Tang et al. BMC Oral Health (2025) 25:629
https://doi.org/10.1186/s12903-025-06012-3

BMC Oral Health

RESEARCH

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Evaluating the effectiveness of clear aligner therapy in leveling the curve of spee: a comparative study of extraction vs. non-extraction patients

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Abstract

Background The proper leveling of curve of Spee (CoS) is critical in orthodontic treatment. However, achieving a leveled CoS using clear aligner therapy (CAT), particularly in cases involving premolar extractions, poses significant challenges. This retrospective study aims to evaluate the effectiveness of clear aligners in leveling the CoS in premolar extraction and non-extraction patients, and to identify key factors influencing post-treatment CoS.

Methods Thirty non-extraction patients and thirty patients with bilateral mandibular first premolar extractions, all of whom received CAT, were included in the study. The CoS of the pre-treatment, predicted post-treatment, and actual post-treatment dentition models were measured using Geomagic Studio software.

Results The pre-treatment CoS showed significant correlations with overbite, overjet, and Angle classification. Both the non-extraction and extraction groups failed to achieve the predicted improvement in CoS. However, the extraction group exhibited a greater discrepancy between the predicted and actual changes (1.38 ± 0.74 mm for the extraction group vs. 0.84 ± 0.58 mm for the non-extraction group). The regression model indicated that the post-treatment CoS was positively correlated with pre-treatment CoS, predicted CoS, and the use of Class II intermaxillary elastics, while it was negatively correlated with initial crowding.

Conclusions The extraction group showed less effectiveness in leveling the curve of Spee compared to the non-extraction group. The results of the regression analysis can aid clinicians in identifying factors that impact the post-treatment curve of Spee, thereby contributing to improved treatment outcomes.

Keywords Clear aligner therapy, Extraction treatment, Curve of Spee, Regression analysis

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Background

In the field of orthodontics, the curve of Spee (CoS) plays a crucial role. It describes the sagittal arc formed by the mandibular dentition from the incisal edge of the incisors to the buccal cusps of the posterior teeth. An appropriate CoS is essential for increasing the occlusal contact area of the teeth, enhancing the crush/shear ratio between the posterior teeth [1], balancing masticatory muscle forces [2], and improving chewing efficiency [3]. An exaggerated CoS can pose challenges in achieving a Class I canine relationship and may lead to occlusal interferences during mandibular function [2]. Dr. Andrews considers a relatively flat CoS as one of the six keys of normal occlusion, making the leveling of the CoS a primary goal of orthodontic treatment [4].

Clear aligner therapy (CAT), with its aesthetic appeal and comfort, has become increasingly popular. However, the efficiency of tooth movement with CAT has been questioned. Reports indicate that the efficiency of aligners in achieving anterior intrusion and posterior extrusion–two primary mechanisms for leveling the curve of Spee [5]–is 40% and 10%, respectively [6]. A previous study reports that the accuracy of leveling curve of Spee in non-extraction patients using clear aligners is less than 40% [7]. Recently, CAT has been more frequently used to treat cases involving premolar extractions. In these cases, leveling the CoS becomes more complicated due to the relative extrusion of the mandibular incisors caused by torque loss during space closure [8, 9]. This not only compromises the treatment results but also significantly prolongs the treatment duration [10]. Notably, to date, there is no specific clinical research evaluating the effectiveness of clear aligners in leveling the CoS in premolar extraction patients.

Therefore, this study aims to explore the effectiveness of clear aligner therapy to level the curve of Spee in premolar extraction patients, using non-extraction patients as a reference, and to identify factors influencing CoS leveling in order to improve clinical outcome.

Materials and methods

Sample collection

This retrospective study was approved by the Ethics Review Committee of West China Hospital of Stomatology, Sichuan University (WCHSIRB-CT-2022-160). All subjects were treated under the supervision of a specialist orthodontist and commenced their orthodontic therapy between January 2016 and January 2022. A total of 297 patients in the ClinCheck account of the aforementioned orthodontist were screened for eligibility. Based on a previous study indicating the difference between achieved and predicted change of CoS in non-extraction patients was 0.55 ± 0.22 mm [7], a sample size of 13 per group was necessary to determine significance in a mean difference of 0.25 mm between extraction and non-extraction groups, with type I error at 0.05, and type II error at 0.20 (statistic power at 0.8).

Inclusion criteria were: (1) Age ≥ 18 years; (2) Underwent clear aligners therapy (Invisalign) and completed the first series of aligners (with no more than 3 remaining steps), followed by at least one refinement; (3) Treatment encompassing all mandibular permanent teeth, with the exception of third molars; (4) Non-extraction of mandibular teeth or extraction of bilateral mandibular first premolars. Exclusion criteria were: (1) History of orthodontic treatment or orthognathic surgery; (2) Congenital craniofacial or dental abnormalities; (3) Severe periodontal disease or periapical pathology; (4) Combined treatment with fixed appliances or other appliance during this treatment phase.

A total of 60 patients were included, with an average age of 27.9 ± 7.28 years. Among them, 30 patients underwent extraction of bilateral mandibular first premolars, and 30 patients were non-extraction cases. All the patients changed aligners every 10 days, with a daily wearing time of at least 20 h.

Evaluation of basic information and measurement of curve of Spee

The dental characteristics, including overbite, overjet, and Angle classification, were evaluated using pre-treatment dentition models. The craniofacial characteristics, specifically sagittal skeletal classification and vertical skeletal pattern, were assessed through pre-treatment cephalometric analysis.

The pre-treatment dentition models, the predicted post-treatment models (refer to the final treatment dentition models of the first series of aligners), and the actual post-treatment models (refer to the initial dentition models of the sequential refinement aligners) were exported in STL format using ClinCheck software (Align Technology, San Jose, California, USA). The curve of Spee for these three models were measured using Geomagic Studio software (3D Systems, Rock Hill, South Carolina, USA). The distobuccal cusp tips of the bilateral mandibular second molars and the mesioincisal angle of the mandibular central incisors located more occlusally were used to establish the reference plane. The curve of Spee was then quantified by measuring the distance from the buccal cusp tip of the mandibular second premolar to the reference plane.

Statistical analysis

All measurements were performed by two researchers, and the average values were used for further analysis. After 2 weeks, 20% of the patients were randomly selected for re-measurement. The intra-class correlation coefficient (ICC) was used to assess consistency between

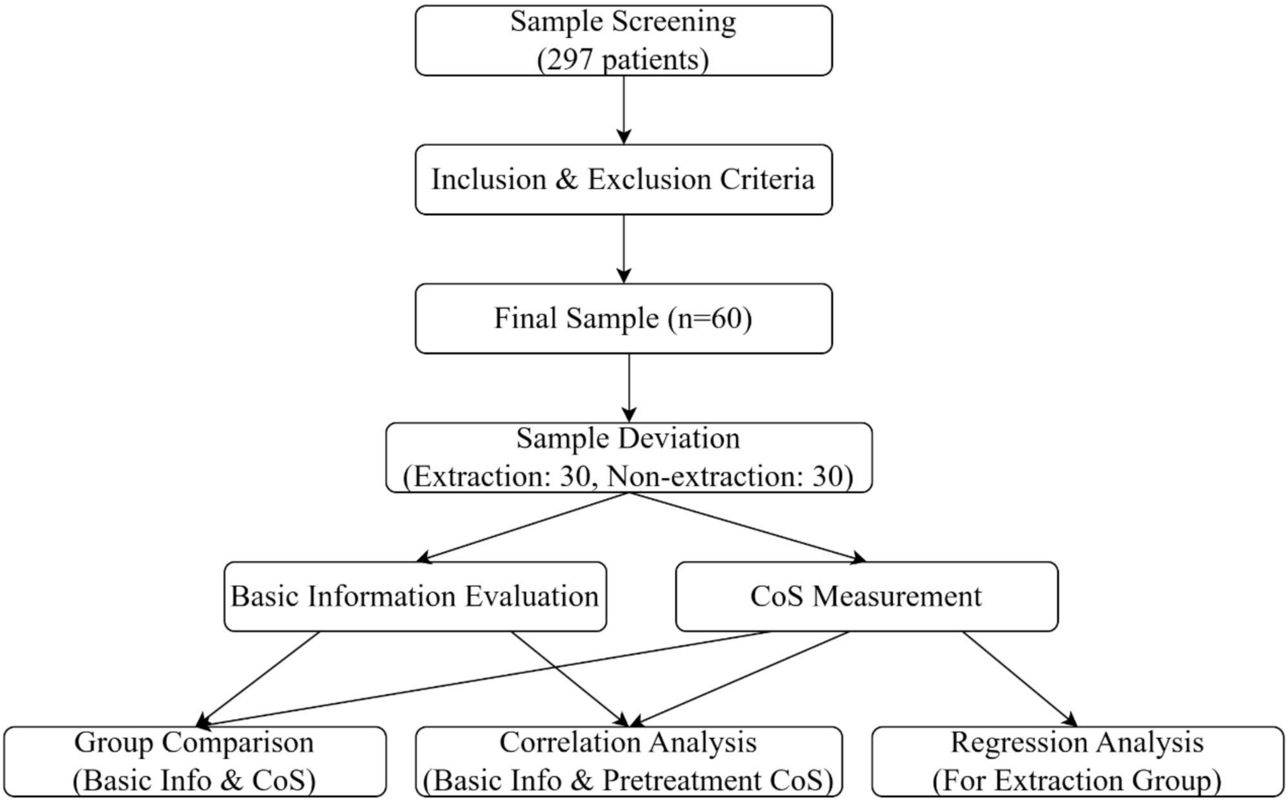

Fig. 1 The workflow of sample collection, evaluation, and analysis

Table 1 Basic information of non-extraction and extraction groups

Variable	Non-extraction	Extraction	*P* value
Age (y)	26.97 ± 6.96	27 (10)	0.399[a]
Initial crowding (mm)	1.23 ± 2.02	1.68 (3.39)	0.188[a]
Overbite (mm)	3.13 ± 2.14	1.61 ± 1.68	0.004[b]*
Overjet (mm)	3.62 ± 2.19	3.46 ± 1.68	0.757[b]
Gender			1.000[c]
Female	22	21	
Male	8	9	
Angle classification			0.174[c]
Class I	15	21	
Class II	14	7	
Class III	1	2	
Sagittal skeletal classification			0.042[c]*
Class I	22	13	
Class II	5	13	
Class III	3	4	
Vertical skeletal pattern			0.037[c]*
Hypodivergent	14	11	
Normodivergent	16	13	
Hyperdivergent	0	6	

Normally distributed data presented as mean ± standard deviation, skewed data presented as median (interquartile range), categorical data presented as counts

[a]Mann-Whitney U test, [b]independent t-test, [c]Fisher's exact test, *Statistically significant at $p < 0.05$

and within the observers. For all patients, bilateral measurements were pooled to obtain a doubled sample ($n = 60$ for extraction group and $n = 60$ for non-extraction group). The Shapiro-Wilk test was used to assess data normality. Independent sample t-tests were used to compare normally distributed data between the extraction and non-extraction groups, while Mann-Whitney U tests were used for non-normally distributed data. The correlation between pre-treatment CoS and potential related factors was explored using Pearson correlation for normally distributed data or Eta correlation tests for categorical data. Multiple linear regression analysis was performed to determine the impact of potential factors on the post-treatment CoS. Statistical analysis was conducted using SPSS 21.0 software (IBM, Armonk, NY, USA). For all the tests, $p < 0.05$ was considered statistically significant. The workflow of sample collection, evaluation, and analysis was illustrated in Fig. 1.

Results

The ICC demonstrated excellent agreement, with intra-operator values from 0.995 to 0.999 and inter-operator values from 0.885 to 0.981. Basic patient information was summarized in Table 1. No statistically significant differences were observed between the two groups in terms of age, gender, initial crowding, overjet and Angle classification. However, there were significant differences in

Table 2 Correlation test (Pearson and Eta) between pre-treatment CoS and potential variables

Variable	r/η	P value
Age	0.012	0.893[a]
Initial crowding	-0.028	0.758[a]
Overbite	0.510	< 0.001[a*]
Overjet	0.524	< 0.001[a*]
Gender	0.040	0.664[b]
Angle classification	0.255	0.020[b*]
Sagittal skeletal classification	0.205	0.082[b]
Vertical skeletal pattern	0.095	0.599[b]

[a]Pearson correlation coefficient, [b]Eta correlation coefficient, *Statistically significant at $p < 0.05$

overbite, sagittal and vertical skeletal patterns between the two groups. These differences may be the main factors affecting tooth extraction decisions.

The result of Pearson correlation and Eta correlation test was shown in Table 2, which indicated that the pre-treatment CoS was significantly corelated with overbite, overjet and Angle classification, while not with the other factors.

The difference of CoS and its change between the extraction and non-extraction groups were documented in Table 3. The pre-treatment CoS was 2.15 ± 1.15 mm and 1.34 ± 0.92 mm in the non-extraction group and extraction group, respectively, which showed a statistically significant difference ($p < 0.01$). However, there was no statistically significant difference in actual post-treatment CoS between the two groups. The actual change of the CoS was significantly greater in the non-extraction group (-0.98 ± 1.02 mm) compared to the extraction group (-0.24 ± 0.99 mm). The discrepancy between the predicted and actual change of CoS was significantly lager in the extraction group (-1.38 ± 0.74 mm) compared to the non-extraction group (-0.84 ± 0.58 mm) ($p < 0.01$).

The results of the multiple linear regression analysis (Table 4) revealed a significant correlation ($p < 0.05$) between post-treatment CoS and the following variables: pre-treatment CoS, predicted CoS, and Class II intermaxillary elastics, all of which were positively correlated with post-treatment CoS. Conversely, initial crowding was negatively correlated with post-treatment CoS. However, gender, bite ramps, and the type of attachments used on canines, second premolars, first molars and second molars did not show a significant correlation with post-treatment CoS.

Discussion

In this study, we compared the effectiveness of clear aligner therapy in leveling the curve of Spee (CoS) between premolar extraction and non-extraction patients. Both groups had similar predicted changes in CoS, while the extraction group experienced significantly less actual change in CoS compared to the non-extraction group. In other words, the discrepancy between the predicted and actual changes was significantly greater in the extraction group, indicating that extracting the mandibular first premolars reduced the effectiveness of clear aligners in leveling the CoS. The possible reasons include: (1) Mechanical defects of the clear aligner material: The insufficient stiffness of clear aligners hinders them from producing the necessary counterforce required for bodily movement of incisors under retraction forces, resulting in torque loss and relative extrusion [6, 11]. (2) Difficulty of anterior intrusion after premolar extraction: According to a beam model, increasing beam length proportionally decreases strength, exponentially decreases stiffness, and exponentially increases range [12]. Specifically, extracting the first premolars increases the distance between the aligner's support points, namely the second premolar and the canine. As a result, the posterior teeth may fail to provide sufficient anchorage for anterior intrusion, and the situation may worsen when the anterior six teeth are intruded together. Hence, it is recommended to intrude the canines and incisors separately, using specific attachments for mutual anchorage. Delaying the first premolar extraction is advisable, particularly when significant anterior intrusion is needed. (3) Inappropriate attachment design: Different tooth movements may necessitate distinct attachment designs. The G5 attachments are primarily designed to level the CoS by improving control of premolar extrusion and anterior intrusion [13]. In contrast, the G6 attachments are specifically engineered for first premolar extraction cases, aimed at facilitating canine bodily movement and maximizing posterior anchorage [14]. For optimal results, it is advisable to use different attachment at different stages. Initially, the G5, G7 or horizontal beveled attachments

Table 3 Comparison of CoS between non-extraction and extraction groups

CoS	Non-extraction	Extraction	Difference	P value
Pre-treatment	2.15 ± 1.15	1.34 ± 0.92	0.80 ± 0.19	< 0.001*
Predicted	0.33 ± 0.65	-0.28 ± 0.50	0.61 ± 0.40	< 0.001*
Post-treatment	1.17 ± 0.82	1.10 ± 0.88	0.07 ± 0.15	0.670
Predicted change	-1.82 ± 1.05	-1.62 ± 0.95	-0.19 ± 0.18	0.295
Actual change	-0.98 ± 1.02	-0.24 ± 0.99	-0.74 ± 0.18	< 0.001*
Discrepancy between predicted and actual change	-0.84 ± 0.58	-1.38 ± 0.74	0.55 ± 0.12	< 0.001*

*Statistically significant at $p < 0.05$

Table 4 Multivariate linear regression analysis results

Variable	β (95% CI)	t	*P* value
Pre-treatment CoS	0.265 (0.041, 0.489)	2.376	0.022*
Predicted CoS	0.749 (0.376, 1.121)	4.045	< 0.001*
Age	0.027 (-0.004, 0.058)	1.756	0.086
Initial crowding	-0.091 (-0.174, -0.009)	-2.227	0.031*
Gender			
Male	0.327 (-0.178, 0.831)	1.304	0.199
Female	Reference	/	/
Intermaxillary elastics			
Class II	0.668 (0.146, 1.190)	2.576	0.013*
Class III	-0.330 (-1.865, 1.205)	-0.432	0.667
None	Reference	/	/
Bite ramps			
Yes	0.429 (-0.640, 1.497)	0.807	0.424
No	Reference	/	/
L3 attachment			
Rectangle	-0.140 (-0.717, 0.437)	-0.489	0.627
Optimized	Reference	/	/
L5 attachment			
Rectangle	0.253 (-0.385, 0.891)	0.799	0.429
Optimized	Reference	/	/
L6 attachment			
Rectangle	-0.329 (-1.024, 0.366)	-0.952	0.346
Optimized	Reference	/	/
L7 attachment			
Rectangle	-0.335 (-0.983, 0.313)	-1.041	0.303
Optimized	Reference	/	/

*Statistically significant at $p < 0.05$

[15] should be utilized to level the CoS. Once leveling is achieved, new attachments can be bonded for effective space closure.

Our research has identified a substantial correlation between the pre-treatment CoS and various dental characteristics, including overbite, overjet, and Angle's classification. However, this relationship does not apply to initial crowding or demographic factors like age and gender, consistent with the results of a previous study [16]. The literature presents contradicting results on the potential association of the CoS with craniofacial features. Trouten et al. [17] reported a negative CoS in hyperdivergent patients and a pronounced CoS in hypodivergent patients. Orthlieb [18] found a flatter CoS in skeletal Class III patients compared to Class II. Contrary to these reports, our data indicates that sagittal and vertical skeletal patterns, as measured by the ANB angle and the FH-MP angle, do not show a significant association with pre-treatment CoS, which is consistent with the findings of other analogous studies [16, 19–21].

The results of multivariate linear regression analysis showed a positive correlation between the post-treatment and pre-treatment CoS, suggesting that a deeper pre-treatment CoS increases challenges in its leveling. This finding aligns with previous research on non-extraction clear aligner therapy, which indicated a decline in the accuracy of leveling as the pre-treatment CoS increased [7]. Additionally, it was found that initial crowding negatively correlated with post-treatment CoS, indicating that greater crowding leads to a flatter post-treatment CoS. Increased crowding may reduce the amount of anterior retraction, thereby mitigating the torque loss of anterior teeth, which is detrimental to the leveling of the CoS. In the present study, 8 patients had bilateral Class II elastics and 1 patient had Class II elastics in one side, and Class III elastics in the other side. The regression model indicated that Class II elastics negatively impacted the leveling of the CoS. According to a previous finite element analysis, the application of Class II elastics in first premolar extraction cases, although effective in minimizing lower anterior torque loss, resulted in increased extrusion and mesial tipping of molars, as well as greater intrusion of second premolars [22]. Based on the finite element study and our findings, switching the elastics to the mandibular second premolars may be beneficial when anchorage is not a priority. This adjustment may help facilitate second premolar extrusion and improve the CoS leveling. Although the regression model showed no connection between Class III elastics and the CoS leveling, the influence of Class III elastics needs to be extrapolated carefully due to the small sample size.

Previous research has shown that employing anterior bite plates in fixed orthodontics helped deep overbite correction by promoting the extrusion of posterior teeth [23, 24]. However, this approach appears to be less effective in clear aligner therapy due to the occlusal coverage provided by the aligner trays [25], which may also impact the leveling of the CoS. The regression analysis revealed that the use of bite ramps in clear aligner therapy does not significantly contribute to the leveling of the CoS. This finding is consistent with a study by Husain et al. [26], which found no significant difference in overbite reduction whether precision bite ramps were used or not. Additionally, our study suggests that the type of attachment on the lateral teeth does not have a significant impact on the CoS leveling. Whether the attachments on the canines, second premolars, first molars or second molars were optimized or rectangular, they did not seem to influence the CoS after treatment. As mentioned earlier, the current attachments available may not be capable of addressing dental sagittal and vertical problems simultaneously.

As a retrospective study, there were several limitations. Selection bias was unavoidable, and performance bias was present since all patients were treated by a single practitioner. Several treatment aspects were not considered in the analysis, including the sagittal and vertical skeletal patterns, the duration of intermaxillary elastics, and the sequencing of tooth movement. These factors could potentially influence the results and should be taken into account in future research. Additionally, patients who did not complete the first series of aligners due to severe off-tracking were excluded, which could potentially overestimate the aligner's effectiveness in leveling the curve of Spee, particularly in the extraction group. The study concentrated exclusively on the CoS without assessing the movement of individual teeth, such as the incisors, second premolars, and second molars. Further research is needed to determine how these specific tooth movements impact the leveling of the CoS.

Conclusion

The effectiveness of clear aligner therapy to level the curve of Spee (CoS) may be diminished when mandibular first premolars are extracted. Our regression analysis results can assist clinicians in identifying factors that influence the post-treatment CoS, thereby enhancing treatment outcomes.

Abbreviations

CoS curve of Spee
CAT clear aligner therapy
ICC Intraclass correlation coefficient

Acknowledgements

Not applicable.

Author contributions

TZX was responsible for the data collection, data analysis, interpretation and manuscript development. HK collected clinical data and conducted analysis. SY and YYR helped with the statistical analysis and modification of the manuscript. LY developed the idea for the study and supervised the whole study. All authors read and approved the final manuscript.

Funding

This research was supported by the Joint Research Fund of Chengdu Medical College & Chengdu Seventh People's Hospital under Grant number 23LHQYY-01.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Review Committee of West China Hospital of Stomatology, Sichuan University (WCHSIRB-CT-2022-160). This study was conducted in accordance with the Declaration of Helsinki. Informed consent was obtained from all of the participants in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 13 January 2025 / Accepted: 16 April 2025
Published online: 24 April 2025

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