3 mm, with a mean maxillary expansion of 3.2 ± 2.1 mm, and a mean mandibular compression of 3.5 ± 2.4 mm (*table VII*, *figures 5–7*). There was a statistically significant difference ($p < 0.001$) between the

Table VII

Descriptives of the metric transverse measurements in the crossbite group and Wilcoxon signed rank test statistics

Variables	Achieved T1–T2B					Planned T1–T2A					Difference T2A-T2B					Wilcoxon test T1–T2B/T1–T2A
	Mean	SD	95% CI	Min	Max	Mean	SD	95% CI	Min	Max	Mean	SD	95% CI	Min	Max	Sig
Maxillary expansion	3.21	2.10	2.53–3.88	−0.4	9.0	3.79	2.27	3.06–4.52	0.0	10.7	−0.58	0.99	−0.90 to −0.27	−2.0	2.3	< 0.001*
Mandibular compression	3.49	2.38	2.73–4.25	−2.4	9.9	2.23	2.40	1.47–3.00	−2.1	10.0	1.26	1.46	0.80–1.73	−2.2	4.5	< 0.001*
Total correction	6.70	2.32	5.96–7.44	3.1	13.1	6.02	2.75	5.14–6.90	0.6	12.3	0.68	1.39	0.23–1.12	−2.2	4.5	0.006*

SD: standard deviation; Sig: significance (P-value).
* < 0.05.

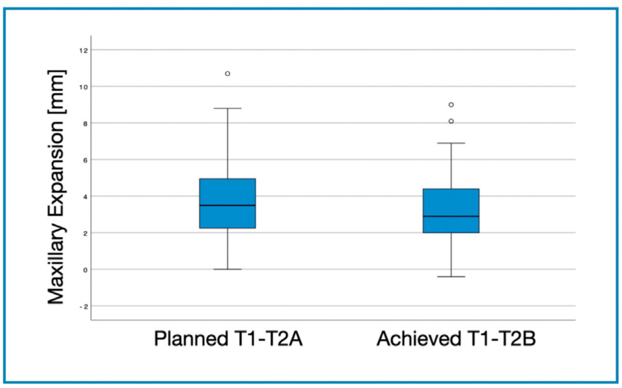

Figure 5

Planned and achieved maxillary expansion (mm)

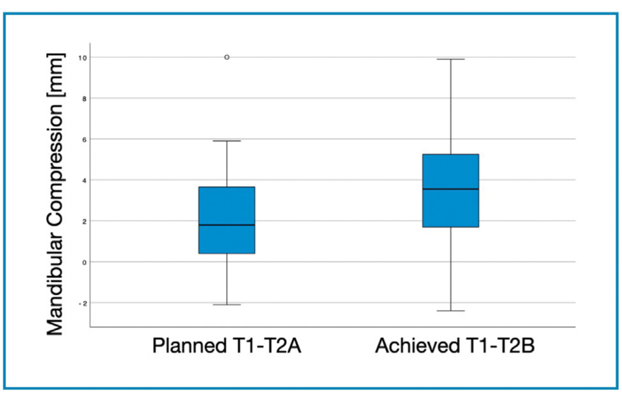

Figure 6

Planned and achieved mandibular compression (mm)

planned (T2A) and achieved (T2B) mean amount of transverse correction when looking at the two jaws separately: maxillary expansion (3.2 mm) was smaller than planned (3.8 mm) and mandibular compression (3.5 mm) was greater than planned

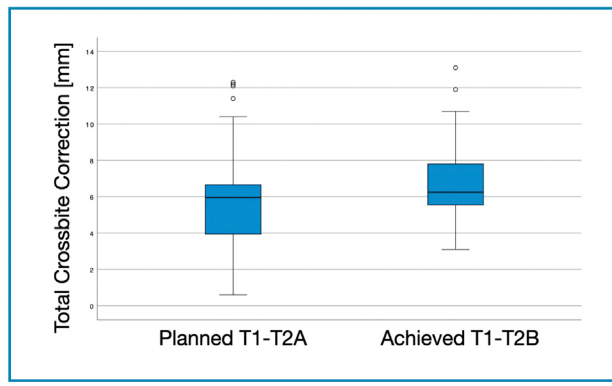

Figure 7

Planned and achieved total crossbite correction (mm)

(2.2 mm) (*figures 6 and 7*). Looking at both jaws together, no statistically significant difference became obvious between the planned and achieved total amount of transverse correction (*table IV*, *figure 7*).

Discussion

The aim of the present investigation was to evaluate the occlusal outcome of posterior crossbite corrections using CCLAs and expansion/compression archwires, compared with patients showing no crossbite before their orthodontic treatment. The results of this study showed no statistically significant difference between the crossbite and non-crossbite patients for the total ABO MGS score (*table VI*, *figure 4*). Therefore, the null hypothesis is rejected.

It is important to highlight the clinical significance of the present findings, especially for adult patients who traditionally might not be treated with a correction involving both arches: this study demonstrates that posterior crossbites were completely corrected in all patients, a critical finding for adult patients where surgical intervention is often considered. A mean transverse correction of 6.7 mm was achieved with 3.2 mm of upper arch expansion and 3.5 mm of lower arch compression on average (*table VII*, *figures 5–7*), which is in line with previous findings [11,12]. This indicates that a transverse correction using CCLAs combined with expansion and compression archwires is a valid treatment modality, even in severe cases, while the lower compression expressed better than the upper expansion.

The total transverse correction obtained in the present study may be comparable to other surgical options like SARPE or MARPE [13,24]. Therefore, transverse non-surgical correction using CCLA and CAD/CAM expansion and compression archwires can be highly effective to treat posterior crossbites in adults and may provide an alternative to more invasive procedures, making it a beneficial option for many patients.

In the crossbite group, a mean reduction of 90% was obtained for the overjet score compared with the set-up. A mean score of 14.6 was observed at T1, the set-up (T2A) planned a score of 0.5 and a final score of 2.0 penalty points was obtained at T2B (*table IV*). It is important to keep in mind that this score evaluates the overjet in the posterior as well as in the anterior region. A score of only 2.0 penalty points after treatment thus indicates an excellent crossbite correction in every patient. For the overjet posttreatment score, no statistically significant difference was found between the two groups ($p > 0.05$), although the score was higher in the crossbite group at the onset of treatment because of the uni- or bilateral crossbite which was present (*tables IV, V, VI*). All the posterior crossbites were fully corrected in the crossbite group. This is in line with previous studies [11,12], and it confirms that this method is efficient for correcting posterior crossbites in adults.

The buccolingual inclination score went from 6.3 at T1 to 6.0 at T2B in the crossbite group, indicating an excellent torque control during the crossbite correction using CCLAs and customized archwires (*table IV*). Even though a statistically significant difference was found between the two groups at T2B (6.0 penalty points for the crossbite group versus 4.3 for the non-crossbite patients), the difference was not considered clinically significant (*tables IV, V, VI*). Moreover, the crossbite cases showed a more severe buccolingual inclination at the onset of treatment and this inclination was improved despite the major transverse dentoalveolar movements that have been made (*tables IV and V*). This is coherent with the study of Schmid et al. who showed that there is not more tipping in treatments using CCLAs and expansion/compression archwires, compared with SARPE and labial straightwire fixed appliances [13]. Therefore, the lateral buccolingual inclination was maintained despite important transverse corrections: this confirms that tranversal non-surgical corrections using CCLAs and expansion/compression archwires do not result in increased buccolingual tipping but in translational movements. This is allowed by a very good torque control with the use of CCLAs [25–29].

For the occlusal contacts criterion, no statistically significant difference could be found between the two groups ($p > 0.05$) posttreatment with a score of 1.4 in the crossbite group and of 1.5 in the non-crossbite group (*tables IV, V, VI*). This indicates that only one tooth on average was not in perfect contacts with its antagonists, showing an excellent posttreatment interdigitation. This demonstrates that an excellent interdigitation can be obtained after a transverse dentoalveolar correction using CCLAs and expansion/compression archwires in adults with posterior crossbites. This may be related to the fact that the correction involved both arches, thus avoiding premature contacts on "hanging palatal cusps'' of upper posterior teeth if the expansion to the buccal had been conducted in the upper arch only, consequently causing buccal tipping [11].

The difference found in the mean total treatment duration between the crossbite and no-crossbite patients is related to the fact that the non-crossbite cases were mild Class I malocclusions without sagittal discrepancy, allowing shorter treatment durations.

In the crossbite group, a mean score of 20.7 penalty points was obtained, with 95% of the patients (38/40 patients) passing the ABO examination (passing score = 25), which is excellent considering the initial severity of the malocclusions (*table IV*, *figure 4*). This means that this treatment strategy is very reproducible, given the fact that the patients were included consecutively. Moreover, although the majority of the crossbite patients also showed sagittal discrepancies (50% of Class II patients and 12.5% of Class III patients), the end occlusal results were comparable to the non-crossbite patients, all of whom were easier Class I cases ($p < 0.05$) (*tables III, IV, V, VI*, *figure 4*). This is consistent with previous studies on the quality of treatments conducted with CCLAs and their ability to treat every malocclusion to a very high standard of care, reaching the treatment goal defined by a target set-up through the use of a very precise customized lingual appliance [11–13,17–20,25–27,29–37].

When comparing the results obtained in the present study with the other aesthetic orthodontic appliances available, i.e. clear aligners, we see that the ability of the latter to produce a significant change in the transverse dimension is very limited. Indeed, most authors show that the upper arch expansion is mainly correlated with buccal crown inclination, aligners being unable to produce transverse bodily movements in the posterior region. These studies also show that the effect is very limited on first molars (maximum 1 to 2 mm intermolar width increase) and almost absent on second molars, which is not sufficient for a uni- or bilateral posterior crossbite correction in adults [38–45]. Recent studies have described that if excellent occlusal results are achieved after treatment, good long-term stability can be expected in patients with a fixed retainer in the anterior lower region [15,16]. For that reason, we could expect excellent stability over time of the results obtained after transverse

FIGURE 8

Removable plates used for the transverse retention, in addition to anterior fixed retainers from canine to canine in both arches. A hole is present in the upper plate to allow a favourable tongue posture with the tongue contacting the palatal mucosa. In the lower arch, the resin is placed on the outside surface of the teeth to work against transverse relapse directed to the outside of the arch and an acrylic coverage of the lower anterior teeth is present to increase the rigidity of the appliance and act as "a tongue lifter"

correction using CCLAs combined with expansion and compression archwires in adults with posterior crossbites, if a suitable retention strategy is used.

In studies conducted at the University of Washington, Little wrote about the arch form "The greater the treatment change, the greater the tendency for relapse" [7]. Accordingly, a correction in both arches may allow for less arch form changes compared with expansion in the upper arch only, and this could play a role in long-term stability.

In the same studies, Little also advised to "retain the arch form long-term and continue to monitor patient response into and throughout adult life" [7]. Therefore, the retention protocol used for the patients of the present study combined a fixed anterior retainer from canine to canine in both arches, and removable appliances in both arches to retain the arch form (*figure 8*).

Acrylic resin plates are preferred to thermoformed removable retainers, because the latter were not rigid enough to retain the modified arch form, even with a palatal coverage in the upper jaw [11]. The aim of the retention devices is to help attaining a good myofunctional balance, but this equilibrium can only be found when orofacial functions are normal, starting with nasal breathing [46–48]. Myofunctional therapy might be helpful in attaining this goal [49–52].

Strengths and limitations of the study

The use of the ABO MGS provides a standardized and widely accepted method to assess occlusal outcomes [17–20,53–58]. The intrarater reliability was high for all measurements, thanks to the training and calibration followed by the main examiner (Y.J.), with the former ABO president (P.F.) (*table I*). Such a calibration process is mandatory when assessing models according the ABO grading system, as showed in other studies [18–20]. The ABO MGS measurements were initially meant to be conducted on analogue plaster models without using optical magnification [59]. Several studies have shown that digital measurements made on virtual models are less suitable for the ABO examination [60–62]. As a consequence, the measurements were made on plaster models for this study, as done previously in other investigations [17–20,53–58].

The ABO MGS measurements were invented to assess models presented for the ABO examination of cases. These criteria were not initially designed to score pretreatment malocclusion models. Nevertheless, this methodology can be a useful tool to compare before and after treatment occlusal situations, and this comparison was conducted in previous studies already [19–22]. The ABO MGS criteria were used in numerous other studies to evaluate post-treatment occlusal outcomes [45,55,63–65].

The ABO score reductions expressed in percentages were taking the score of the set-up (T2A) as a goal. Indeed, for anatomical reasons (teeth sizes variability), it is unrealistic to aim for an ABO score of 0. This calculation methodology was also used in previous studies [19–22], thus allowing comparison of the results.

A limitation of this study is its retrospective design. This type of design may introduce bias, as it depends on historical data and could be subject to selection bias, affecting the internal validity. But the retrospective design of the present study is due to its innovative approach, describing a new concept [11–13]. In addition, all patients were included consecutively, and no patient was excluded from this consecutive sample for any reason, reducing the risk of selection bias. Nevertheless, further studies in this field with a prospective design and an additional evaluation timepoint after a longer retention period (> 2 years) would be desirable to underline the findings of our investigation. Future research should also consider other concepts for posterior crossbite correction in adults in combination with lingual appliances.

Performing radiological examinations beyond standard orthodontic diagnostics for research purposes is not permitted in

Germany. As a result, an assessment of the bony structures before and after treatment using CBCT imaging is not possible. However, both Thiem et al. and Wiechmann et al. have described a high level of adaptability, including extensive remodelling of the alveolar process in the context of comparable tooth movements [27,29]. Similarly, Schmid et al., in a comparative study (SARPE versus expansion/compression archwires), found no significant differences regarding gingival recessions [66].

All patients were treated in a single orthodontic specialist practice in Germany with extensive experience in lingual orthodontics. While this may limit the generalizability of the findings to other populations or settings, it also serves as a strength of the present study. The treatments were performed by highly experienced orthodontic specialists following standardized protocols, reducing variability in the treatment approach and enhancing internal validity.

Even though age and gender were matched, other confounding variables (e.g. skeletal discrepancies, periodontal health) could still influence the treatment outcomes but were not controlled for in this study. Excellent occlusal outcomes may enable a good long-term stability [15,16]. Nevertheless, while the study provides useful short-term outcomes, it lacks long-term follow-up data to assess the stability of the occlusal results over time. Future studies should investigate the long-term stability of occlusal outcomes after using CCLAs and CAD/CAM expansion and compression archwires to confirm whether the results hold up after the retention phase.

Conclusions

Non-surgical crossbite correction did not lead to compromised occlusal results. Completely customized lingual appliances in combination with CAD/CAM expansion and compression archwires can correct posterior crossbites successfully in adult patients. The final occlusal outcome can be of a similar high quality in crossbite and non-crossbite patients.

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