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Original Article

Quality of occlusal outcome in adult Class II patients treated with completely customized lingual appliances and Class II elastics compared to adult Class I patients

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Abstract

Objectives: The aim of this investigation was to evaluate whether Class II malocclusion in adult patients can be successfully corrected using a completely customized lingual appliance (CCLA) in combination with Class II elastics.

Methods: In order to detect differences in the final treatment outcome, two groups were matched for age and gender. Treatment results of 40 adult orthodontic patients with a Class I malocclusion (Group 1) were compared to 40 adults with a Class II malocclusion (Group 2). All patients had completed treatment with a CCLA (WIN, DW Lingual Systems, Bad Essen, Germany) without known centric occlusion—centric relation discrepancies, issues of compliance, or overcorrection in the individual treatment plan which was defined by a target set-up. In order to compare the treatment results of the two groups, 7 measurements using the American Board of Orthodontics Model Grading System (ABO MGS) and linear measurements for anterior-posterior (AP) and vertical dimensions were assessed at the start of lingual treatment (T1), after debonding (T2B) and compared to the individual target set-up (T2A).

Results: A statistically significant AP correction was achieved in Group 2 which represented 95% of the planned amount. The planned overbite correction was fully achieved in the Class I and Class II group. In both groups, there was a statistically significant improvement in the ABO scores, with no significant difference between the two groups at T2. 100% of the patients in Group 2 and 92.5% in Group 1 would meet the ABO standards after CCLA treatment.

Limitations: The main limitation of this study is that only patients who were wearing the elastics as prescribed were retrospectively included. Therefore, the results of this study may have limited generalizability.

Conclusions: Completely customized lingual appliances in combination with Class II elastics can correct a Class II malocclusion successfully in adult patients. The final treatment outcome can be of a similar high quality in Class I and Class II patients.

Keywords: orthodontic appliances; completely customized lingual appliances; Angle Class II correction; adult orthodontics; intermaxillary elastics; maxillomandibular elastics; Objective Grading System

Introduction

In the late 1970s, an American, Craven Kurz, and a Japanese, Kinja Fujita were the first orthodontists who bonded complete fixed appliances to the lingual surfaces of the teeth [1, 2]. After what has to be called a marketing hype, the 1990s saw disenchantment, since numerous orthodontists were faced with unsolved problems when using the first lingual appliances. Among other things, high rates of bracket loss and finishing issues spoiled lingual techniques for many colleagues. It was the introduction of completely customized lingual appliances (CCLA) that turned the lingual technique into something fit for everyday use that interested orthodontists were able to handle [3–5]. Further improvements in the fields of slot precision, archwire fabrication, and clinical handling made the lingual approach using CCLA's more and more popular (Figs 1–3). In Europe, in particular, in France and Germany, many orthodontic practices with a high share of lingual-treatment patients built their reputation. In the meantime, many studies have demonstrated that completely customized lingual appliances allow the achievement of a high-quality outcome in an efficient manner [6–25]. Along with the above-average torque control, the significantly lower risk of decalcification has been stressed again and again for the lingual treatment in children and adolescents [26–29].

In the field of aesthetic orthodontics, methods with fixed appliances are being complemented today more and more frequently by clear thermoformed tray-based removable-appliance techniques, so-called aligners. Numerous investigations into the effectiveness and efficiency of these treatment devices have given the orthodontic community indications of

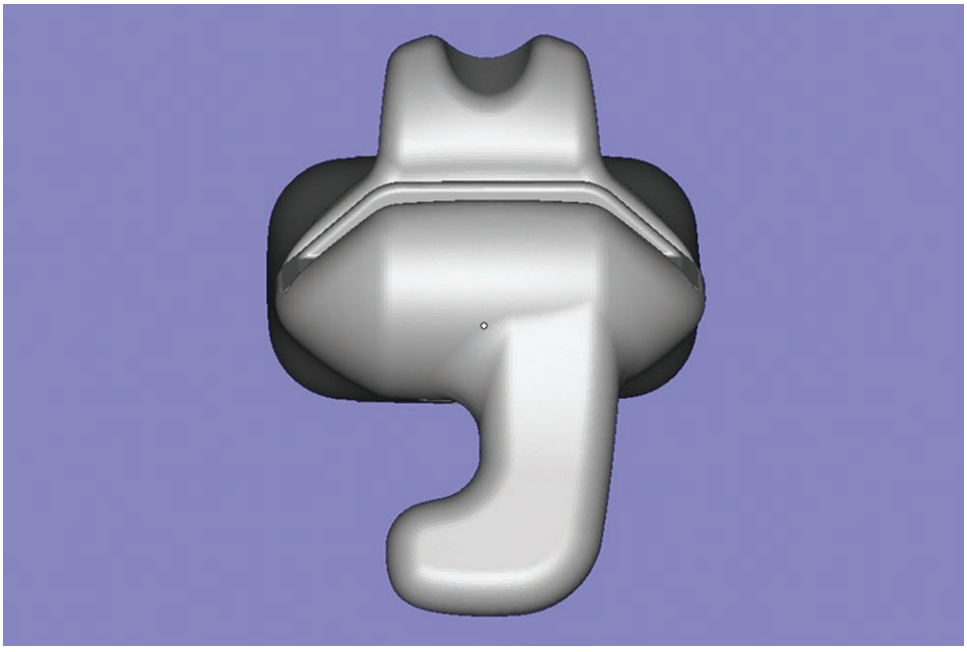

Figure 1. Canine bracket of the CCLA WIN with vertical insertion into the ribbonwise slot. The three-dimensional programming is performed with the help of the target set-up. To every individual inclination of the lingual surface, the hook can be adapted individually.

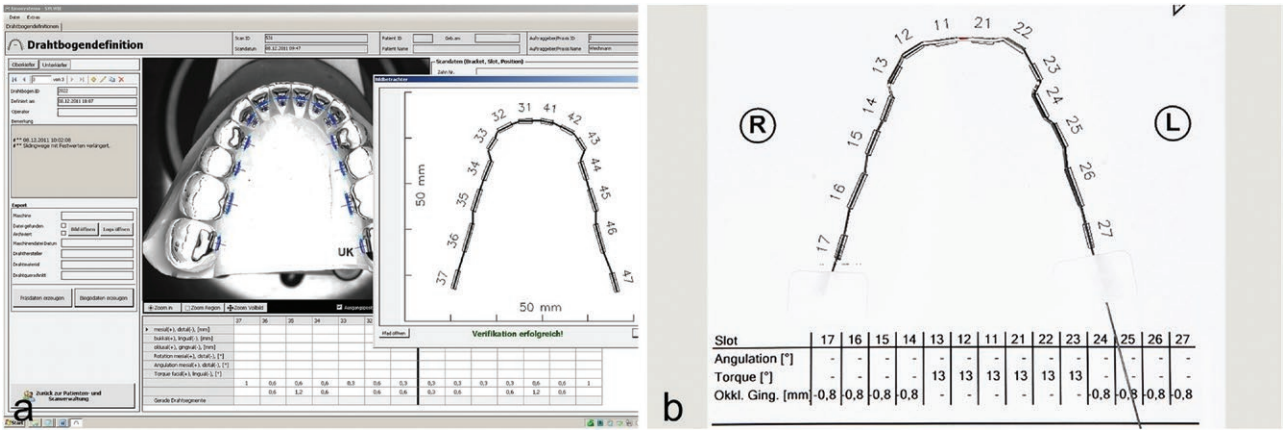

Figure 2. One key feature of CCLAs is the computer-assisted fabrication of customized archwires. Every bracket slot is digitally identified (a) and the individual shape is calculated (b).

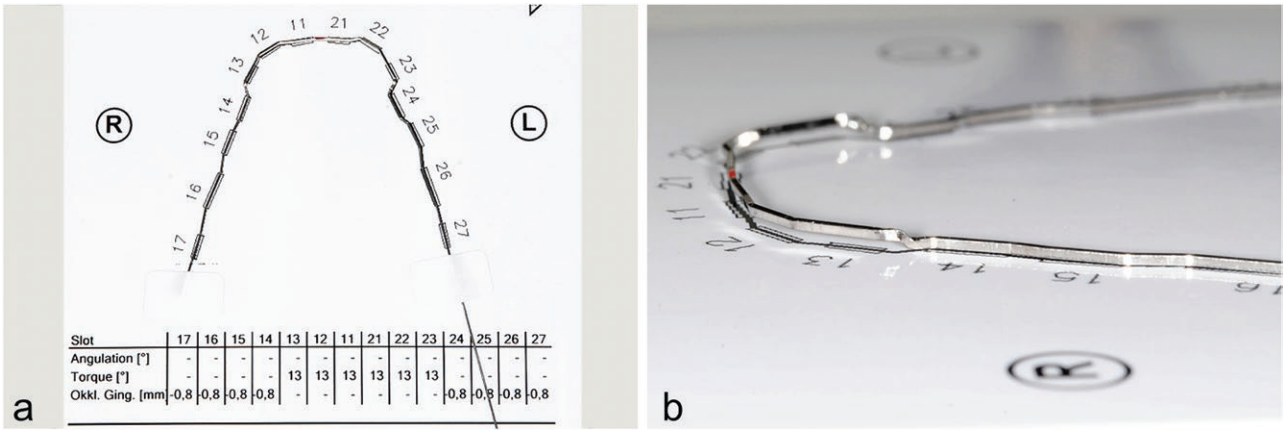

Figure 3. Optional extra-torque bends of 13° or 21° can be incorporated in the anterior region (a). 2b shows a 0.016" × 0.024" stainless steel archwire with an extra-torque bend of 13° from canine to canine. The archwire orientation is ribbonwise.

what these treatments can accomplish. Recently, Patterson *et al.* [30] and Leavitt [31] have pointed out how capable aligner treatment is in the case of Class II malocclusion correction in adult patients when using intermaxillary elastics.

There is evidence that Class II elastics are effective in correcting Class II malocclusions in adolescents, and their effects are primarily dentoalveolar [32]. Dentoalveolar effects include reclination and extrusion of upper incisors, proclination and intrusion of lower incisors, and mesialisation and extrusion of lower molars [32]. The literature on Class II elastics remains very heterogeneous, as different diameters, forces, wear times, and age groups have been investigated. In the studies of Patterson *et al.* [30] and Leavitt [31], Class II correction with intermaxillary elastics appeared to be almost impossible, even with good compliance. The limited capabilities of levelling the arches and controlling upper incisor torque in aligner treatment may contribute to these findings [18]. In contrast, labial fixed appliances can correct a Class II malocclusion in compliant adult patients up to a certain degree [33]. Lingual fixed appliances are biomechanically different from labial ones and to the best knowledge of the authors, apart from a few case reports, no studies have described the efficacy of lingual appliances in this aspect. Therefore, this present study duplicated the method used by Patterson *et al.* exactly in order to be able to compare with Invisalign (Align Technology, San Jose, CA), how a fixed lingual appliance (WIN, DW Lingual Systems, Bad Essen, Germany) performs in Class II correction in adults using intermaxillary elastics. In the two aligner studies, as well as in the present investigation, a control group including adult patients exhibiting Class I malocclusion was used as the benchmark.

To date, there have been almost no studies on the correction of Class II malocclusions with Class II elastics in adult patients [32, 34] and none of them has evaluated the quality of the treatment outcome. This study adds to the literature on this topic.

Testing was performed against the null hypothesis that there is a statistically significant difference in the quality of occlusal outcome after orthodontic treatment with completely customized lingual appliances between a group of adult Class I patients and a group of adult Class II patients who were treated with intermaxillary elastics.

Materials and methods

This retrospective cohort study received approval from the ethical committee of the Hannover Medical School, Hannover, Germany: Approval number: 3151-2016 the 4th of May 2016; it is similar to the methodology of the studies by Patterson *et al.* [30] and Leavitt [31]. All included patients were treated in one orthodontic specialist practice (Bad Essen, Germany) and were debonded after bi-maxillary lingual fixed appliance treatment in the period from 2013 to 2023.

A total of 80 patients treated with the CCLA WIN were selected for inclusion in this study. The sample size for this study was adopted from the investigation conducted by Patterson *et al.* 2021 [30]. With a sample size of $n = 40$ and SD = 9 per group with 1- $\beta = 0.80$ and $\alpha = 0.05$, a group difference of 5 points can be detected, which is considered clinically significant. All treatments were completed by orthodontic specialists with extensive experience of CCLA treatment. Two groups were formed: Group 1 with Class I malocclusions ($n = 40$; f/m 25/15; mean age 31.2 ± 7.9 years) and Group 2 with Class II malocclusions ($n = 40$ f/m 25/15; mean age 30.3 ± 8.6 years). Even distribution in both groups was ensured by matching age (31.2/30.3 years) and gender (f/m 25/15) of patients with Class I to the included patients with a Class II. Inclusion and exclusion criteria were similar to the studies of Patterson *et al.* [30] and Leavitt [31], with the exception of the orthodontic appliance used:

- All patients were 18 years of age or older at the onset of lingual treatment.
- Patients included in the Class II group had at least half a unit Class II occlusal relationship on one side. ABO classifications for molar relationships were used for the selection.
- Included patients had no issues with compliance related to Class II elastics.
- There was no known centric occlusion-centric relation discrepancy at T1 and T2B.
- A history of previous orthodontic treatment or missing teeth did not limit the inclusion.
- Patients with planned extractions and space closure or space opening were excluded.
- Also excluded were patients with dental bridges, dental implants, or extensive prosthodontic restorations.

After the phase of levelling and aligning, the Class II patients were asked to wear Class II elastics (3/16", 6oz) from the upper canine to the lower second molar on 0.016" × 0.024" stainless steel archwires for 24 hours per day until a slight overcorrection (0.5–1.0 mm) of a Class II molar relationship (unilateral or bilateral) was achieved. In cases of a unilateral Class II relationship, elastics were only worn on the affected side. Compliance was evaluated by patient interview. Patients who admitted that they did not wear the Class II elastics as prescribed were remotivated twice. If the compliance did not improve, the patients were excluded from this study, and their treatment plan was changed to mini-screw assisted maxillary total arch distalisation [20]. As it is known that fixed orthodontic appliances can deliver full three-dimensional control, an ideal occlusion without over-corrections or compromises was defined for all included cases as the goal of the target set-up process. The individual set-up was made on plaster models ensuring a no-compromise and really three-dimensional view for the well-trained dental technicians.

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). These measurements included alignment and rotations, marginal ridges, buccolingual inclinations, occlusal contacts, occlusal relationship, overjet, and interproximal contacts (Table 1). All measurements were made using the ABO measuring gauge (resolution: 0.5 mm) on the plaster models, and the scores were recorded on the ABO Cast-Radiograph Worksheet. The set-up models did not include panoramic radiographs to assess root angulation; therefore, only the model grading system (MGS) portion of the cast-radiograph evaluation (CRE) was analysed.

For alignment, 1 penalty point was scored for each tooth presenting with a deviation from 0.5 to 1 mm, and 2 points for a deviation of more than 1 mm. For the marginal ridges, 1 point per interproximal contact was scored in cases of a

deviation ranging from 0.5 mm to 1 mm, and 2 points if the marginal ridge discrepancy was greater than 1 mm. For the buccolingual inclination, 1 point per tooth was scored for a discrepancy between 1 and 2 mm, and 2 points above 2 mm. For the occlusal contacts, for each tooth, if a cusp was out of contact with the opposing arch but with a distance of 1 mm or less, 1 point was scored, and 2 points were scored if the distance was greater than 1 mm. For the occlusal relationship, 1 point was scored for each deviating maxillary tooth with a buccal cusp deviating between 1 and 2 mm from a neutral occlusion, and 2 points above 2 mm. For the overjet, in the posterior region 1 point was scored for each maxillary tooth when a mandibular buccal cusp was deviating 1 mm or less from the centre of this opposing tooth, and 2 points when it deviated more than 1 mm, and in the anterior region 1 point was scored for each maxillary tooth when the mandibular canines or incisors were not contacting their lingual surface and the distance was 1 mm or less, and 2 points when the distance was greater than 1 mm. For the interproximal contacts, 1 point was scored for each interproximal contact showing a space between 0.5 mm and 1 mm, and 2 points when more than 1 mm space was present between two teeth.

Furthermore, the overbite and the anterior-posterior relationship at the first molar were measured in millimetres using a digital calliper (Table 1) [35]. As in a previous study in which final occlusal outcomes were compared to an individual set-up, no radiographs were assessed for root parallelism [21]. 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.F.). In line with the studies of Patterson *et al*. [30] and Leavitt [31], the ABO passing score was set to 27 penalty points.

The percentage of treatment accuracy was calculated by comparing the achieved correction at T2B to either the correction intended according to the individual target set-up (T2A) or a theoretical ideal correction with an ABO MGS score of 0 penalty points at the end of treatment. The following formula was used: percentage accuracy = (initial-achieved)/(initial-predicted) × 100.

Statistical analysis

Descriptive statistics were calculated for all variables. Wilcoxon signed rank tests were used to investigate intragroup differences and Mann–Whitney *U* tests were used to evaluate intergroup differences. The significance level was set to $\alpha = 5\%$, and a P-value < .05 was considered significant. Intrarater reliability was evaluated using intraclass correlation coefficients (ICC) and method error was determined using Dahlberg's formula [36]. For this purpose, 10% of the sample (eight patients) were randomly selected and remeasured after at least 2 weeks by the main investigator (Y.J.). ICC estimates were calculated based on a single measurement, absolute-agreement, 2-way mixed effects model. Interpretation of the correlation coefficients followed the cut-off limits of Koo and Li 2016 [37]. The datasets were analysed using IBM SPSS Statistics 29 (IBM, Armonk, NY).

Results

Intrarater reliability was excellent for all variables, except for marginal ridges with good reliability (Table 1). According to Dahlberg's formula, a measurement error of 0.4 points for ABO MGS scores and 0.1 mm for linear measurements must be assumed for this study. The total treatment time amounted to an average 15.6 months (SD: 6.77) for the Class I group

Table 1. 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.	0.995
Marginal ridges	Assessment of vertical positioning of posterior teeth. Marginal ridges of adjacent teeth should be at the same level.	0.771
Buccolingual inclination	Assessment of buccolingual inclination of posterior teeth. Upper and lower buccal and lingual cusps should be at the same height.	0.939
Occlusal contacts	Assessment of intercuspation of opposing teeth. The functioning cusps should be contacting the occlusal surfaces of opposing teeth.	0.974
Occlusal relationship	Assessment of anteroposterior position of posterior teeth. The occlusion should be an Angle Class I relationship.	0.998
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.	0.984
Interproximal contacts	Assessment of spacing within the dental arch. All teeth should be in contact with one another.	0.995
Total score	Sum of the of grading scores for the above parameters. Total score should be as low as possible.	0.997
Overbite	Measurement [mm] between two antagonistic incisors comprising the greatest vertical overlap. Overbite should be 1–2 mm.	0.994
A-P4	Measurement [mm] of the discrepancy of the buccal cusp of the upper first premolar in relation to the interdental area of the lower first and second premolars. Anterior-posterior relation 4 should be 0 mm.	0.998
A-P6	Measurement [mm] of the discrepancy of the mesiobuccal cusp of the upper first molar in relation to the buccal central groove of the lower first molar. Anterior-posterior relation 6 should be 0 mm.	0.999

ICC < 0.5: poor reliability; 0.5 ≤ ICC < 0.75: moderate reliability; 0.75 ≤ ICC < 0.9: good reliability; ICC ≥ 0.9: excellent reliability. A-P4: anterior-posterior relationship at first premolar; A-P6: anterior-posterior relationship at first molar.

and 24.3 months (SD: 7.9) for the Class II patients. Descriptive statistics for the ABO MGS measurements at T1, T2A, and T2B and the comparisons between the time points are shown in Tables 2 and 3 for patients with Class I and Class II malocclusion, respectively. Assuming a passing threshold of 27 or lower, all individual target setups (T2A) would meet ABO standards in both groups. Posttreatment (T2B), all Class II cases (100%) and 37 out of 40 Class I cases (92.5%) would pass (Figs 4 and 5). In both groups, all MGS categories improved from pre-treatment to posttreatment. There were substantial improvements in total scores in both groups and at the end of fixed lingual appliance treatment, the mean ABO MGS score was reduced to 19.4 in Group 1 and 17.9 in Group 2. However, despite major improvements in final mean ABO MGS scores in both groups, a statistically significant difference between the scores for the planned (T2A) and the achieved (T2B) average total ABO MGS scores remained. Looking at the different areas in Group 1, there was no statistically significant difference between predicted and achieved scores for marginal ridges, occlusal contacts, occlusal relationship, and interproximal contacts. In Group 2, there was no statistically significant difference between predicted and achieved scores for marginal ridges, occlusal contacts, and interproximal contacts. Furthermore, there was no statistically significant difference between predicted and achieved AP correction at the first molars in the Class II group, as 95% of the planned AP correction was achieved (Tables 3 and 4).

The mean overbite percentage change was 103% in the Class I malocclusion group and 107% in the Class II group, which indicates that the overbite correction resulted in some

Table 2. Class I descriptive and Wilcoxon signed-rank test statistics.

	Descriptive						Wilcoxon signed-rank test	
	T1		T2A		T2B		T1-T2B	T2A-T2B
Variables	Mean	SD	Mean	SD	Mean	SD	Sig	Sig
Total score	43.83	12.32	12.83	4.95	19.40	5.71	<.001	<.001
AR	23.88	7.65	2.00	2.54	5.08	2.54	<.001	<.001
MR	3.65	2.30	2.70	1.88	3.25	1.78	.261	.054
BI	4.53	2.79	2.45	2.28	4.38	2.62	.578	<.001
OJ	5.25	3.57	0.95	1.13	1.93	1.47	<.001	<.001
OC	1.83	3.14	1.38	2.02	1.60	2.05	.748	.142
OR	3.93	3.21	3.35	2.23	3.10	2.05	.062	.491
IC	0.78	1.90	0.00	0.00	0.08	0.35	.022	.180
A-P4	0.47	0.58	0.20	0.37	0.17	0.33	.005	.800
A-P6	−0.15	1.02	0.06	0.81	−0.21	0.80	.831	.004
OvB	3.51	1.83	2.23	0.53	2.20	0.59	<.001	.450

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; A-P4: anterior-posterior relationship at first premolar; A-P6: anterior-posterior relationship at first molar; OvB: Overbite.

Table 3. Class II descriptive and Wilcoxon signed-rank test statistics.

	Descriptive						Wilcoxon signed-rank test	
	T1		T2A		T2B		T1-T2B	T2A-T2B
Variables	Mean	SD	Mean	SD	Mean	SD	Sig	Sig
Total score	56.33	13.21	9.80	3.81	17.88	4.64	<.001	<.001
AR	23.25	6.47	1.73	1.41	4.53	2.34	<.001	<.001
MR	4.08	1.99	2.15	1.61	2.73	1.87	.002	.097
BI	6.20	3.89	1.75	1.46	4.68	3.06	<.001	<.001
OJ	6.65	4.41	0.63	1.15	1.60	1.72	<.001	.007
OC	2.50	3.22	1.38	1.76	1.50	1.80	.079	.615
OR	12.55	3.52	2.17	1.65	2.85	2.01	<.001	.025
IC	1.10	2.67	0.00	0.00	0.00	0.00	.011	1.0
A-P4	4.16	0.81	0.59	0.54	1.24	1.04	<.001	<.001
A-P6	3.91	0.55	0.37	0.69	0.69	0.93	<.001	.095
OvB	3.99	1.88	2.40	0.53	2.23	0.69	<.001	.120

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; A-P4: anterior-posterior relationship at first premolar; A-P6: anterior-posterior relationship at first molar; OvB: Overbite.

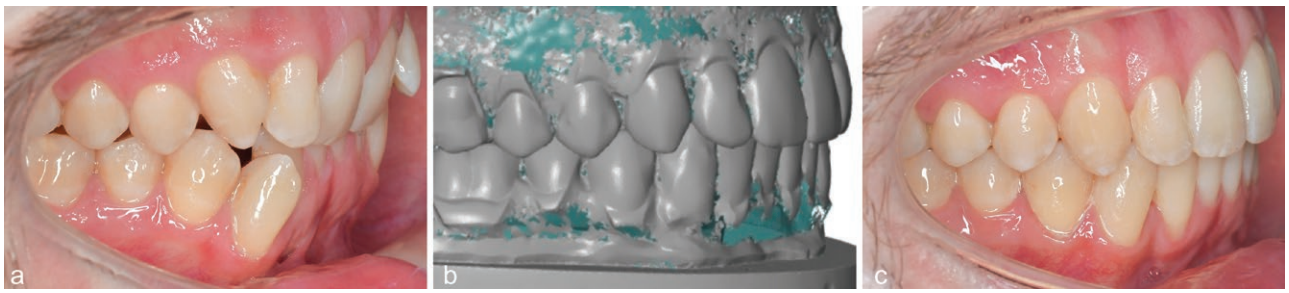

Figure 4. 31-year-old male patient with Class I molar relationship, deep overbite, and severe crowding in the lower arch (a). The ABO MGS score at T1 was 64. The target set-up shows a corrected overbite with an improved interincisor angle and an ABO MGS score at T2A of 17 (b). After 25 months of fixed appliance treatment with a CCLA, the intended corrections were mostly achieved, with a final ABO MGS score of 24 (c).

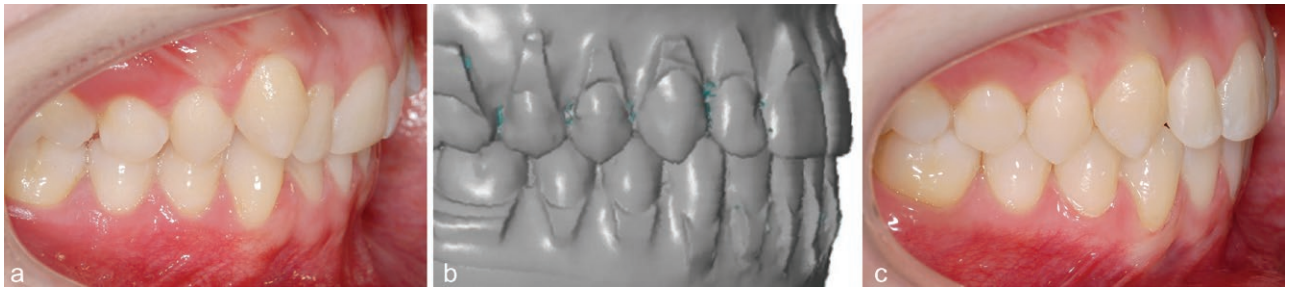

Figure 5. 21-year-old female patient with Class II malocclusion of more than half a unit, deep overbite, and an initial total ABO MGS score of 68 at T1 (a). The target set-up shows a corrected molar relationship with a total ABO MGS score of 17 at T2A (b). After 24 months of fixed appliance treatment (T2B) with a CCLA and 7 months of Class II elastic wearing, the intended anterior-posterior correction of 5.0 mm was achieved (c).

Table 4. Anterior-posterior relationship and overbite millimetric measurements.

	Class I		Class II		
Variables	Mean	SD	Mean	SD	Sig
A-P6					
Needed (T1)	−0.15	1.02	3.91	0.55	<.001
Predicted (T1-T2A)	−0.22	0.90	3.54	0.78	<.001
Achieved (T1-T2B)	0.05	0.89	3.22	0.98	<.001
Achieved (T1-T2B)/(T1-T2A) %	0.81	1.15	0.95	0.38	.142
OvB					
Needed (T1-T2A)	1.28	1.65	1.59	1.72	.175
Predicted (T1-T2A)	1.28	1.65	1.59	1.72	.175
Achieved (T1-T2B)	1.31	1.57	1.75	1.66	.121
Achieved (T1-T2B)/(T1-T2A) %	1.03	0.95	1.07	0.46	.731

SD: standard deviation; Sig: significance (*P*-value); A-P6: anterior-posterior relationship at first molar; OvB: Overbite.

form of overcorrection (Table 4). There was no statistically significant difference between predicted and achieved overbite correction in both groups (Tables 4).

The intergroup comparison of ABO MGS measurements showed higher total scores in Group 2 at T1, mainly due to higher scores for the occlusal relationship (Table 5). In the individual target set-up (T2A), statistically significantly lower total scores were found in Group 2, but it should be noted that when looking at the absolute numbers, these differences may be clinically irrelevant (Table 5). Finally, at the end of lingual fixed appliance treatment (T2B), there was no statistically significant difference between the two groups for any of the different areas (Table 5).

Table 6 shows the mean percentage of penalty point reduction in both the Class I and the Class II malocclusion groups. When comparing the achieved reduction to the predicted one, a high reduction of the total score was found in both groups (78.8% in Class I and 82.3% in Class II patients). Furthermore, a mean 93.5% reduction of penalty points for occlusal relationship was achieved in the Class II group as compared to the individual target set-up. However, the greatest discrepancies between the final outcomes and the target set-up, percentagewise, occurred for marginal ridges, buccolingual inclination, and occlusal contacts. This was similar when comparing the treatment outcomes to an ideal score (ABO score = 0).

Discussion

Previous studies have evaluated the accuracy of tooth movements with completely customized lingual appliances by comparing the results with the individual treatment plan, which was represented by a target set-up [6, 8, 15, 17, 20, 24]. This study was meant, among other aims, to allow for maximum comparability with two investigations about Class II correction in adult patients using aligners [30, 31]. This is the reason why patient inclusion criteria and evaluation methods were selected as an exact copy of those studies. In this study, too, 2 groups of 40 patients each were compared with one another in order to be able to make a statement about the effectiveness and efficiency of Class II correction with CCLAs in combination with intermaxillary elastics in adult patients. The null hypothesis could be rejected: in contrast to the results published by Patterson *et al*. and Leavitt, it showed that Class II malocclusion in adult patients could be corrected effectively and efficiently combining completely customized lingual appliances and Class II elastics [30, 31]. The measured anterior-posterior correction in the area of the first molar was, on average, 95% of the planned correction, and even deep overbite was found to have been slightly overcorrected clinically with respect to the set-up. In Patterson's paper, a comparable outcome was aimed for after completing treatment with the initial set of aligners and intermaxillary elastics [30]. The achieved outcome for the correction of the overbite (39%) was not even half of what had been intended and the improvement of the anterior-posterior relationship was as little as 0.25 mm (6.8% of the planned correction). Likewise, in Leavitt's [31] follow-up study, which consisted of checking up on the patients in Patterson's investigation who continued treatment, the anterior-posterior correction that could be achieved after 3.6 refinements on average and a mean of 76 aligners, amounted to only 1.05 mm (33% of the intended correction). These figures demonstrate the considerable difference in terms of effectiveness and efficiency of Class II correction using Class II elastics in adult patients when comparing the use of state-of-the-art lingual appliances with aligner treatments. At first glance, the striking difference would seem surprising, all the more so as poor compliance in terms of wearing the elastics would have resulted in a patient's exclusion. Furthermore, the paper by Simon *et al*. [38], which has been repeatedly quoted on the subject of Class II correction with aligners, reported a maxillary distalisation of 88% of what was intended. It is interesting to note that in this investigation, the digital model's pre- and post-space opening after attempted molar distalisation were superposed on the

Table 5. Intergroup Mann-Whitney U test statistics.

	Class I		Class II		
Variables	Mean	SD	Mean	SD	Sig
T1					
Total score	43.83	12.32	56.33	13.21	<.001
AR	23.88	7.65	23.25	6.47	.806
MR	3.65	2.30	4.08	1.99	.290
BI	4.53	2.79	6.20	3.89	.035
OJ	5.25	3.57	6.65	4.41	.163
OC	1.83	3.14	2.50	3.22	.304
OR	3.93	3.21	12.55	3.52	<.001
IC	0.78	1.90	1.10	2.67	.946
T2A					
Total score	12.83	4.95	9.80	3.81	.005
AR	2.00	2.54	1.73	1.41	.657
MR	2.70	1.88	2.15	1.61	.192
BI	2.45	2.28	1.75	1.46	.227
OJ	0.95	1.13	0.63	1.15	.104
OC	1.38	2.02	1.38	1.76	.861
OR	3.35	2.23	2.17	1.65	.016
IC	0.00	0.00	0.00	0.00	1.0
T2B					
Total score	19.40	5.71	17.88	4.64	.375
AR	5.08	2.54	4.53	2.34	.419
MR	3.25	1.78	2.73	1.87	.187
BI	4.38	2.62	4.68	3.06	.756
OJ	1.93	1.47	1.60	1.72	.167
OC	1.60	2.05	1.50	1.80	.992
OR	3.10	2.05	2.85	2.01	.796
IC	0.08	0.35	0.00	0.00	.155

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.

Table 6. Mean percentage accuracy of tooth movements.

	Class I		Class II	
Variables	% Achieved (T2A)	% Achieved (ABO = 0)	% Achieved (T2A)	% Achieved (ABO = 0)
	(T1 - T2B) / (T1 - T2A)	(T1 - T2B) / T1	(T1 - T2B) / (T1 - T2A)	(T1 - T2B) / T1
Total score	78.81	55.74	82.63	68.26
AR	85.92	78.73	86.99	80.52
MR	42.11	10.96	69.95	33.09
BI	7.21	3.31	34.16	24.52
OJ	77.21	63.24	83.89	75.94
OC	51.11	12.57	89.29	40.00
OR	143.10	21.12	93.45	77.29
IC	89.74	89.74	100.00	100.00

ABO = 0: ABO OGS Score of 0.

anterior teeth, which led to interpreting every millimetre of space opening as an effective distalisation. It would seem doubtful that this kind of approach makes sense for space opening that will in any case be partially reciprocal.

On the whole, dentoalveolar Class II correction using aligners would appear to be an ambitious undertaking as such, since meeting the two preconditions that are essential for it is a challenge with removable appliances of this kind (Fig. 6), i.e. reliable levelling of the curve of Spee in the lower jaw, including bodily intrusion of the anterior teeth, as well as torque control in the area of the maxillary anterior teeth before and during the correction of the bite [39–41]. It is exactly these tooth movements, however, that fixed appliances and in particular CCLAs have been demonstrated to be able to reliably achieve, without relying on patient compliance [7, 10, 12, 16, 18]. These circumstances described here can explain the obvious differences in the quality of treatment outcome. Assuming the ABO passing score to be 27, none of the patients in the Class II group of Patterson *et al*. [30] would have passed. With an additional 3.6 refinements and a mean of 76 aligners in Leavitt's [31] follow-up study, 13.6% would have made it in that same group, while 100% of the patients in the Class II group in this study would have passed.

As does this investigation, numerous current studies indicate that the quality of the treatment outcome when using CCLAs is high. Vu *et al*. [9] report a PAR score reduction of an average of 86% in a patient cohort with a marked Class II/2. The mean final PAR score was 2.9, where a score of lower than or equal to 5 has to be seen as a 'High Quality Result' [22]. An assessment of outcomes of Class II correction treatment with CCLAs combined with a Herbst appliance was performed by Mujagic *et al*. [19] based on the Objective Grading System of the ABO. At the end of treatment, the average score was 15.0. AlQatami et al [21] assessed more lingual patients, who had received treatment in the course of a lingual Master program (Master of Science in Lingual Orthodontics, Hannover Medical School, 2006–2020). The average ABO MGS score at the end of treatment was 17.8. Only recently, Graf *et al*. [22] published the results of their multi-centre study on the subject of quality of orthodontic treatment outcomes in Germany. 96% of the lingual cases which were all treated with a CCLA finished with a 'High

Figure 6. Situation in the patient from Fig. 5 after bonding of upper and lower completely customized lingual appliances (a). The deep overbite is raised immediately because of the contacts on the half-occlusal pads on the second molars. The mandible rotates downwards and backwards, which, as a consequence, worsens the Class II relationship and allows for a certain overcorrection. The archwire orientation ribbonwise is very helpful for levelling the lower curve of Spee. Slightly overcorrected molar relationship after dentoalveolar Class II compensation with Class II elastics for 7 months (b). Overcorrection especially is very beneficial, but not only in asymmetric distocclusions. One can notice that the actual bite correction amounted to much more than what was measured from T1 to T2B. Levelling of the mandibular curve of Spee before, and upper incisor torque control during, Class II correction are tooth movements indispensable for a successful bite correction of this kind. After the phase of levelling and aligning with 0.014" round and 0.016" × 0.022" superelastic NiTi wires, 0.016" × 0.024" stainless steel archwires are used for Class II correction with intermaxillary elastics. In the upper anterior segment (3-3), the wires have an extra-torque bend of 13°. In order to prevent space-opening mesial to the canines, the steel wire is bent vertically behind the second molar tubes (c). Also, in the lower arch 0.016" × 0.024" SS wires are inserted for anterior-posterior correction. In order to improve patient comfort, the wire is bent horizontally behind the second molars (d). The Class II elastics connect the hook of the upper canine brackets to a buccal button on the lower second molars.

Quality Result', meaning a PAR score of lower than or equal to 5 and a mean PAR score reduction of more than 90%.

Strengths and limitations of the study

The main limitation of this study is that only patients who were wearing the elastics as prescribed were retrospectively included, which may introduce selection bias. Therefore, the results of this study may have limited generalizability.

Another limitation could be found in the retrospective nature of this study in terms of lack of randomization, selection bias, and less control over potential confounding variables. In contrast to this, retrospective studies can be carried out much faster, which is advantageous especially in areas in which there is rapid technological development. Moreover, it allows existing studies to be replicated in a methodologically similar way, but with a different intervention. This was the case here, replicating the study by Patterson *et al*. who evaluated the treatment outcome of Class II correction using Invisalign.

All patients were treated in one orthodontic specialist practice in Germany with extensive experience in lingual orthodontics, which may limit the generalisability of the findings to other populations or settings. However, the fact that all treatments were completed by orthodontic specialists with great experience in CCLA treatment can also be seen as a strength of our study. It ensures standardized treatment protocols and minimized variability in the treatment approach, thereby enhancing the internal validity.

Comparability was ensured by the inclusion of a nearly identical adult patient cohort, which minimizes the influence of gender and age on the comparative interpretation. The cases of both studies were evaluated with the ABO MGS, the only difference being that the Invisalign cases were not evaluated on the hand-held cast, but digitally with the ClinCheck Pro software. The results of this study may therefore be slightly different from those found if the measurements were taken digitally [42].

The protocol used in this study is also comparable as regards the evaluation times, where T1 gives information about the initial severity of the malocclusion and the ClinCheck prediction at T2A corresponds to the WIN set-up prior to manufacturing the appliance. For Class II, this study was able to form a patient group with an almost identical ABO score compared to Patterson *et al*. Thus, the baseline conditions are almost identical. For T2B, there is limited comparability with the aligner study by Patterson *et al*. [30], who evaluated only the first aligner set. However, an anterior-posterior correction of only 0.25 mm after 7 months of Class II elastic wearing is not a convincing result.

In both studies, the intra-rater reliability was evaluated with a 10% subset of the cases. This study used the ICC instead of Cronbach's alpha, which was used in the two aligner studies because ICC allows assessment of the variability within the examiner's measurements and is suitable for assessing the reliability of continuous values such as the obtained AP discrepancy measurements in millimetres.

The present study primarily focussed on post-treatment outcomes, providing limited insight into the long-term stability of treatment effects or potential relapse over time.

Conclusions

Completely customized lingual appliances in combination with Class II elastics can correct a Class II malocclusion successfully in adult patients. Therefore, the final treatment outcome can be of a similar high quality in Class I and Class II patients.

Author Contributions

Yann Janssens (Conceptualization [Lead], Data curation [Lead], Formal analysis [Equal], Methodology [Equal], Writing—original draft [Lead], Writing—review & editing [Supporting]), Frauke Beyling (Conceptualization [Equal], Investigation [Equal], Project administration [Equal], Visualization [Lead], Writing—review & editing [Supporting]), Thomas Stamm (Conceptualization [Equal], Data curation [Equal], Formal analysis [Equal], Supervision [Equal], Writing—review & editing [Equal]), Rainer Schwestka-Polly (Project administration [Equal], Supervision [Equal], Writing—review & editing [Equal]), and Jonas Schmid (Conceptualization [Equal], Data curation [Lead], Formal analysis [Lead], Validation [Equal], Writing—review & editing [Equal])

Conflict of interest

All authors declare that they have no conflict of interest.

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Ethics approval

This retrospective cohort study received approval from the ethical committee of the Hannover Medical School, Hannover, Germany (3151-2016).

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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