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Treatment outcome differences between pass and fail scores and correlation between cephalometric changes and cast-radiograph evaluation of the American Board of Orthodontics

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Abstract:

OBJECTIVE: Using the cast-radiograph evaluation (CRE) score of the American Board of Orthodontics (ABO), the purpose of this study was 1) to find the post-treatment discrepancies that contributed to low-quality outcomes and 2) to identify if there might be any correlation between cephalometric changes and post-treatment discrepancies.

MATERIALS AND METHODS: About 200 records submitted for the Thai Board of Orthodontics examination were analyzed. Overall, 23 parameters of the CRE scores and 12 cephalometric changes were collected. Based on the total CRE score, the cases were classified into three categories: pass (score <20), undetermined (score 20–30), and fail (score >30). Kruskal–Wallis was used to analyze the differences of mean CRE scores among these three categories. In addition, the cases were further classified into fixed appliance, two-phase and orthognathic surgery groups. Correlation tests were carried out to determine if there might be any association between cephalometric changes and CRE parameters.

RESULTS: Significant differences of mean CRE scores were found for all CRE components except interproximal contacts. Significant correlation coefficients with the total CRE scores were found for all parameters except interproximal contacts. Significant moderate association was found between lower incisor changes and CRE scores in the two-phase and orthognathic surgery group.

CONCLUSIONS: In order to improve treatment outcome quality, the top four parameters that orthodontists should pay attention to are occlusal contacts, occlusal relationship, marginal ridges, and alignment and rotations. Cephalometric changes were not suitable as weighting factors for total CRE scores.

Keywords:

American board of orthodontics, cast-radiograph evaluation score, cephalometric changes, objective grading system, orthodontic treatment outcome

Introduction

Over the years, there have been numerous attempts to formulate an objective means of determining the successful outcome

of orthodontic treatment. Examples of these systems are the American Board of Orthodontics Objective Grading System, peer assessment rating index, index of complexity, outcome and need, dental esthetic index, and comprehensive clinical assessment (CCA).^[1-7]

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The American Board of Orthodontics (ABO) developed an Objective Grading System (OGS) for post-treatment evaluation, using the ABO cast-radiograph evaluation (CRE).^[4,8,9] CRE scores have been tested for its validity and reliability in many studies to evaluate the quality of treated orthodontic cases in university and private practice patients.^[3,7,10-14] Mean total CRE scores reported were highly varied, ranging from 16.3^[15] to 45.5^[16]. These differences could be attributed to the clinicians' skill,^[13,16] orthodontic appliances,^[17-19] extraction versus nonextraction,^[20] etc., Nonetheless, most of these studies were in agreement that using ABO CRE scores would help in improving the quality of their completed cases.

Although the CRE was considered the most rigid and sensitive tool for post-treatment outcome evaluation, it was not able to show the degree by which the case improved from its pretreatment condition. Several attempts have been made to search for parameters that might be associated with the CRE score. Such parameters could then be used as weighting factors for the orthodontic board examiners. One of the most studied parameters was the ABO discrepancy index (DI). However, the results have been contradictory. Some studies reported no correlation between the DI and CRE scores.^[9,10] On the other hand, Campbell *et al.*^[21] and Pulfer *et al.*^[22] found a positive but weak correlation between the DI and CRE scores. In any case, cephalometric changes have not been studied in the past. Clinicians may have doubt whether greater discrepancies in post-treatment outcomes could be due to severe dento-skeletal problems.

Therefore, our research questioned if there could be any parameters of cephalometric changes associated with CRE scores. The specific purpose of this study was as follows:

1. Identifying the weaknesses of post-treatment outcomes in cases submitted for the Thai Board of Orthodontics (ThaBO) examination by using the CRE score
2. Evaluating the contribution of each CRE component to the total CRE score
3. Identifying if any parameters of cephalometric changes were associated with CRE scores.

Materials and Methods

This research was granted the certificate of approval by the institutional review board of Faculty of Dentistry/ Faculty of Pharmacy, Mahidol University, COA No. MU-DT/PY-IRB 2018/037.2806.

Sample size

Sample size was calculated based on the expected correlation coefficient, $r = 0.2$, two-sided type I error (α) of 0.05, and type II error (β) of 0.2 (80% power) and found that 194 samples were needed.

Data collection

The samples for this retrospective study were selected from the archives of cases submitted for the ThaBO examination for the year 2014. The cases had been treated by orthodontic residents in university-affiliated, 3-year accredited training programs from various institutions. In total, 200 cases which were obtained from 25 residents who were required to submit 8 cases each that met the specifications of 10 malocclusion categories, resembling the ABO criteria.

The names of the residents, institutions, and patients were not exposed to the researcher, and each case was assigned a random number. They were collected as three main sections: (1) pretreatment characteristics and treatment type, (2) ABO CRE score, and (3) cephalometric changes.

Pretreatment characteristics and treatment type

Pretreatment characteristics were recorded for frequency according to the following subcategories: (1) malocclusion type, (2) missing teeth, (3) crowding, and (4) treatment type. The details are shown in Table 1 and Figure 1.

Cast-radiograph evaluation score

The raw data of ABO CRE scores were obtained from our previous study as our research was conducted as an extension project.^[9] Emphasis was placed on the main and subcomponents of the CRE data, which had not yet been reported elsewhere.

Table 1: Descriptive frequencies of pretreatment variables and treatment types

Variable	Frequency, <i>n</i> (%)
Malocclusion	
Class I	74 (37.0)
Class II	16 (8.0)
Class II division 1	41 (20.5)
Class II division 2	19 (9.5)
Class III	50 (25.0)
Missing teeth	
None	126 (63.0)
Incisors	8 (4.0)
Canines-premolars	15 (7.5)
Molars	23 (11.5)
Combination	8 (4.0)
Impacted teeth	20 (10.0)
Crowding	
Mild	84 (42.0)
Moderate	54 (27.0)
Severe	36 (18.0)
Spacing	26 (13.0)
Treatment type	
One-phase fixed appliances	
Nonextraction	55 (27.5)
Extraction	100 (50.0)
Two-phase	19 (9.5)
Orthognathic surgery	26 (13.0)

n – Number of cases

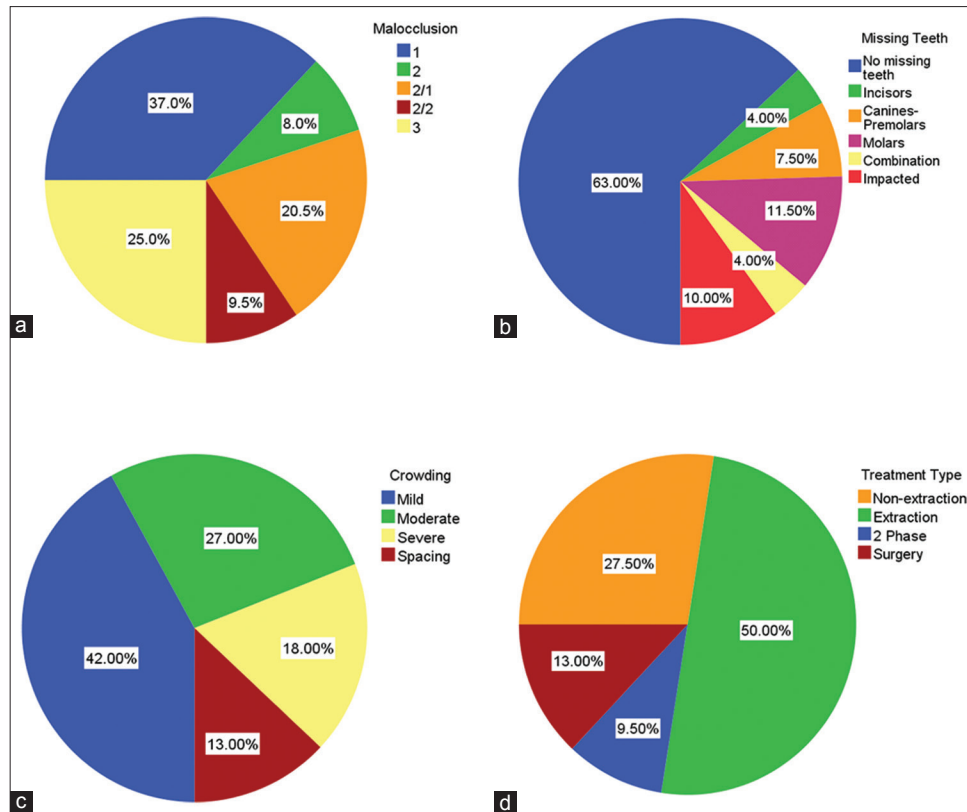


Figure 1: Pie charts of pretreatment variables and treatment types. (a) Malocclusion. (b) Missing teeth. (c) Crowding. (d) Treatment type

According to the methodology of the previous study, the 200 posttreatment records were assessed with the CRE score sheet using the ABO measuring gauge, by scoring various aspects on the study casts and panoramic radiographs to cover the following eight main components: (1) alignment and rotations, (2) marginal ridges, (3) buccolingual inclination, (4) overjet, (5) occlusal contacts, (6) occlusal relationships, (7) interproximal contacts, and (8) root angulation. Each component was further separated into maxillary and mandibular measurements, except for overjet (separated into anterior and posterior regions), occlusal contacts (buccal and lingual subcomponents), and occlusal relationships.

In total, 23 parameters (total CRE score, 8 main components, 14 subcomponents) related to the CRE score were obtained [Table 2].

All cases were further divided into three categories for the pass/fail status according to the CRE scores as suggested by Casiko *et al.*^[1] as follows:

1. Pass: CRE <20
2. Undetermined: CRE 20–30
3. Fail: CRE >30.

Cephalometric changes

Twelve measurements of cephalometric changes were obtained from the patients file records. Because most candidates did not report the same sets of measurements,

Table 2: Descriptive statistics of cast-radiograph evaluation components (n=200)

Cast-radiograph evaluation components	Mean	SD	Range
1. Alignment and rotations	4.97	2.68	0-12
Maxilla	2.95	1.75	0-8
Mandible	2.03	1.43	0-7
2. Marginal ridges	3.46	2.48	0-10
Maxilla	1.99	1.63	0-6
Mandible	1.47	1.50	0-7
3. Buccolingual inclinations	5.39	3.26	0-19
Maxilla	1.73	1.82	0-14
Mandible	3.66	2.76	0-11
4. Overjet	2.97	2.59	0-15
Anterior	2.30	2.30	0-10
Posterior	0.64	1.10	0-6
5. Occlusal contacts	3.75	3.07	0-17
Buccal	2.08	1.83	0-9
Lingual	1.66	2.09	0-11
6. Occlusal relationship	2.51	2.84	0-15
7. Interproximal contacts	0.06	0.25	0-2
Maxilla	0.03	0.17	0-1
Mandible	0.03	0.20	0-2
8. Root angulation	3.42	1.95	0-10
Maxilla	1.55	1.15	0-5
Mandible	1.93	1.59	0-7
Total CRE	26.53	9.57	6-55
Pass (<20), (n=52; 26%)	15.58	3.23	6-19
Undetermined (20-30), (n=86; 43%)	24.90	3.32	20-30
Fail (>30), (n=62; 31%)	38.00	5.90	30-55

n – Number of cases; CRE – Cast-radiograph evaluation; SD – Standard deviation

only those cephalometric changes that were consistently reported in all 200 cases were selected for our study.

Statistical analysis

All data were subjected to statistical analyses using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA).

Test of normality

The Shapiro–Wilk Test signified that the CRE scores were not of normal distribution; hence, nonparametric tests were to be conducted. Histograms of the frequency and distribution for the scores of the eight main CRE components and total CRE are presented in Figure 2.

Descriptive statistics

Descriptive frequencies of pretreatment characteristics (malocclusion type, missing teeth, crowding) and treatment type were analyzed [Table 1].

Descriptive statistics were also carried out for the scores of the total CRE, 8 main CRE components, and 14 CRE subcomponents to determine means, standard deviations (SD), and range [Table 2], as well as for the subcategories of pass, undetermined, and fail groups [Table 3]. Means, SD, and range were computed for cephalometric changes in absolute values according to the treatment type [Table 4].

Comparative statistics

Comparisons of differences among means of all 23 CRE parameters across pass, undetermined, and fail categories were performed by Kruskal–Wallis tests to ascertain whether significant differences across these three categories existed. This was followed by post-hoc tests for significant parameters.

Correlation tests

Nonparametric Spearman’s rank-order correlation tests were conducted between 22 CRE subcomponents with the total CRE scores, as well as between the total CRE scores with the 12 parameters of cephalometric changes according to the treatment type.

Standard error of measurement

Standard error of measurement (SEM) was determined using the intraclass correlation coefficient, where the two-way random model was selected for absolute agreement for both intraobserver and interobserver measurements.

Results

Descriptive frequencies of pretreatment characteristics and treatment type

The frequencies and percentages of pretreatment characteristics, such as malocclusion type, region of

missing teeth, degree of crowding, as well as treatment type, are described in Table 1 and Figure 1. According to the treatment type, the statistics showed that 50% were extraction cases, 27.5% were nonextraction cases, whereas orthognathic surgery and two-phase treatment were done in 13% and 9.5% of the total cases, respectively.

Frequency distributions and means of total cast-radiograph evaluation and its components

The frequency distributions of the scores of the total CRE and its eight main components are shown in Figure 2. The total CRE score was normally distributed, whereas the eight main CRE components displayed variably skewed distributions.

The means, SD, and range of the total CRE score and its main components are summarized in Table 2. The highest mean values came from buccolingual inclinations and alignment and rotations, with scores of 5.39 and 4.97, respectively. The mean of the total CRE score was 26.53 (SD 9.57), which falls into the undetermined category (CRE 20–30). The majority of cases also fell within this undetermined category, making up 43% of the total sample.

Comparisons of means of cast-radiograph evaluation components

Most CRE components exhibited significant differences in mean scores across the categories of pass, undetermined, and fail, except interproximal contacts and root angulation [Table 3 and Figure 3]. Post-hoc tests showed significant differences in the means between pass and fail groups for the total CRE and all CRE components except interproximal contacts and root angulation (maxilla).

Descriptive mean cephalometric changes

The means, SD, and range of cephalometric changes in absolute values according to the treatment type are shown in Table 4.

Correlations between cast-radiograph evaluation components with total cast-radiograph evaluation score

Results of the Spearman’s rank-order correlation tests performed between the CRE components with the total CRE score are displayed in Figure 4 and Table 5.

In Table 5, significant correlations at a moderate level can be noted for all variables except for interproximal contacts and maxillary root angulation. For the eight main CRE components, the correlation coefficients, r , ranking from highest to lowest were as follows: (1) occlusal contacts (0.62), (2) occlusal

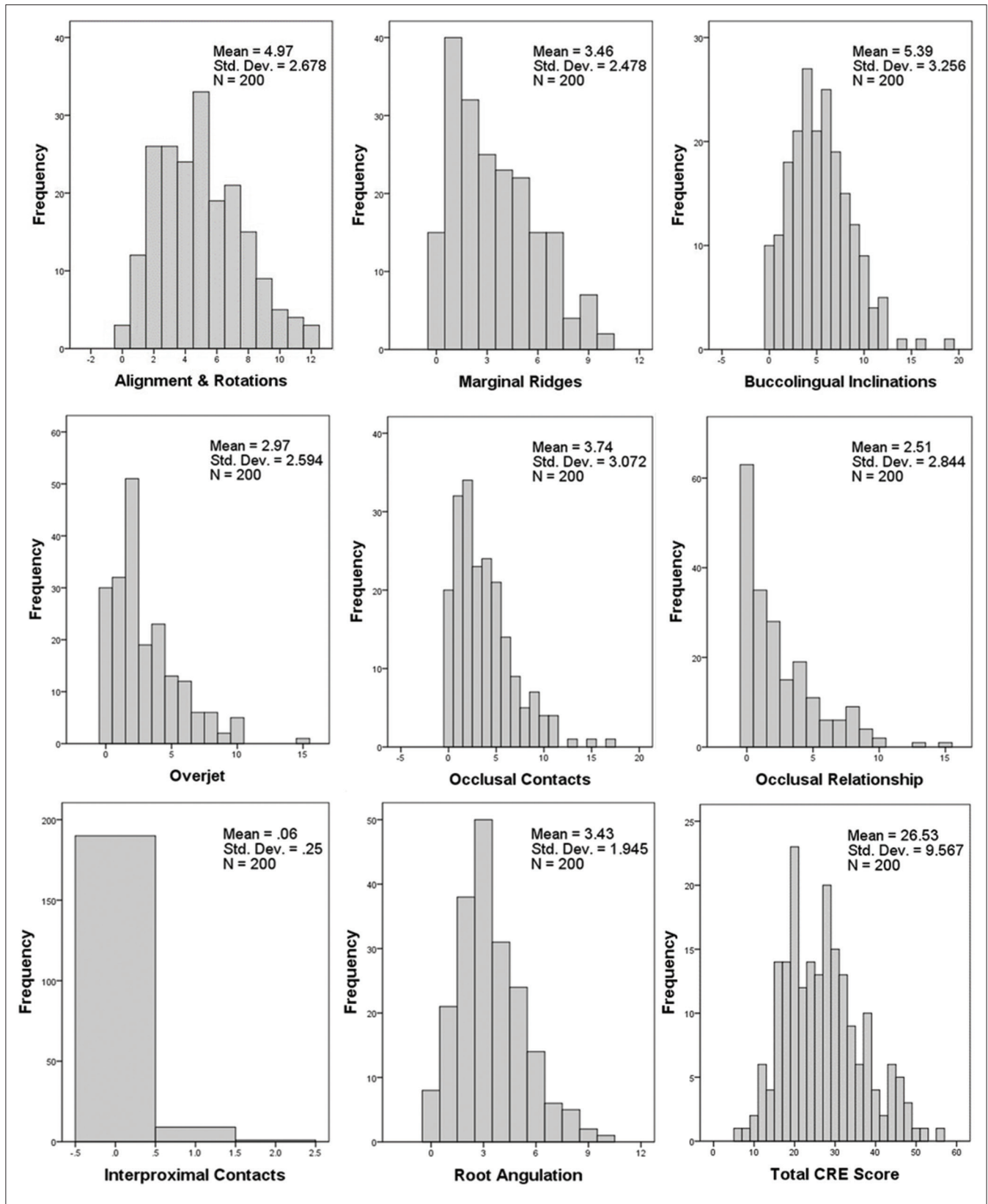


Figure 2: Frequency and distribution of different cast-radiograph evaluation components and the total cast-radiograph evaluation score

relationship (0.60), (3) marginal ridges (0.58), (6) buccolingual inclinations (0.38), and (7) root angulation (0.25) ($P < 0.05$), (4) alignment and rotations (0.57), (5) overjet (0.38),

Table 3: Results of Kruskal-Wallis and *post hoc* tests, across pass, undetermined, and fail cast-radiograph evaluation (n=200)

Cast-radiograph Evaluation components	Group	Minimum	Maximum	Mean	SD	Significance		
						P/U/F	P versus U	P/U versus F
Alignment and rotations	Pass	0	9	3.12	2.00	*	**	***
	Undetermined	1	11	4.53	2.20			***
	Fail	2	12	7.15	2.30			
Maxilla	Pass	0	5	1.90	1.33		*	***
	Undetermined	0	7	2.66	1.47			***
	Fail	1	8	4.21	1.69			
Mandible	Pass	0	4	1.21	1.09		*	***
	Undetermined	0	5	1.87	1.20			***
	Fail	0	7	2.94	1.48			
Marginal ridges	Pass	0	6	1.83	1.67	*	**	***
	Undetermined	0	7	2.94	1.92			***
	Fail	0	10	5.53	2.36			
Maxilla	Pass	0	6	1.08	1.3		*	***
	Undetermined	0	6	1.67	1.32			***
	Fail	0	6	3.19	1.59			
Mandible	Pass	0	4	0.75	1.13		*	***
	Undetermined	0	5	1.27	1.27			***
	Fail	0	7	2.34	1.68			
Buccolingual inclination	Pass	0	8	3.42	1.94	*	***	***
	Undetermined	0	12	5.86	2.95			NS
	Fail	0	19	6.37	3.83			
Maxilla	Pass	0	5	0.98	1.16		*	***
	Undetermined	0	6	1.69	1.60			NS
	Fail	0	14	2.40	2.27			
Mandible	Pass	0	4	0.75	1.12		*	**
	Undetermined	0	10	4.17	2.85			NS
	Fail	0	11	3.97	3.02			
Overjet	Pass	0	8	1.94	1.83	*	NS	***
	Undetermined	0	10	2.67	2.34			**
	Fail	0	15	4.23	2.98			
Anterior	Pass	0	8	1.56	1.75		NS	**
	Undetermined	0	10	2.20	2.23			NS
	Fail	0	9	3.05	2.58			
Posterior	Pass	0	4	0.35	0.84		NS	***
	Undetermined	0	4	0.48	0.94			***
	Fail	0	6	1.11	1.33			
Occlusal contacts	Pass	0	7	1.90	1.72	*	*	***
	Undetermined	0	9	3.12	2.25			***
	Fail	0	17	6.16	3.45			
Buccal	Pass	0	5	1.46	1.36		NS	***
	Undetermined	0	8	1.72	1.63			***
	Fail	0	9	3.10	2.04			
Lingual	Pass	0	3	0.44	0.80		**	***
	Undetermined	0	8	1.40	1.57			***
	Fail	0	11	3.06	2.63			
Occlusal relationship	Pass	0	3	0.48	0.80	*	***	***
	Undetermined	0	8	2.47	2.35			**
	Fail	0	15	4.26	3.40			
Interproximal contacts	Pass	0	1	0.02	0.14	NS	NS	NS
	Undetermined	0	2	0.08	0.32			NS
	Fail	0	1	0.05	0.22			
Maxilla	Pass	0	1	0.02	0.14		NS	NS
	Undetermined	0	1	0.03	0.19			NS

Contd...

Table 3: Contd...

Cast-radiograph Evaluation Components	Group	Minimum	Maximum	Mean	SD	Significance		
						P/U/F	P versus U	P/U versus F
Mandible	Fail	0	1	0.03	0.18			
	Pass	0	0	0.00	0.00		NS	NS
	Undetermined	0	2	0.06	0.28			NS
Root angulation	Fail	0	1	0.02	0.13			
	Pass	0	6	2.94	1.55	*	NS	**
	Undetermined	0	9	3.17	1.68			*
Maxilla	Fail	0	10	4.18	2.36			
	Pass	0	5	1.63	1.31		NS	NS
	Undetermined	0	4	1.52	1.05			NS
Mandible	Fail	0	4	1.50	1.14			
	Pass	0	5	1.33	1.22		NS	***
	Undetermined	0	6	1.69	1.30			**
Total CRE	Fail	0	7	2.77	1.88			
	Pass	6	19	15.58	3.23	*	***	***
	Undetermined	20	30	24.90	3.32			***
	Fail	30	55	38.00	5.90			

P – Pass; U – Undetermined; F – Fail; CRE – Cast-radiograph evaluation; NS – Not significant; SD – Standard deviation. *Statistically significant difference at $P < 0.05$. **Statistically significant difference at $P < 0.01$. ***Statistically significant difference at $P < 0.001$

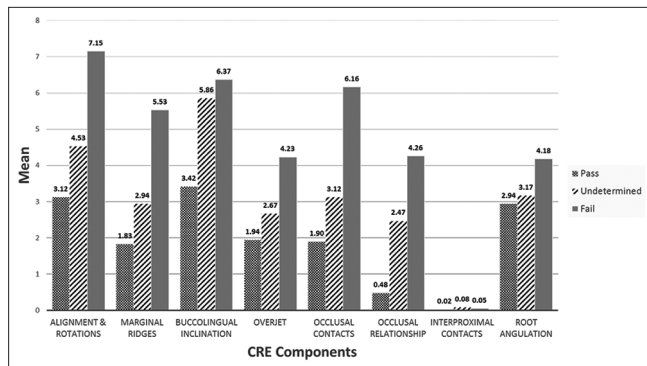


Figure 3: Clustered bar chart of distribution of means of eight main cast-radiograph evaluation components across pass, undetermined, and fail categories

Correlations between total cast-radiograph evaluation with cephalometric changes according to treatment type

Statistically significant correlations at moderate levels were found as follows: (1) total CRE score with L1-NB (° and mm.) in two-phase treatment ($r = 0.479$ and 0.473 , respectively) and (2) total CRE score with L1-MP (°) in orthognathic surgery cases ($r = -0.434$) [Table 6 and Figure 4].

Standard error of measurement

Reliability tests showed that the intraclass correlation coefficient for intraobserver reliability was computed to be 0.89 and 0.81, while interobserver was 0.73.

Discussion

In this study, we aimed to identify the CRE components that contributed significantly to the total CRE score, and specifically in cases with scores that would

potentially fail the ABO examination. Our results show that significant treatment outcome differences among pass, undetermined, and fail categories of cases submitted for the ThaBO examination were found in the following CRE components: (1) alignment and rotations, (2) buccolingual inclinations, (3) occlusal contacts, (4) marginal ridges, (5) occlusal relationship, (6) overjet, and (7) root angulations. However, there were no significant differences for interproximal contacts.

For overall cases, we found no correlation between any cephalometric changes and total CRE score. However, lower incisors inclination and position were significantly correlated with total CRE in the two-phase treatment and orthognathic surgery subgroups

Cast-radiograph evaluation components

The results of our study were generally in agreement with other past studies. According to Table 7, the mean total CRE score of 26.5 (SD 9.6) in our study is found to be comparable to the majority of other university-based studies.^[8,12,14,23,24] In fact, there were several other studies that reported even greater mean total CRE scores (>30).^[3,7,16-18]

Though this may seem rather alarming, a review of other studies done over the past two decades showed quite similar results when this pass criteria of CRE score <20 was used.^[8,12,14,18,21,23-30]

However, the level of experience and skill of orthodontists may account for differences in mean CRE scores. Yang-Powers *et al.*^[16] reported that cases submitted for the ABO examination had significantly better

Table 4: Descriptive statistics of cephalometric changes (absolute values) according to treatment type

Cephalometric Measures	Treatment Type	Mean	SD	Range
SNA (°)	Fixed appliances (n=155)	0.86	1.19	0-8
	2-Phase (n=19)	1.71	1.34	0-5
	Orthognathic surgery (n=26)	1.83	2.09	0-7
SNB (°)	Fixed appliances (n=155)	0.96	1.08	0-6
	2-Phase (n=19)	1.23	0.96	0-4
	Orthognathic surgery (n=26)	4.04	2.28	0-8
ANB (°)	Fixed appliances (n=155)	1.06	1.13	0-7.5
	2-Phase (n=19)	1.84	1.40	0-5
	Orthognathic surgery (n=26)	5.14	2.64	1-11
Wits Analysis (mm)	Fixed appliances (n=155)	1.93	2.31	0-13
	2-Phase (n=19)	2.73	2.24	0-8
	Orthognathic surgery (n=26)	8.40	4.69	2.5-23
NS-MP (°)	Fixed appliances (n=155)	1.38	1.56	0-8
	2-Phase (n=19)	2.47	1.59	0-6
	Orthognathic surgery (n=26)	2.00	1.70	0-6
U1-NA (°)	Fixed appliances (n=155)	8.84	5.74	0-25
	2-Phase (n=19)	8.61	5.65	1-18
	Orthognathic surgery (n=26)	6.49	5.57	1-26
U1-NA (mm)	Fixed appliances (n=155)	3.60	2.37	0-10.5
	2-Phase (n=19)	3.52	2.55	0-8.5
	Orthognathic surgery (n=26)	2.69	2.24	0-8
L1-NB (°)	Fixed appliances (n=155)	6.88	5.45	0-25
	2-Phase (n=19)	7.90	5.92	0-23
	Orthognathic surgery (n=26)	7.52	5.32	1-19
L1-NB (mm)	Fixed appliances (n=155)	2.68	2.04	0-11.7
	2-Phase (n=19)	2.76	2.07	0-7
	Orthognathic surgery (n=26)	7.52	5.32	0-4
L1-MP (°)	Fixed appliances (n=155)	7.04	5.49	0-27
	2-Phase (n=19)	9.61	7.21	0-24
	Orthognathic surgery (n=26)	8.85	6.66	0-23
U1-L1 Angle (°)	Fixed appliances (n=155)	13.28	9.37	0-44
	2-Phase (n=19)	10.50	10.49	0-32
	Orthognathic surgery (n=26)	10.74	8.51	0-38
LL to E-Plane (mm)	Fixed appliances (n=155)	2.43	2.10	0-12
	2-Phase (n=19)	2.00	1.57	0-5.5
	Orthognathic surgery (n=26)	2.47	2.04	0-7.5

SD – Standard deviation

scores, particularly for occlusal contacts and overjet components, which possibly reflected higher skill in finishing cases, compared with those that were treated consecutively by university residents and not necessarily for ABO examination purposes.

Correlations: Cast-radiograph evaluation components with total cast-radiograph evaluation score

Occlusal contacts

Occlusal contacts was ranked as the highest contributor, demonstrating significance at a moderate level with the total CRE score ($P < 0.01$). We found that lingual occlusal contacts ($r = 0.542$) contributed to the total CRE score slightly more than the buccal aspects ($r = 0.399$). These deficiencies in occlusal contacts could be due to

Table 5: Results of Spearman's rank-order correlation tests between cast-radiograph evaluation components with the total cast-radiograph evaluation score

CRE Components	Correlation coefficients (r) (n=200)
Alignment and rotations	0.567*
Maxilla	0.494*
Mandible	0.458*
Marginal ridges	0.575*
Maxilla	0.529*
Mandible	0.398*
Buccolingual Inclination	0.381*
Maxilla	0.379*
Mandible	0.184*
Overjet	0.376*
Anterior	0.277*
Posterior	0.320*
Occlusal contacts	0.615*
Buccal	0.399*
Lingual	0.542*
Occlusal relationship	0.604*
Interproximal contacts	0.031
Maxilla	0.024
Mandible	0.014
Root Angulation	0.250*
Maxilla	-0.052
Mandible	0.333*

CRE – Cast-radiograph evaluation components. *Correlation is significant at $P < 0.01$

(1) infraocclusion, (2) excessive mesiodistal crown tip, and (3) nonharmonized torque (buccolingual inclination) in the transverse dimension.

Despite this seemingly large contribution, many authors have suggested that occlusal settling could occur during the retention phase,^[11] which would actually improve and increase the number of occlusal contacts post-treatment.^[31,32-34] Nevertheless, the potential of this occlusal settling period should not be used as justification for post-treatment deficiencies as reflected in the CRE scores. Therefore, it was recommended that the cases should be finished with as good quality occlusions as possible, rather than relying on any post-treatment changes for improvements.

Occlusal relationship

Deficiencies in occlusal relationship, once present, would almost always lead to high scores, as the discrepancies would usually be affected all the way from the canines right through to the second molars, and also affecting both right and left sides.

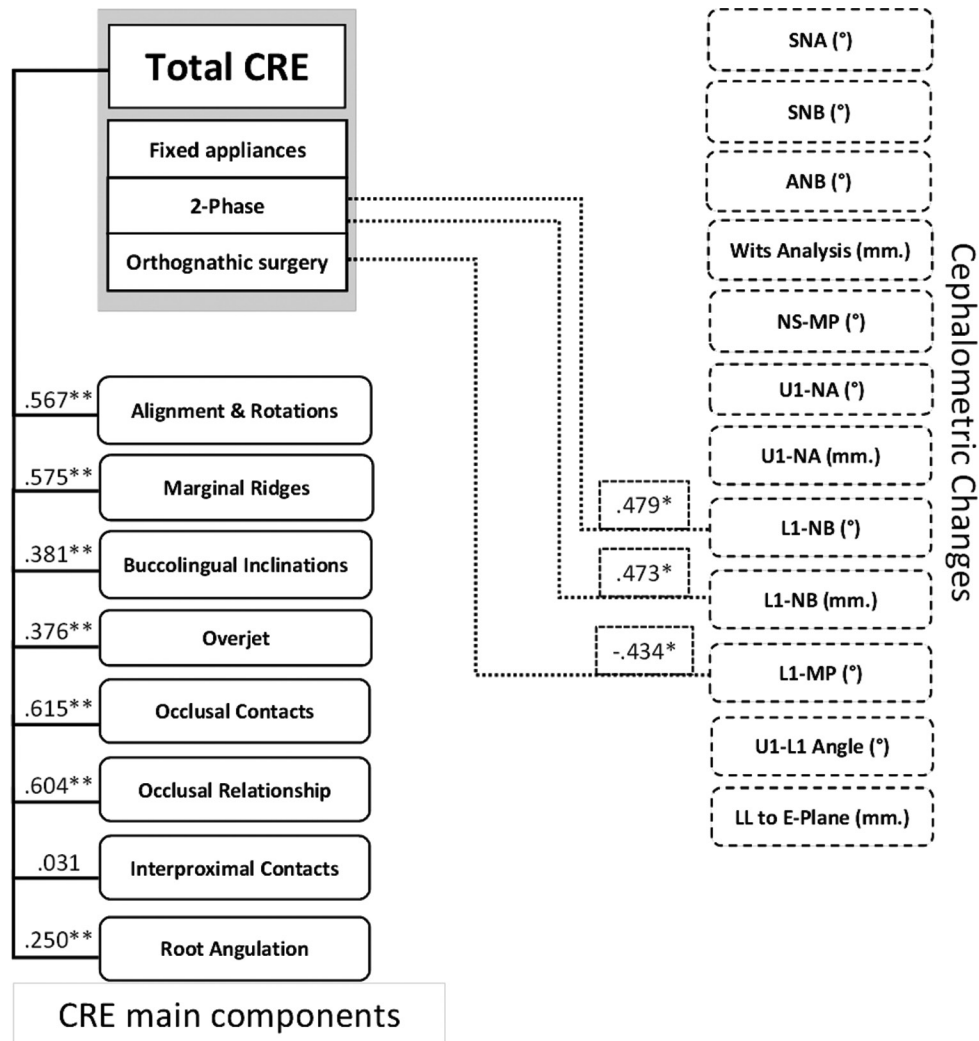
Marginal ridges

The presence of marginal ridge discrepancies is concomitant with those of occlusal contacts. Cases with deficient occlusal contacts, that is, vertical infraocclusion, excessive mesiodistal crown tip, and/or nonharmonized torque (buccolingual inclination), would have many

Table 6: Results of Spearman’s rank-order correlation tests between total cast-radiograph evaluation score with cephalometric changes according to treatment type

Treatment type	Correlation coefficient (r)											
	SNA (°)	SNB (°)	ANB (°)	Wits Analysis (mm.)	NS-MP (°)	U1-NA (°)	U1-NA (mm.)	L1-NB (°)	L1-NB (mm.)	L1-MP (°)	U1-L1 (°)	LL to E Plane (mm.)
Total CRE												
Fixed appliances (n=155)	-0.075	0.017	-0.051	-0.013	-0.141	-0.034	0.029	-0.034	-0.058	-0.011	-0.066	-0.100
2-Phase (n=19)	0.086	0.072	-0.337	-0.340	0.215	-0.063	-0.209	0.479*	0.473*	0.417	0.003	0.015
Orthognathic surgery (n=26)	0.059	-0.081	0.006	0.047	0.086	0.065	-0.144	-0.281	-0.108	-0.434*	-0.177	0.066
Total (n=200)	-0.034	0.009	-0.57	-0.036	-0.070	-0.023	-0.008	-0.016	-0.010	-0.013	-0.062	-0.067

CRE – Cast-radiograph evaluation. *Correlation is significant at P<0.05



**Correlation is significant at p<.01
 * Correlation is significant at p<.05

Figure 4: Conceptual framework and correlation coefficients between investigated variables

scores deducted. We also found that these marginal ridge discrepancies were more prevalent in the maxilla ($r = 0.520$) than in the mandible ($r = 0.398$). This finding is in agreement with the ABO report, which stated that the most common mistakes in marginal ridge alignment occurred between the maxillary first and second molars,

whereas the second most common problematic area was between the mandibular first and second molars.^[2]

Alignment and rotations

The results of the four field tests by the ABO study showed that the most commonly mal-aligned teeth

Table 7: Summary of results for cast-radiograph evaluation components and treatment duration from previous studies

Author	Source (country)	Sample Variables size	Total CRE		Alignment and rotations		Marginal ridges		Buccolingual inclinations		Overjet		Occlusal contacts relationship		Interproximal contacts		Root angulation		Total treatment duration			
			\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD
Abei et al., 2004	Case Western Reserve University (USA)	Specialists	26.0	11.4	5.39	4.37	3.92	2.87	4.51	4.03	4.20	3.96	4.05	4.34	3.11	3.44	0.78	1.49	NA	NA	NA	NA
			29.6	12.8	7.8	5.21	4.4	2.87	4.18	3.02	3.77	3.10	4.91	5.21	3.30	3.48	1.21	2.77	NA	NA	NA	NA
			29.07	7.11	5.60	2.90	3.13	2.08	8.90	3.79	3.03	2.26	4.63	2.26	2.33	2.15	0.00	0.00	1.43	1.17	NA	NA
			27.04	6.30	5.40	2.41	2.88	1.30	8.44	3.26	2.60	1.68	3.68	3.98	2.64	2.36	0.04	0.20	1.36	0.91	NA	NA
			18.39	2.17	2.51	1.79	3.32	2.34	1.88	1.77	4.87	3.94	3.36	3.44	1.89	2.72	0.37	0.86	0.19	0.52	27.70	11.54
Cansunar et al., 2014	Izmir Katip Celebi University (Turkey)	267	19.83	2.22	2.50	1.72	3.67	2.35	1.82	1.80	5.10	3.79	3.57	3.39	2.58	2.86	0.37	1.21	0.22	0.60	30.73	10.70
			16.63	2.02	2.46	2.46	3.52	2.45	1.91	1.69	4.53	3.34	2.93	3.25	1.64	2.51	0.23	0.69	0.11	0.45	22.41	10.04
Cook et al., 2005	University of Tennessee (USA)	77	NA	2.48	1.75	3.51	2.40	1.88	1.74	4.75	3.61	3.19	3.34	1.93	2.68	0.30	0.89	0.15	0.51	25.73	11.18	
			25.14	11.87	6.08	3.14	2.92	2.21	1.51	1.39	5.69	4.42	2.52	3.44	5.03	4.27	1.40	2.23	NA	NA	31.79	9.64
Deguchi et al., 2005	Okayama University (Japan)	72	33.6	13.6	5.5	2.3	3.2	2.2	6.9	3.7	6.6	2.5	4.7	3.4	3.1	3.0	0.4	0.6	3.2	2.3	34.6	10.4
			32.8	10.3	6.1	3.8	2.9	3.5	5.6	3.3	4.5	3.2	5.8	3.4	3.7	3.8	0.7	1.3	3.5	2.3	16.6	32.1
Deguchi et al., 2015	Okayama University (Japan)	25	24.5	7.9	3.2	1.6	3.3	1.7	5.1	2.3	2.6	2.5	3.7	3.0	3.6	3.1	0.4	0.6	2.6	2.0	29.4	5.6
			25.3	6.7	3.6	2.0	2.8	1.5	4.5	2.4	1.7	1.3	3.8	2.9	4.5	4.1	0.3	0.7	4.2	1.7	32.5	6.7
Detterline et al., 2010	Indiana University (USA)	613	30.2	12.9	3.2	1.9	3.0	2.0	3.9	2.3	4.4	3.5	4.9	3.5	4.0	3.4	0.6	1.5	2.3	1.7	16.1	9.6
			34.1	14.4	3.6	2.2	3.4	2.2	3.8	2.3	5.0	3.9	4.9	3.3	4.3	3.6	0.7	1.7	2.6	1.8	16.6	8.9

\bar{x} – Mean; SD – Standard deviation; CRE – Cast-radiograph evaluation; NA – Not available

Author	Source (country)	Sample Variables Size	Total CRE		Alignment and rotations		Marginal ridges		Buccolingual inclinations		Overjet		Occlusal contacts relationship		Interproximal contacts		Root angulation		Total treatment duration			
			\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD	\bar{x}	SD
Djeu et al., 2005	Albert Einstein College of Medicine (USA)	48	45.35	15.56	7.56	3.36	4.90	2.55	4.19	2.73	6.21	4.64	10.5	7.06	7.71	4.76	0.77	1.39	3.56	2.35	1.7	NA
			32.21	11.73	6.75	3.31	4.44	2.56	2.81	2.63	3.56	2.54	5.65	4.66	5.50	4.71	0.65	1.62	2.85	1.87	1.4	NA
Fleming et al., 2007	St Louis University (USA)	138	24.94	7.99	5.20	2.76	4.50	2.32	4.64	2.31	2.62	1.85	6.25	3.75	1.74	1.83	NA	NA	NA	NA	NA	NA
			29.80	NA	7.43	NA	4.28	NA	2.57	NA	4.00	NA	4.89	NA	3.08	NA	1.47	NA	2.03	NA	24.7	2.1
Hoybjerg et al., 2013	Oklahoma (USA)	20	23.85	2.70	3.80	1.32	4.00	2.17	7.35	1.78	2.40	1.66	3.55	1.46	2.95	1.66	0.20	0.52	1.55	1.27	19.75	1.6
			21.20	2.37	3.15	1.18	3.85	1.53	4.75	1.33	2.00	1.21	2.45	1.66	2.50	1.31	0.35	0.67	1.10	1.07	20.35	2.2
Knierrim et al., 2006	Indiana University (USA)	437	25.19	11.16	3.54	2.04	3.68	2.11	4.14	2.29	2.84	3.01	4.58	3.63	3.29	3.13	0.75	1.20	2.37	1.47	36.21	16.0
			25.44	9.81	5.41	3.47	2.53	1.76	3.66	3.44	3.16	2.30	5.25	3.78	3.38	3.02	0.16	0.45	1.91	1.51	NA	NA
Mislík et al., 2016	Athens (Greece)	34	25.94	7.69	5.12	2.20	3.85	2.40	5.94	3.43	2.62	2.17	4.47	3.65	2.53	2.78	0.15	0.44	1.26	0.86	NA	NA
			21.46	8.75	5.01	2.82	3.60	2.45	2.99	2.02	4.11	2.79	3.91	3.48	1.84	3.16	NA	NA	NA	NA	NA	NA
Pinskaya et al., 2004	Washington (USA)	521	39.08	11.86	3.09	1.84	1.92	1.73	2.19	1.58	4.60	3.11	2.45	2.18	4.05	3.48	0.84	1.35	3.73	2.43	33.94	14.05
			3.14	1.69	1.44	1.20	3.31	1.96	3.62	2.26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Struble et al., 2010	Washington (USA)	133	16.3	4.7	4.6	2.1	3.3	1.7	1.7	1.5	2.3	1.8	4.1	2.5	0.4	1.0	0.0	0.1	NA	NA	26.0	NA
			23.1	11.6	8.3	3.1	5.4	2.5	3.2	2.1	5.3	3.4	7.6	3.4	2.5	3.9	0.0	0.0	NA	NA	NA	NA

\bar{x} – Mean; SD – Standard deviation; CRE – Cast-radiograph evaluation; NA – Not available

Table 7: Contd...

Author	Source (Country)	Sample Size	Variables	Total CRE	Alignment and Rotations		Marginal Ridges	Buccolingual Inclinations		Overjet		Occlusal Contacts		Occlusal relationship		Interproximal contacts		Root angulation		Total treatment duration			
					χ	SD		χ	SD	χ	SD	χ	SD	χ	SD	χ	SD	χ	SD	χ	SD	χ	SD
Vu et al., 2008	Indiana University (USA)	99	2004	24.15	12.48	3.39	2.28	2.91	2.30	3.77	2.3	2.71	3.07	4.43	3.71	3.56	3.64	1.01	1.68	2.15	1.86	28.86	11.00
		145	2005	23.78	12.71	3.05	2.18	2.48	2.11	3.74	2.27	3.74	3.73	4.70	4.26	2.97	3.67	0.71	1.18	2.40	1.79	30.14	10.89
		211	2006	22.66	9.40	3.26	2.11	2.71	2.07	3.78	2.40	3.35	3.08	3.76	2.86	2.91	2.99	0.58	1.32	2.31	1.85	28.38	11.09
Wes Fleming et al., 2008	St Louis University (USA)	138	-	24.9	8.0	5.20	2.76	4.50	2.32	4.64	2.31	2.62	1.85	6.25	3.75	1.74	1.83	NA	NA	NA	20.6	6.0	
Yang-Powers et al., 2002	University of Illinois (USA)	92	PG Ortho Specialist	45.54	18.33	8.79	5.13	5.35	3.41	9.42	5.03	6.52	5.01	8.24	7.02	4.55	4.14	0.64	1.22	2.03	1.89	35.07	10.46
Present study 2017	ThaBO (Thailand)	200	-	26.53	9.57	4.97	2.68	3.46	2.48	5.39	3.26	2.97	2.59	3.75	3.07	2.51	2.84	0.06	0.25	3.42	1.95	38.67	13.38

χ – Mean; SD – Standard deviation; CRE – Cast-radiograph evaluation; NA – Not available

post-treatment were the lateral incisors and second molars, which accounted for nearly 80% of the discrepancies.^[2]

Overjet

The post-treatment overjet problems may be attributed to the shovel shaped anatomy of upper incisors prevalent in the Asian phenotype. It was suspected that thicker lingual marginal ridges and larger tooth size of upper incisors in Asians would lead to increased overjet and a more mesially aligned dentition.^[3]

Buccolingual inclination

We found significant correlations in buccolingual inclination with stronger associations in the maxillary teeth ($r = 0.379$) compared with the mandibular teeth ($r = 0.184$). Similarly, Deguchi *et al.*^[3] identified the maxillary or mandibular second molars to be the main problematic areas. Along with Yang-Powers *et al.*,^[16] they inferred that this could be a result of inadequate torque control due to one of these factors: (1) the second molars were banded late in treatment, (2) difficulty of visual assessment (3) larger tooth size compared with arch length leading to molars flaring out, and (4) use of preadjusted appliances with inadequate torque.

Root angulation

Our result was in agreement with the ABO study, which reported that the mistakes in root angulation commonly occurred in the maxillary lateral incisors, canines, second premolars, and mandibular first premolars.^[2] However, it should be noted that the assessment of mesiodistal root angulations in panoramic radiographs should be approached with caution and reinforced with a thorough clinical examination of the dentition.^[35] Root angulation discrepancies detected by panoramic films could be related to mesiodistal tipping, insufficient torque, or tooth rotations.

Cephalometric changes

It was our assumption that greater cephalometric changes could be associated with higher CRE scores due to greater treatment difficulty. It should also be kept in mind that 13% of cases in this sample underwent orthognathic surgery and 9.5% underwent two-phase treatment. These treatment modalities could have some impact in reducing the difficulty of orthodontic treatment.

No significant correlations were found between any cephalometric changes with the total CRE score in the fixed appliances group. We can infer that the candidates were sufficiently skilled to finish their cases selected for fixed appliances to acceptable quality whether or not they performed a large or small amount of changes in the skeletal or dental components.

However, we found a significant moderate correlation existed between changes in the lower incisal inclination and position (L1-NB) with the total CRE score in cases which underwent two-phase treatment. We can suggest that though the first phase of treatment in such patients was successful in correcting the skeletal discrepancy by growth modification, further extractions were still required in the second phase for correction of protrusion or crowding. This would demand additional good control of tooth movement, which could, in turn, worsen certain aspects of the occlusion as measured by the CRE.

For the cases that underwent orthognathic surgery, a significant negative and moderate correlation was found between the L1-MP change (lower incisor inclinations) and the total CRE score. As the majority of orthognathic cases presented by the candidates were of skeletal type III patterns, we can expect that more dental decompensation of the pretreatment lower incisors would enable more accurate anteroposterior correction of the skeletal discrepancy, hence producing a better final occlusion and lower CRE score. If the dentition was not adequately decompensated presurgically, the surgical procedure could have been compromised. This could have resulted in a large remaining overjet or a residual Class III occlusal relationship postsurgically, producing less ideal CRE scores.

Limitations

The samples in this study were only limited to a select amount and type of orthodontic cases, treated by orthodontic residents in postgraduate training programmes in institutes across the country. All candidates were not aware that their submitted cases would be evaluated with the ABO CRE and they had never been trained to use this system. Hence, the results of this study may not reflect the overall quality of orthodontic treatment outcome to encompass those treated by more recent residents or practitioners in the private sector. In addition, the passing criteria used by the ThaBO was based on both outcome evaluation and case presentation which made the percentage passing/fail results differently from ABO.

Clinical implications

It is our recommendation that orthodontic training program directors should strongly emphasize inclusion of ABO CRE assessment in their curriculum in order to improve the overall quality of orthodontic treatment. Suggestions for future studies may involve the ABO case management form or the CCA as a supplement to the CRE.

Conclusions

1. Significant differences in the mean CRE scores among the three categories (pass, undetermined,

and fail) were found for all CRE components except interproximal contacts

2. Significant correlation coefficients, r , were found, ranking from highest to lowest: (1) occlusal contacts (0.62), (2) occlusal relationship (0.60), (3) marginal ridges (0.58), (4) alignment and rotations (0.57), (5) overjet (0.38), (6) buccolingual inclinations (0.38), and (7) root angulation (0.25) ($P < 0.05$)
3. Cephalometric changes were not suitable as weighting factors for CRE scores of overall cases
4. There were moderately significant correlations between changes in lower incisor inclinations with the total CRE score in 2-phase treatment and orthognathic surgery cases.

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Conflicts of interest

There are no conflicts of interest.

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