

Comparison of Diagnostic Value of Cast Analyzer X Iranian Software versus Curve Expert Software for Arch Form Construction based on Mathematical Models

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Abstract

Objective: For the assessment of primary arch form, different methods have been used including qualitative classifications, inter-canine and inter-molar widths and quantitative and numerical methods using mathematical models. The purpose of this study was to compare the validity and reliability of Cast Analyzer X Iranian software with those of Curve Expert Professional version 1.1 for arch form construction based on mathematical models.

Methods: This diagnostic, *in vitro* study was performed on 18 sets of dental casts with normal Class I occlusion. The clinical buccal points (bracket attachment sites)(CBPs) were marked on each tooth and their spatial coordinates were digitized using a three-dimensional (3D) laser scanning system. These coordinates were entered in Cast Analyzer X and Curve Expert software programs. Arch forms were constructed by the software programs using Brown's beta function, Noroozi's beta function and fourth order polynomial equation. The root mean square (RMS) of the distance from a reference point to their corresponding points on the curve was calculated. The RMS values in the two software programs were compared.

Results: The RMS values in Brown's beta function, Noroozi's beta function and fourth order polynomial equation were significantly different in the Cast Analyzer X software ($p < 0.001$) and the fourth order polynomial equation had the lowest RMS. The difference in RMS values between the two software programs was not clinically considerable and was 0.45 and 0.68 mm for the fourth order polynomial equation and Brown's beta function, respectively.

Conclusion: Considering the RMS values, the fourth order polynomial equation is the most suitable analysis for describing normal dental arch forms best fitted with the CBPs. Although the difference between the two software programs was statistically significant, this difference was not clinically noticeable. The RMS value was lower in Cast Analyzer X and consequently the fitting of curves with the landmarks (CBP) was better in the Iranian software.

Key words: Dental arch, Diagnosis, Orthodontic.

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Introduction:

Creating an ideal, customized dental arch for the patients is among the main goals of orthodontic treatment (1). To achieve stability, the primary arch form must be maintained during orthodontic treatment; otherwise, the changed

arch form tends to return to its primary shape (2, 3).

Andrews, the father of the Labial Straight Wire appliance, emphasized the arch form as the 7th key to achieve normal Class I occlusion. Thus, accurate analysis of dental arch form prior to treatment is an important step in orthodontic

diagnosis.

Qualitative classification of dental arch form into 3 or 5 simple shapes has been often used to assess the primary arch form in the process of orthodontic diagnosis (4, 5). For instance, qualitative classification of dental arch form into three arch shapes of triangular, oval and square was extensively used for selection of orthodontic prefabricated arch wires for specific patients (5). Another commonly used technique for dental arch analysis under *in-vivo* and *in-vitro* conditions is the measurement of inter-canine and inter-molar widths (6).

At present, quantitative methods using mathematical and geometric models are also increasingly used for quantitative description of arch form (7-13) including beta function (14), parabola or second degree polynomial (15), cubic spline function (16) and fourth order or higher degree polynomial equations (8, 17, 18). AlHarbi, *et al.* in 2008 compared these equations and concluded that fourth order polynomial equation was the most suitable analysis when the goal is to describe the general smooth curve of dental arch (13).

Noroozi, *et al.* in 2001 suggested the function $Y=aX^6+ bX^2$ using four parameters of inter second-molar width, inter-canine width, second molar depth and canine depth. The mean correlation coefficient (CC) of points on each cast with the respective curve was 0.98 ± 0.02 according to the mentioned equation (19).

Braun, *et al.* in 1998 reported the CC between the measured arch-shape data and the mathematical arch form to be 0.98 with a standard deviation of 0.02 using the beta function (14).

Arai and Will in 2011 evaluated the correlation between subjective classification of dental-arch form and objective analyses using arch-width measurements and the fitting with the fourth order polynomial equation and suggested that fourth order polynomial equation with flexible accuracy and mathematical description can be

used for description of dental arch form in orthodontic patients (20).

Considering the key role of an ideal dental arch customized for each patient, possession of an advanced tool with high precision and speed for cast analysis and construction of a dental arch simulating the actual arch form as much as possible is a necessity. The Cast Analyzer X Iranian software turns this necessity into reality. The purpose of this study was to compare the validity and reliability of Cast Analyzer X Iranian software with those of Curve Expert Professional version 1.1 for arch form construction based on mathematical models.

Methods:

This diagnostic, *in-vitro* study was conducted on 18 orthodontic casts of patients with normal Class I occlusion who were selected among those presenting to the Orthodontic Department of Shahid Beheshti University, School of Dentistry using convenience sampling. The specimens were 18 sets of dental casts (maxillary and mandibular) including permanent teeth from second molar to second molar. All selected casts had fully erupted teeth with no attrition, fracture, ectopic eruption, crowding or midline deviation.

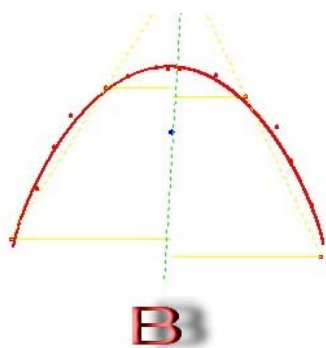
Sample size was calculated to be 15-25 specimens according to a previous study (21). We evaluated 18 patients in the current study yielding a total of 36 casts. Thus, for sample size calculation, no parameter was extracted from any study.

The CBPs were marked on the teeth according to the manufacturer's instructions for bracket placement with the preadjusted appliance (22) and using an orthodontic gauge (3M/UnitekTM, Monrovia, CA, USA). The spatial coordinates of these points were digitized by a 3D laser scanner and saved in a file with txt format. The 3D laser scanner had been designed in the Laser Research Center and Dental Research Institute of Shahid

Beheshti University and its diagnostic value had been previously assessed and confirmed (23).

Cast Analyzer X is an Iranian software program developed in Iran by the authors(24) designed for arch form construction. The three mathematical models of Brown's beta function, Noroozi's beta function and fourth order polynomial equation (yielding the best results in terms of fitting the constructed arch form with the reference points in previous studies) have been defined in this software. Using the coordinates of the landmarks (i.e. CBPs in this study) and the mentioned three models, this software can construct three curves for each dental cast. Also, it has the ability to calculate RMS for each curve. The RMS is the root of the sum of squares of the distance from the landmarks to their corresponding points on the curve. The calculation of RMS is an accurate method to fit the curve on some points with known coordinates. In this method, the best-fitted curve on a collection of points is the curve with the least amount of RMS (19).

The spatial coordinates of all CBPs were entered in Cast Analyzer X software and the software constructed three curves for each specimen using the three mathematical models of Brown's beta function, Noroozi's beta function and fourth order polynomial equation. The RMS values were also calculated for each curve.

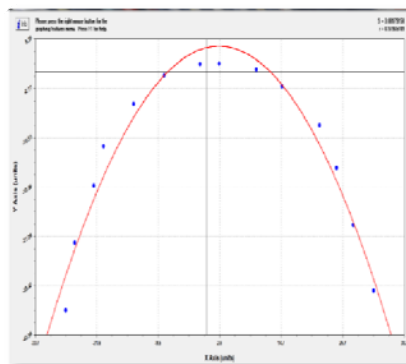


A. Cast Analyzer X (RMS=0.93)

In the next step, the spatial coordinates of CBPs were entered in the standard Curve Expert Professional version 1.1 software, which is the gold standard for the assessment of the reliability of the Iranian software. Using Brown's beta function and fourth order polynomial equation, two curves were constructed for each specimen and the RMS values were calculated for each curve.

Figures 1 and 2 show the constructed curves for two specimens by the Iranian and foreign made software programs and the calculated RMS according to the Brown's beta function and fourth order polynomial equation.

For statistical analysis, normal distribution of data was tested using one-sample Kolmogorov-Smirnov test. Fitting of curves constructed by Brown's beta function, Noroozi's beta function and fourth order polynomial equation with the CBPs was compared by calculating the mean and standard deviation (SD) of RMS values of 18 sets of dental casts using t-test. Models were compared using paired t-test. To assess the validity of the Cast Analyzer X, its RMS was compared with that of Curve Expert using paired t-test and the numerical value of the difference in RMS values of the two software programs was calculated using the Dahlberg's test. The reliability coefficient of the two software programs was compared using ICC test.



B. Curve Expert Professional (RMS=4.56)

Figure 1- Comparison of the curve based on Brown's beta function for specimen #15 constructed by the Cast Analyzer X and Curve Expert Professional

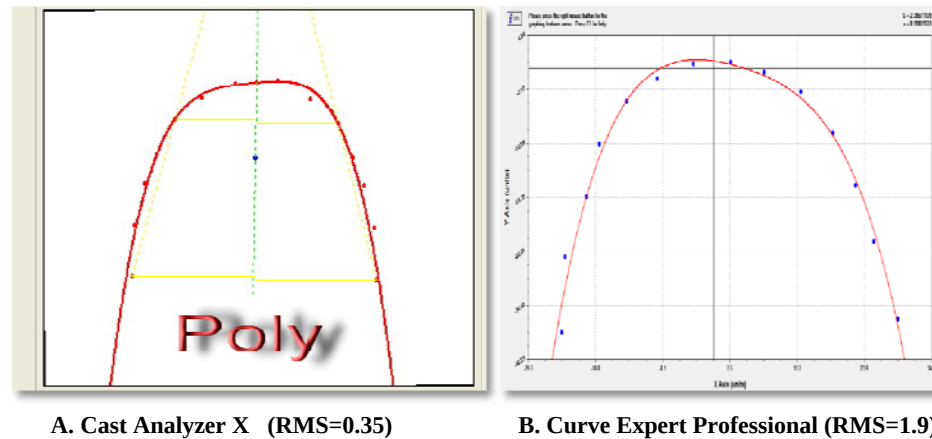


Figure 2- Comparison of the curve based on fourth order polynomial equation for specimen #24 constructed by the Cast Analyzer X and Curve Expert Professional

Results:

The mean, SD, minimum and maximum values of RMS for the three functions of Brown's beta

function, Noroozi's beta function and the fourth order polynomial equation of the Cast Analyzer X software are shown in Table 1.

Table 1- The mean, SD, minimum and maximum RMS in Brown's beta function, Noroozi's Beta function and fourth order polynomial equation in Cast Analyzer software

	Number	Mean	SD	Standard error	Minimum	Maximum	F	p-value
Brown	36	1.2644	0.48222	0.080	0.49	2.58	90.639	0.000
Noroozi	36	0.6364	0.18745	0.031	0.27	1.09		
Fourth order polynomial equation	36	0.4544	0.15413	0.026	0.29	0.99		

As seen in Table 1, the fourth order polynomial equation had the lowest RMS and thus is the best analysis for fitting with the landmarks. Also, the three functions had statistically significant differences with one another. Pair wise comparison of functions revealed significant differences between Brown and fourth order polynomial equation, Brown and Noroozi's beta function and Noroozi's beta function and fourth order polynomial equation (all $p < 0.001$).

The mean RMS calculated for the three functions of Brown's beta function, Noroozi's Beta function and fourth order polynomial

equation in Cast Analyzer X software is shown in Figure 1.

Table 2 compares the Cast Analyzer X and Curve Expert software programs. Based on Table 2, the RMS of the two software programs had a significant difference in Brown's beta function ($p < 0.01$). The numerical value of this difference according to Dahlberg's test was 0.68mm. Also, the RMS of the two software programs was significantly different in fourth order polynomial equation ($p < 0.001$). The numerical value of this difference according to Dahlberg's test was 0.45mm.

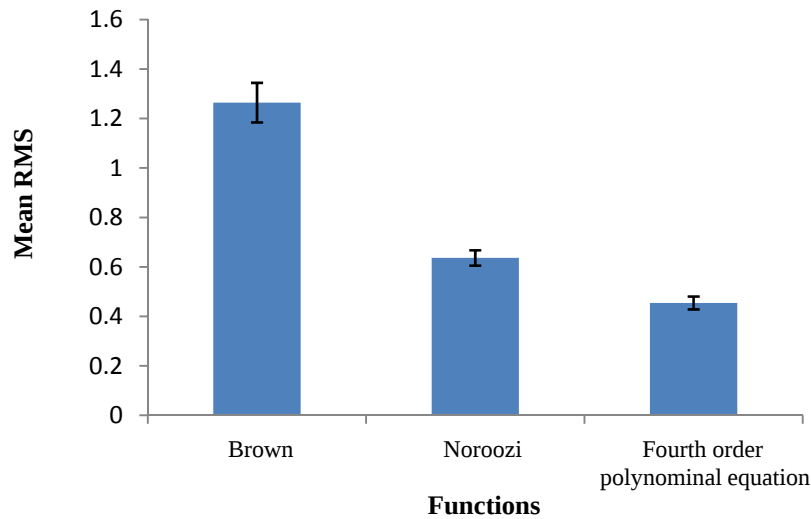


Figure 1- The mean RMS calculated for the three functions of Brown's beta function, Noroozi's Beta function and fourth order polynomial equation in Cast Analyzer software

Table 2- Comparison of RMS of the two software programs

	Number	Mean	SD	Standard error	Significancy	mean difference	ICC
Cast Analyzer Brown	36	1.2644	0.48222	0.08037	0.008	0.68	0.307
Curve Expert Brown	36	1.6761	0.94744	0.15791			
Cast Analyzer fourth order polynomial equation	36	0.4544	0.15413	0.02569	0.000	0.45	0.244
Curve Expert fourth order polynomial equation	36	0.9106	0.49006	0.08168			

Discussion

In the current study, the three functions of Brown's beta function, Noroozi's beta function and fourth order polynomial equation were used; because the arch forms constructed by these functions have had the best fitting with the landmarks. None of the previous studies have compared these three functions.

In the current study, CBPs on the facial surface of teeth were used as the landmarks for arch form construction because in orthodontic treatment, brackets are placed on the facial surfaces of the teeth. Thus, the CBPs are the most suitable landmarks for this purpose. However, most previous studies have used

reference points on the incisal edge of the incisor teeth or the buccal cusp tip of other teeth (13, 14, 19, 20).

In the current study, the RMS values were used to compare the arch forms constructed by different functions and also the two software programs. Using the RMS is an accurate method to fit the constructed arch form on some points with known coordinates. Since the RMS of the distance between the landmarks and the corresponding points on the arch is used, the effect of positivity or negativity of these distances is eliminated and the calculations would be more accurate and simple.

The difference in RMS between the two software programs was statistically significant

for both Brown's beta function and fourth order polynomial equation; however, the numerical value of this difference was less than 1mm (0.68 for Brown's beta function and 0.45mm for fourth order polynomial equation) and did not seem to be clinically significant. Therefore, the images of the arch fitted on the landmarks for cases with the highest difference in RMS values were visually compared between the two software programs and it was found that this difference was not clinically significant. Also, the numerical difference in RMS between the two software programs based on the definition of the best fitted curve, which is achieved with the lowest RMS, was in favor of the Cast Analyzer software. In other words, the mean RMS for both Brown's beta function and fourth order polynomial equation in Cast Analyzer was lower than that in Curve Expert. Since the coordinates of landmarks in both programs were similar, it may be concluded that the functions have been more accurately defined in Cast Analyzer.

Lombardo *et al.* in 2010 used Curve Expert software and defined their reference points on the lingual surface of the teeth in order to select the polynomial function that best described the shape of the dental arch (25). They used residual analysis method to find the best curve that fitted the reference points. This method is based on the difference of reference points with their corresponding points on the curve i.e. $y_i - f(x_i)$. If this difference is a positive value, it means that the reference point is above the curve and if it is a negative value, it means that the landmark is below the curve. The closer the value to zero, the closer the points to the curve and the better the fit. This is a quantitative method for evaluation of the fit of a curve with the corresponding landmarks; however, the positive and negative values may ultimately neutralize each other. But, in the method used in the current study (RMS), the square of the differences is used and thus, the positive and

negative values cannot neutralize each other.

Braun *et al.* (1998) in their study regarding the human dental arch form introduced the beta function which was based on the width and depth of arch at the second molar area to describe dental arch form. They used 40 sets of dental casts with Angle's Class I, II and III malocclusions. They digitized the dental landmarks including the mid-incisal point on the incisors, canine tip, buccal cusp tip of premolars and mesiobuccal and distobuccal cusp tips of molars. Using beta function, an arch was constructed for each cast and its fit with the dental landmarks was assessed using Curve Fitting software and Least Square method. They reported that the average CC between the measured arch-shape data and the mathematical arch form was 0.98 with a standard deviation of 0.02 (14).

Evaluating casts of all three Angle's malocclusion classes is a strength point of the study by Braun *et al.* (1998) (14) compared to our study; which only evaluated Class I normal occlusion patients. However, using the width and depth of the dental arch at the second molar area does not seem to be adequate for constructing the best fitted arch form; because there are numerous dental arches that vary in shape, but have similar arch width and depth at the second molar area. Moreover, beta function is naturally a symmetric function and therefore, is not suitable for use in asymmetric arches (13). However, in the current study, Noroozi's beta function and fourth order polynomial equation were also employed in addition to the Brown's beta function to find the function that best describes the dental arch shape. The method used to assess the best fit of landmarks with the dental arch form in our study was similar to that used in the study by Braun *et al.* (1998) (14).

In 2001, Noroozi *et al.* attempted to find the equation of a curve that would be similar to the beta function curve and at the same time could be as flexible in the anterior as in the posterior

region. Twenty-three sets of dental casts with normal Class I occlusion were selected, and their depths and widths were measured at the canine and second molar regions. Using the mean depths and widths, the general function of $Y=aX^m + bX^n$ was calculated that passed through the dental midline, canines, and distobuccal cusp of second molars. They replaced different values in this function for m and n and each function was compared with the beta function using root mean square. They concluded that the $Y = aX^6 + bX^2$ was the closest to the beta function and can be an accurate substitute for it in describing less common dental arch forms like the square and triangular arch shapes (19). Similar to their study, the RMS values were used in the current study.

In 2008, AlHarbi *et al.* (2008) in their study on mathematical analysis of dental arch curve in normal occlusion used 40 sets of dental casts to compare several mathematical equations to find the formula that best described the normal occlusion dental arches. Dental landmarks (i.e. mid-incisal point on the incisors, canine tip, premolars' buccal cusp tip and mesiobuccal and distobuccal cusp tips of molars) were marked and digitized. Second degree, fourth degree, sixth degree, eighth degree, tenth degree and twelfth degree polynomial equations, the beta function, natural cubic splines, and Hermite cubic splines were defined for the software to construct different arches for each specimen using these functions and the coordinates of landmarks (13). The fit of curves with landmarks was visually evaluated and it was concluded that the fourth degree polynomial function was the most appropriate analysis to describe smooth curvature of the dental arch. The method of assessing the fit of curves with the landmark points in their study was different from ours since in the current study, we used RMS values to quantitatively assess the best fitted curve; while AlHarbi *et al.* (2008) evaluated this issue visually and qualitatively (13) was approved and

fun. Also, in their study, Noroozi's beta function was not compared with other equations; but, they reported that fourth order polynomial function provided the best fitted curve, which is similar to our results. One limitation of the study by AlHarbi *et al.* (2008) (13) compared to our study was selection of mid-incisal and cusp tip landmarks instead of the CBPs on the facial surfaces of teeth.

In 2011, Arai and Will in their study on the subjective classification and objective analysis of the mandibular dental arch form of orthodontic patients used 27 normal occlusion mandibular casts. Ten orthodontists were asked to serially organize the casts from tapered to square (20). The mean position of the ranking of casts was calculated as the rank of each arch form. Next, this qualitative classification was compared with intercanine-width, intermolar width, ratio of inter-canine to inter-molar width and fourth and second degree polynomial equation. They concluded that the fourth degree polynomial equation is the best mathematical model to fit normal arch forms. Their results were in accord with the findings of the current study. However, using the fourth degree polynomial equation in their study was based on the results of AlHarbi *et al.* (2008) (13); whereas, as stated earlier, in the study by AlHarbi *et al.* (2008) (13) the scientific literature regarding some equations like the one by Noroozi *et al.* (2001) (19) had not been reviewed. In the study by Noroozi, the least square method was used to fit the coordinates of landmarks on the polynomial equation; which is similar to the current study.

Conclusion:

Considering the RMS values, the fourth order polynomial equation is the most suitable analysis for describing normal dental arch forms best fitted with the CBPs. Although the difference between the two software programs

was statistically significant, this difference was not clinically noticeable. The RMS value was lower in Cast Analyzer X and consequently the fitting of curves with the landmarks (CBP) was better in the Iranian software. Add this as the conclusion of the study.

Limitations of the study in the current study, only dental casts of normal, Class I occlusion patients with no crowding were evaluated. The effects of dental crowding, asymmetry, and malocclusion on the form of dental arch should

be evaluated in future studies.

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