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Research

Evaluation of Ricketts' and Bolton's growth prediction algorithms embedded in two diagnostic imaging and cephalometric software

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ABSTRACT

Background: Accurate assessment and prediction of skeletal and dentofacial growth are very important for planning orthodontic treatment and achieving stable and esthetic outcomes. Several algorithms (e.g. Bolton and Ricketts) for predicting craniofacial growth using lateral cephalograms are available to clinicians in commercial computer software packages.
Methods: This retrospective study compares the reliability of craniofacial growth of three growth prediction algorithms currently available in Dolphin Imaging™ 11.0 and RMODS-JOE CEPH® programs. Lateral cephalograms of skeletal normal class I of 56 untreated children obtained from the Craniofacial Growth Legacy Collection of the American Association of Orthodontists Foundation (AAOF) were used to evaluate the Ricketts and Bolton growth prediction algorithms in Dolphin Imaging™ 11.0 as well as the Ricketts growth prediction algorithm in RMODS-JOE CEPH®. The groups were subdivided by growth prediction algorithm, gender, chronological age, developmental age and length of rediction. Student t-tests were used to compare the mean differences of the growth predictions tested.
Results and discussions: This study showed no differences with respect to developmental age and gender, but the two-year predictions appear to be more valid than the four-year predictions. The Bolton growth prediction algorithm in Dolphin Imaging 11.0 and the Ricketts growth prediction algorithm in RMODS-JOE CEPH® were more alike among the three.
Conclusions: The three growth prediction algorithms tested indicated to be within a 1.5 mm clinical reference when compared with the actual growth of the same subject studied for the majority of the landmarks assessed, indicating their clinically reference acceptability specially for a two year prediction.

1. Background

In its early years, cephalometric radiograph was primarily a research tool for studying the development of craniofacial components over time using measurements of dental and facial changes derived from serial records [1]. The longitudinal data of the Bolton Study in particular helped form many of the principles of craniofacial growth and developmental [2]. During this research movement, the investigator proposed the idea of downward and forward face development and the establishment of the pattern of the head and face at an early age [3]. Eventually, those that thought they had a mastery of growth also believed they could wield this knowledge and apply it to the prediction of growth.

In 1971, Ricketts described the breakthroughs that led to greater understanding of mandibular growth and eventually his theory of forecasting. His ideas and methods of forecasting went through scrutiny and many stages of development in the 1950s and 1960s [4–7].

A study by Johnston in 1975 introduced a simplified approach to prediction in the form of a "forecast grid," which shows average

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Authors have obtained and submitted the patient signed consent for images publication.

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increments of growth per year for the points nasion, A, B, nose, posterior nasal spine, and maxillary first molar [8]. The author stated, “the grid did not perform too badly,” explaining that the predictions were not much worse than would be expected from an analysis of cephalometric error.

The Johnston grid system and the Ricketts computerized forecasting techniques were compared in a study by Schulhof and Bagha [9]. They evaluated the ability of the Ricketts long-term forecast, the Ricketts short-range predictions, and the Johnston grid system using average increments from Sella-Nasion to accurately predict the growth at A point, pogonion, Ricketts Xi point, tip of the nose, and mandibular molar position. The computerized Ricketts short-range prediction method showed a 10–20% improvement over the average increments, and finally, the computerized Ricketts long-term forecast was found to be the most accurate, being 21% more accurate than the Ricketts short-range method and 56% more accurate than the Johnston grid system.

In another study, Greenberg and Johnston evaluated the accuracy of Ricketts computerized long-term arcial forecast [10]. The authors found no significant difference between the computerized method of prediction and the average changes in the study population. They concluded that this sophisticated method was unable to individualize the subjects and that more simplistic methods would prove equally satisfactory.

In a more recent study, Kocadereli and Telli [11] studied the Ricketts long-range growth prediction in Turkish children. “Predicted” and “actual” measurements were evaluated. Of the 21 parameters studied, showed a high correlation between “predicted” and “actual” for girls (14 measurements) and boys (nine measurements).

In 2007, Turchetta et al. [12] evaluated three prediction systems: the Ricketts analysis, the Johnston grid system, and the Fishman system of skeletal maturation assessment. They found that the Fishman system was the most accurate for predicting short- and long-term growth but stated that the Ricketts and Johnston systems might have greater predictive accuracy if they were based on maturational age, eliminating unwanted developmental variables.

As part of their study to evaluate the treatment effects of the variable anchorage straightwire technique in Angle Class II patients, Parikakis et al. [13] evaluated a control group of 30 untreated Class II Swedish individual (20 girls, 10 boys). To ensure the validity of the Ricketts Visual Treatment Objectives (VTO) method, they tested an untreated sample. They concluded that the growth prediction method according to Ricketts VTOs was valid for skeletal and dentoalveolar variables in a sample of Swedish post-normal children.

Some software manufacturers have adapted or created algorithms based on the above-mentioned growth prediction techniques. The objective of this study was to evaluate and compare the relative accuracies of three computerized growth prediction methods based on lateral cephalograms, namely the Ricketts and Bolton growth prediction algorithms embedded in Dolphin Imaging™ 11.0 (Alg 1 and Alg 2, respectively) and the Ricketts algorithm (Alg 3) in RMODS® (Rocky Mountain Orthodontics Data Services) JOE CEPH® software. This study tested the hypothesis that three algorithms (Ricketts [Alg 1] and Bolton [Alg 2] in Dolphin Imaging™ 11.0 and Ricketts in RMODS-JOE CEPH® [Alg 3]) provide accurate growth predictions when compared with the actual observed growth of untreated children.

2. Methods

Radiographs from 56 subjects (28 males and 28 females) with relative normal craniofacial with no skeletal deformities (ANB of 3.0 ± 2.0°; FMA of 23.0 ± 5.0°) were obtained from the AAOF Craniofacial Growth Legacy Collection. The AAOF craniofacial growth legacy collection website classified 39 of the subjects as Class I and 17 subjects as Class II, showing that majority of the subjects had relatively normal facial patterns [14,20]. Collection of radiographs obtained must have clearly defined fiducial to correct for magnification, good quality for landmark identification, and follow-up time points at 2 and 4 years with no treatment. Three lateral cephalograms at three different time points were used for each subject. The first time point (T1) for males was approximately between 9 and 11 years of age, and that for females was between 8 and 10 years of age. The second (T2) and third (T3) time points were 2 and 4 years after T1 respectively. The study was approved by the University of Illinois at Chicago Institutional Review Board (No. 2007-0831).

Each cephalogram was traced by the same investigator. Nineteen skeletal cephalometric landmarks were traced (Table 1).

Table 1
Cephalometric landmarks studied

Variables
1. A point
2. ANS (anterior nasal spine)
3. Anatomic gnathion
4. B point
5. Basion
6. Condylion
7. Gonion
8. L1 tip (lower central incisor tip)
9. L6 occlusal (lower 1st molar occlusal)
10. Menton
11. Nasion
12. Orbitale
13. PNS (posterior nasal spine)
14. PT point
15. Pogonion
16. Porion
17. Sella
18. U1 tip
19. U6 occlusal

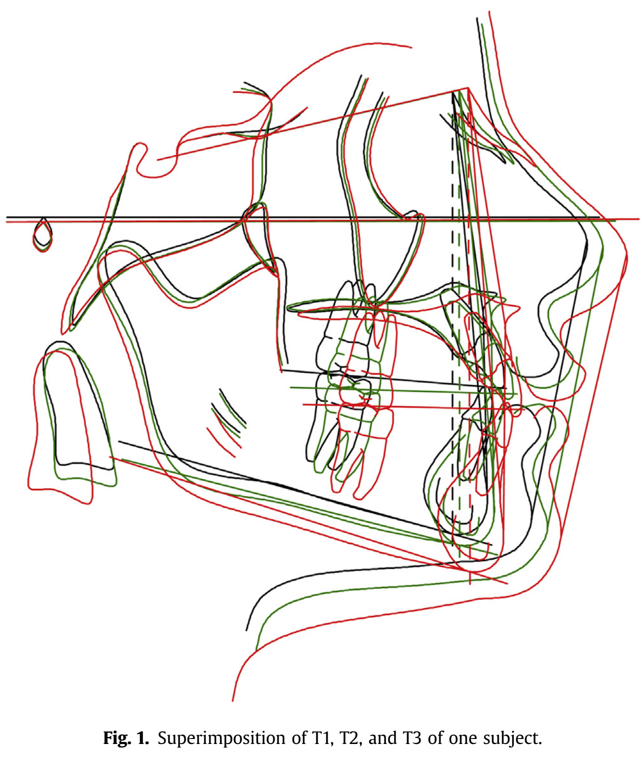

Fig. 1. Superimposition of T1, T2, and T3 of one subject.

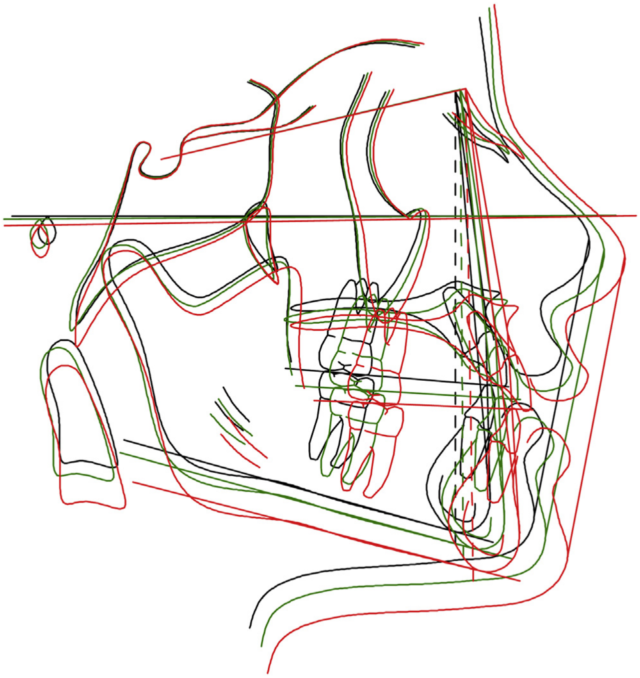

Fig. 2. Superimposition of T1, 2-year prediction, and 4-year prediction of one subject.

Intraexaminer examiner reliability was tested. A transfer-structure method in Dolphin Imaging 11.0™ was used for tracing and digitizing to decrease error between cephalograms for each subject (Fig. 1). The transfer structure methods will ensure all fiducials were accounted for, and cephalometric landmarks/tracings were used as template to be transferred from one time point to the subsequent time point [21,22]. Growth prediction algorithms in Dolphin Imaging 11.0™ and RMODS-JOE CEPH® were used to perform the growth predictions on each T1 cephalogram, using chronologic age, resulting in a 2-year prediction and 4-year prediction, which correspond with T2 and T3 for each subject (Fig. 2).

Skeletal age was determined by using the method described by Mito et al., who used cervical vertebrae [15,16]. Two-year and 4-year predictions were also completed using skeletal age.

Once all the tracings were complete, the 2-year predictions were superimposed with the T2 tracings and the 4-year predictions were superimposed with the T3 tracings. The superimpositions were registered on sella and superimposed on the sella-nasion line with Frankfort horizontal (FHP) parallel to the horizontal plane (floor). All registration and orientation landmarks (sella, nasion, orbitale, porion) were transferred throughout the series of same subject to baseline to establish a Cartesian coordinate system with sella as point (0,0) [23].

For clinical applicability purposes, a clinically acceptable reference mean of 1.5 mm of accuracy was established. In a classic paper, Baumrind et al. [17] discuss the reliability of cephalometric measurements by quantifying the differences in precision in cephalometric landmark identification. The majority of errors occurred within 1.5 mm. Additionally, the study by Toepel-Sievers and Fischer-Brandies [18] tested the validity of the Ricketts VTO and considered length measurements to be clinically useful if the absolute error was less than 1.8 mm.

A one-sample Student *t*-test was used to compare the means differences of the growth predictions, to the means of the actual observed growth. Paired samples *t*-tests were used to compare growth predictions mean differences based on the three growth prediction algorithms.

Table 2
Descriptive statistics of clinically inaccurate landmarks (mm)

Algorithms and variables	Descriptive statistics				
	Mean	SD	SEM	95% CI of the Difference	
				Lower limit	Upper limit
Alg1[†] (Ricketts)					
2-year chronologic age male					
PNS–x	2.47	2.28	0.43	1.58	3.35
4-year chronologic age male					
Basion–x	−2.32	1.41	0.27	−2.87	−1.77
PNS–x	3.71	2.98	0.56	2.56	4.87
Porion–x	−2.64	1.35	0.26	−3.16	−2.11
Gonion–y	3.90	3.81	0.72	2.42	5.38
4-year chronologic age female					
Basion–x	−2.35	1.29	0.24	−2.85	−1.85
Gonion–x	−2.47	2.25	0.43	−3.35	−1.60
PNS–x	3.52	2.54	0.48	2.54	4.50
Porion–x	−3.05	1.23	0.23	−3.53	−2.58
Gonion–y	3.01	2.95	0.56	1.86	4.15
Alg2[‡] (Bolton)					
4-year chronologic age male					
B-point–y	4.05	3.11	0.59	2.85	5.26
Menton–y	3.12	3.14	0.59	1.90	4.34
Orbitale–y	2.39	1.63	0.31	1.76	3.02
4-year chronologic age female					
Menton–x	3.31	4.79	0.90	1.46	5.18
Porion–x	−2.45	1.46	0.28	−3.01	−1.88
Gnathion–y	2.96	3.51	0.66	1.60	4.32
B-point–y	3.65	2.75	0.52	2.58	4.71
Basion–y	−2.27	1.71	0.32	−2.93	−1.60
Menton–y	3.43	3.50	0.66	2.07	4.78
Pogonion–y	2.98	3.13	0.59	1.77	4.19
4-year skeletal age male					
Gnathion–x	2.88	2.65	0.50	1.85	3.90
Menton–x	3.09	2.80	0.53	2.00	4.18
Gnathion–y	3.59	3.93	0.74	2.07	5.11
B-point–y	4.31	3.13	0.59	3.10	5.52
Menton–y	4.17	3.80	0.72	2.70	5.64
Orbitale–y	2.33	1.64	0.31	1.69	2.97
Pogonion–y	3.44	3.67	0.69	2.02	4.87
4-year skeletal age female					
B-point–y	3.48	2.64	0.50	2.46	4.51
Basion–y	−2.64	1.50	0.28	−3.22	−2.05

† Alg 1 = Ricketts growth prediction algorithm in Dolphin Imaging™ 11.0.
‡ Alg 2 = Bolton growth prediction algorithm in Dolphin Imaging™ 11.0.

3. Results

The one-sample statistics provided descriptive statistics, mean differences, standard deviations (SDs), standard error of the mean (SEM), and 95% confidence intervals (CIs) for each of the cephalometric landmarks under consideration, in terms of their *x*- and *y*-coordinate values. This was completed for each prediction method, in regard to chronologic age, skeletal age, 2-year prediction, 4-year prediction, and gender (Table 2).

The study estimated the 95% CIs for the mean difference in each variable to decide if the mean difference was clinically acceptable. A clinically acceptable reference mean of 1.5 mm of accuracy was

Table 3
Counts of clinically acceptable accurate landmarks for each algorithm

Algorithm characteristics		Alg 1[*]		Alg 2[†]		Alg 3[‡]	
		2-year	4-year	2-year	4-year	2-year	4-year
Chronologic age	Male	17	14	18	15	18	N/A
	Female	18	14	18	12	18	N/A
Skeletal age	Male	N/A	N/A	18	13	18	N/A
	Female	N/A	N/A	18	16	18	N/A

* Alg 1 = Ricketts growth prediction algorithm in Dolphin Imaging™ 11.0.
† Alg 2 = Bolton growth prediction algorithm in Dolphin Imaging™ 11.0.
‡ Alg 3 = Ricketts growth prediction algorithm in JOE CEPH®.

Table 4
Clinically acceptable accurate landmarks for each pair of algorithm

Algorithm comparisons	Number of variables with approximately same mean			
	x-axis	*y*-axis	*x*- and *y*-axis	*x*- and *y*-axis variable name
Alg 1* and Alg 2†				
Chronologic age, 2-year, males	7	2	1	Porion
Chronologic age, 2-year, females	2	2	0	N/A
Chronologic age, 4-year, males	0	2	0	N/A
Chronologic age, 4-year, females	0	0	0	N/A
Alg 1* and Alg 3‡				
Chronologic age, 2-year, males	7	4	3	L1 Tip PT point U6 occlusal
Chronologic age, 2-year, females	3	7	2	Nasion PT point
Alg 2† and Alg 3‡				
Chronologic age, 2-year, males	9	7	5	Gonion L1 tip Pogonion U1 tip U6 occlusal
Chronologic age, 2-year, females	8	6	2	Condylion Orbitale
Skeletal age, 2-year, males	7	9	4	Condylion L6 occlusal U1 tip U6 occlusal
Skeletal age, 2-year, females	13	6	6	A point Basion Condylion L1 tip Porion U1 tip

* Alg 1 = Ricketts growth prediction algorithm in Dolphin Imaging™ 11.0.
† Alg 2 = Bolton growth prediction algorithm in Dolphin Imaging™ 11.0.
‡ Alg 3 = Ricketts growth prediction algorithm in JOE CEPH®.

used. Therefore, if the CI included 1.5 mm or less, the variable was considered clinically accurate. Also, if the value in the *x*, *y*, or both coordinates was deemed clinically inaccurate, the landmark was then considered clinically inaccurate to the respective coordinate or to both coordinates (Table 3). A paired-samples *t*-test was used to determine if statistically significant mean differences, ($P \leq .05$) were found between comparisons of the different predictions (Table 4).

Considering gender, the predictions for females were only slightly more accurate. The developmental age also only made a very slight difference in this study. The 2-year predictions were shown to be very accurate for all three algorithms when using a clinical reference mean of 1.5 mm of accuracy. In fact, over a 2-year period, the Bolton growth prediction algorithm (Alg 1) and the RMODS-JOE CEPH® growth prediction algorithm (Alg 3) were able to accurately predict on average all 18 landmarks, regardless of the age or gender. A difference was found between the 2-year and 4-year predictions. The majority of landmarks considered clinically inaccurate were in 4-year predictions of Alg 1 and Alg 2. Moreover, for the Ricketts algorithm in Dolphin Imaging™ 11.0, Alg 1, the clinically unaccepted landmarks were predominantly erroneous due to inaccuracies along the *x*-coordinates with no difference in direction of error. Also, the groups with the most inaccurate landmarks were the 4-year predictions of the Bolton algorithm for females using chronologic age and for males using skeletal age. Most of their clinically inaccurate points were related to the mandible, such as menton (5.64 mm in vertical direction), B-point (5.52 mm in vertical direction), gnathion (5.11 mm in vertical direction), and pogonion (4.87 mm also in vertical direction), illustrating the poor ability to predict the position of the mandible for these groups. Also, it was observed that the dental landmarks, U1 tip, L1 tip, U6 occlusal, and L6 occlusal were accurately predicted across the algorithms.

4. Discussion

This study attempted to compare three growth prediction methods versus actual observed growth. The results for all three algorithms revealed that the predictions were fairly accurate for most, if not all, variables tested. The 2-year predictions for each algorithm appears to be superior to the 4-year predictions, so the validity of longer-term growth predictions, 4 years or greater, should be accepted with some reservation. Although, based on the findings, one could infer if using Dolphin Imaging™ 11.0, that the error would occur in the *x*-coordinate if using Ricketts algorithm and expect an overestimation in the *y*-coordinate and that it would most likely be in the mandible. In addition, one should have reservations with predictions on patients having more abnormal growth patterns, such as significant Class II or Class III presentations.

Unfortunately, studies involving cephalometric measurements are susceptible to the inherent error involved in cephalometric radiography, cephalogram tracing, and landmark identification [17,19]. In this study, measures were taken to mitigate the potential for errors. For example, the transfer structure option in Dolphin Imaging™ 11.0 was implemented to decrease errors. In addition, both interreliability and intrareliability were established.

The selection of the sample subjects were not based on any craniofacial characteristic. The AAOF craniofacial growth legacy collection website classified 39 of the subjects as Class I and 17 subjects as Class II, showing that majority of the subjects had relatively normal facial patterns [14]. Therefore, the Ricketts predictions, whether in Dolphin Imaging™ 11.0 or RMODS-JOE CEPH®, would not necessarily yield predictions differing from an average increment method, such as in the Bolton algorithm. Therefore, one should consider predictions for abnormal facial types with caution.

A worthy future study that parallels the limitation of this study would be to perform predictions on an untreated sample of more extreme skeletal facial types, such as skeletal Class II or Class III subjects or high mandibular plane angle subjects who are still growing, using the same software and algorithms.

5. Conclusion

The three growth prediction algorithms tested were accurate within a 1.5-mm clinical reference compared with the actual growth of the same subject studied for the majority of the landmarks assessed, indicating their clinically acceptability particularly for a 2-year prediction.

This study showed no differences with respect to developmental age and gender, but the 2-year growth predictions results seems to be a better prediction than the 4-year growth predictions. The Bolton growth prediction algorithm in Dolphin Imaging 11.0 and the Ricketts growth prediction algorithm in RMODS-JOE CEPH® were more alike among the three. Also, at this point, one should consider the prediction of a more extreme Class II or Class III case with caution.

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