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Can 3D imaging and digital software increase the ability to predict dental arch form after orthodontic treatment?

Sahar Hadadpour,[a] Mohammad Noruzian,[b] Amir H. Abdi,[c] Alireza Akbarzadeh Baghban,[d] and Mahtab Nouri[e]
Bushehr and Tehran, Iran, and Vancouver, Canada

Introduction: This study aimed to evaluate the ability of dental clinicians to predict posttreatment dental arch forms in patients with malocclusion with the aid of 3D imaging and digital software in comparison with a conventional method. **Methods:** Pretreatment and posttreatment dental plaster casts of 100 patients (200 maxillary models and 200 mandibular models) were selected. Three orthodontists selected the best-fitted archwires among 5 commercially available preformed nickel-titanium archwires using 2 methods. In the conventional method, they fit the archwires to pretreatment casts, and in the digital method, they fit the scanned wire to a 3D digital model, using Ortho-Aid, a locally developed 3D software, using clinical bracket points as reference for wire fitness. The predicted posttreatment archwire in each method was compared with the best-fit archwire on the actual posttreatment model of each patient in both methods, and the level of agreement was calculated. The interobserver agreement between the 3 orthodontists in each method was evaluated using intraclass correlation coefficient and the Dahlberg formula. **Results:** Orthodontists predicted the final treatment outcome in 50% of cases using the conventional method and 58% using the digital method. However, the range of method error was significantly higher in the conventional method (0.425-3.853 mm for the conventional vs 0.451-0.584 mm for the digital). **Conclusions:** Although the clinicians' ability to predict the final dental arch form after orthodontic treatment and the agreement between clinicians increased by the use of digital equipment, orthodontists can predict the final arch form in about 60% of patients. (Am J Orthod Dentofacial Orthop 2019;156:870-7)

Conventionally, orthodontists determine the arch form of orthodontic patients and select an appropriate archwire visually. This technique requires the orthodontist to visually determine the arch form as tapered, ovoid, or square-shaped or to measure the intercanine or intermolar distance. This conventional technique, however, is associated with errors and bias in the reproducibility of assessments made by different orthodontists or even the same orthodontist at different times.[1]

Today, digital casts can replace plaster casts for treatment planning and fabrication of appliances. The use of digital casts increases the accuracy, validity, and reliability of measurements.[2-4] Also, designing the arch form and occlusion digitally for each patient increases the efficacy of orthodontic appliances.[5] Invisalign technology is a well-recognized application of digital orthodontics. Using ClinCheck software (Align Technology, Santa Clara, Calif), the position of the teeth, interproximal reduction, location of attachments, and overcorrections are determined on digital casts.[6] In orthodontic treatment planning, the dental arch form of the patient should be initially determined and further preserved during treatment to achieve optimal esthetics, function, and stability.[7,8] Nouri et al[9] showed that the software environment enables a better fit of archwire with the dental arch and agreement of orthodontists is higher in the selection of archwires for regular occlusion patients.

[a]Department of Orthodontics, School of Dentistry, Bushehr University of Medical Sciences, Bushehr, Iran.
[b]Department of Orthodontics, School of Dentistry, Tehran Shahed University of Medical Sciences, Tehran, Iran.
[c]Electrical and Computer Engineering Department, University of British Columbia, Vancouver, British Columbia, Canada.
[d]Department of Basic Science, Faculty of Rehabilitation Sciences, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
[e]Formerly, Department of Orthodontics, Dentofacial Deformities Research Center, Research Institute of Dental Sciences, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran; currently, Orthodontic Department, Faculty of Dentistry, University of British Columbia, Vancouver, British Columbia, Canada.
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Address correspondence to: Mohammad Noruzian, Department of Biology and Anatomical Sciences, School of Medicine, Shahid Beheshti University of Medical Sciences, Deneshjoo Blvd, Velenjak, Tehran, Iran; e-mail, m_noruzian@yahoo.com.
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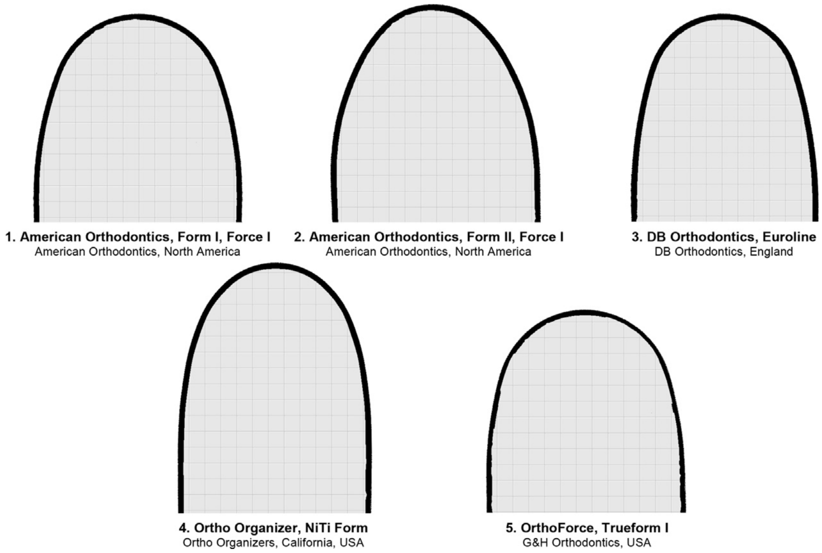

Fig 1. Shapes of 5 maxillary archwires.

The accuracy of prediction of treatment outcome and the final posttreatment arch form by the software programs is a topic less commonly addressed in the literature. Kim et al[10] evaluated the prediction of the outcome of maxillofacial surgical procedures in Class III patients and concluded that 3D predictions are variable in different skeletal dimensions and correct prediction of dental changes has a lower likelihood. Kravitz et al[6] evaluated the outcome of treatment with Invisalign technology and compared it with pretreatment predictions. They concluded that tooth movements could be entirely predicted in averagely 41% of the cases. Thus, it seems that further studies are required on the prediction of treatment outcome by the 3D imaging systems and software programs and their efficacy in achieving high reliability in the prediction of treatment outcome by different clinicians. Thus, this study aimed to assess the accuracy of prediction of posttreatment arch form in malocclusion patients and evaluate the agreement among 3 clinicians in the prediction of posttreatment arch forms using the conventional method and the software.

MATERIALS AND METHODS

This study evaluated before and after dental casts of 100 orthodontic patients (200 maxillary casts and 200 mandibular casts) with different types of malocclusion who underwent comprehensive orthodontic treatment.

The inclusion criteria were the presence of all permanent maxillary and mandibular teeth except for third molars, the presence of malocclusion with different levels of severity, different shapes of dental arches and conduction of fixed orthodontic treatment with acceptable results.

The archwires used in this study were 0.016 × 0.022-inch NiTi archwires as follows: (1) American Orthodontics, Form I, Force I (American Orthodontics, Sheboygan, Wis); (2) American Orthodontics, Form II, Force I (American Orthodontics); (3) DB Orthodontics, Euroline (DB Orthodontics, Silsden, West Yorkshire, England); (4) NiTi form (Ortho Organizers, Carlsbad, Calif); and (5) OrthoForce, Trueform I (G & H Orthodontics, Franklin, Ind)

The wires were placed on a piece of paper and scanned by a Konica Minolta C452 scanner and uploaded into the software in JPEG format (Figs 1 and 2).

For initial selection of archwire in the conventional method, 3 orthodontists were provided with original plaster casts of patients along with dental records and charts, including their demographic information, chief complaint, clinical examination report, primary patient photographs, panoramic radiograph and primary lateral cephalogram (and additional radiographs if required). According to the individual treatment plan, each orthodontist visually selected the best-fitted archwire by adapting the wire to the maxillary and mandibular casts. The 3 orthodontists had 1, 6, and 25 years of clinical experience, respectively.

Ortho-Aid software was used to digitally assess the dental arch forms. Ortho-Aid is an in-house software designed and developed by our lab solely for educational and research purposes. It is compatible with standard surface mesh and point cloud data formats and provides

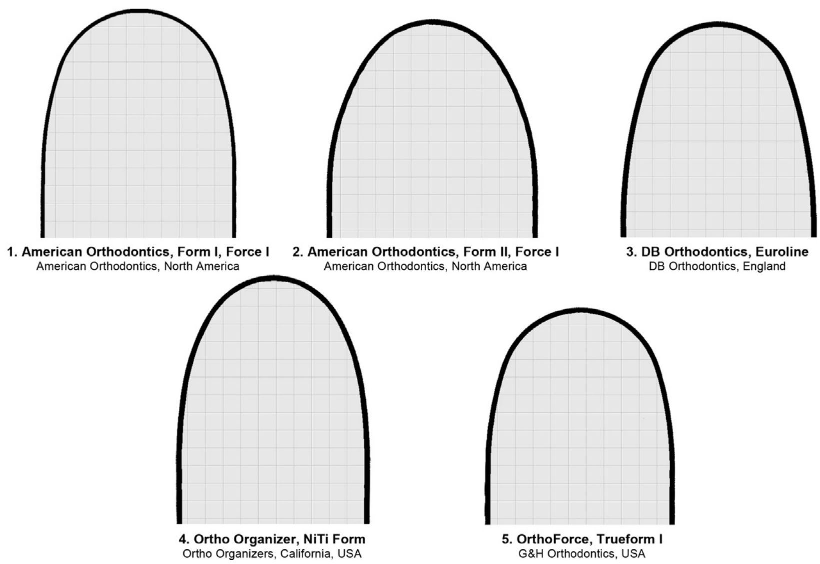

Fig 2. Shapes of 5 mandibular archwires.

the clinician with the ability to define sagittal and occlusal planes and calculate the Euclidean distance of 3D points to lines and surfaces. It can superimpose serial 3D meshes based on a given set of landmarks. Moreover, Ortho-Aid supports features to estimate the inclination of teeth and the form of the dental arch. The software is free and open-sourced under the MIT license with its source code publicly available (https://github.com/amir-abdi/OrthoAid).

Ortho-Aid imports and renders 3D objects in x, y, and z axes and enables the measurement of the distances between points on virtual models, the definition of occlusal and sagittal planes and measurement of the degree of inclination. It also has many other capabilities to enhance measurements.

The primary casts of patients were scanned (Maestro 3D MDS400; AGE Solutions, Pontedera, Italy) and uploaded into the software. Next, the clinical bracket points (CBPs) were identified by each orthodontist according to the criteria for bracket placement when using a visually preadjusted appliance on patient casts in the software environment.[11]

The CBP is defined as the point to which the bracket is bonded in the clinical setting. According to Andrews, this point is reproducible when identified visually by an orthodontist, and it is not necessary to use an orthodontic gauge for this purpose (we did not use it in this study either). On a computer, the spatial coordinates of the points selected as CBPs were determined in the 3 axes (x, y, z). In order to achieve a smooth fitted dental arch first, a plane with the least distance from the points was fitted using the principal component analysis. Next, the points were projected on this plane to obtain 2D points. Accordingly, the x and y coordinates of the CBPs were evaluated as software data to draw the best-fitted arch form for each patient.[12]

The software designed the best-fitted dental arch form by use of CBPs according to a 6-degree polynomial equation ($ax^6 + bx^5 + cx^4 + dx^3 + ex^2 + fx + g$). This mathematical equation is the best model to describe the human dental arch according to previous studies.[1,12] By selecting the curve fit feature of the software, the dental arch curve was designed using the polynomial equation.

Selection of a suitable preformed archwire in this method was based on the level of fit, and the root means square (RMS) values, objective assessment when placing the 5 preformed archwires on the dental arch in the software environment and also based on the experience and treatment plan suggested by the orthodontist.

For calculation of the RMS, the distance from the 14 CBPs in the x-axis relative to the polynomial curve drawn in the previous step was measured and squared, and the mean value was calculated (RMS = $\sqrt{\sum \frac{x^2}{n}}$). Lower RMS values indicate a better fit of archwire with the dental arch. By selecting the ”find best wire” feature of the software, the 5 types of preformed wires according to the calculated RMS values were identified in ascending order. Figure 3 illustrates an analysis of a case by the software.

The thickness of preadjusted brackets that affects wire deflection in the first order bend was not taken

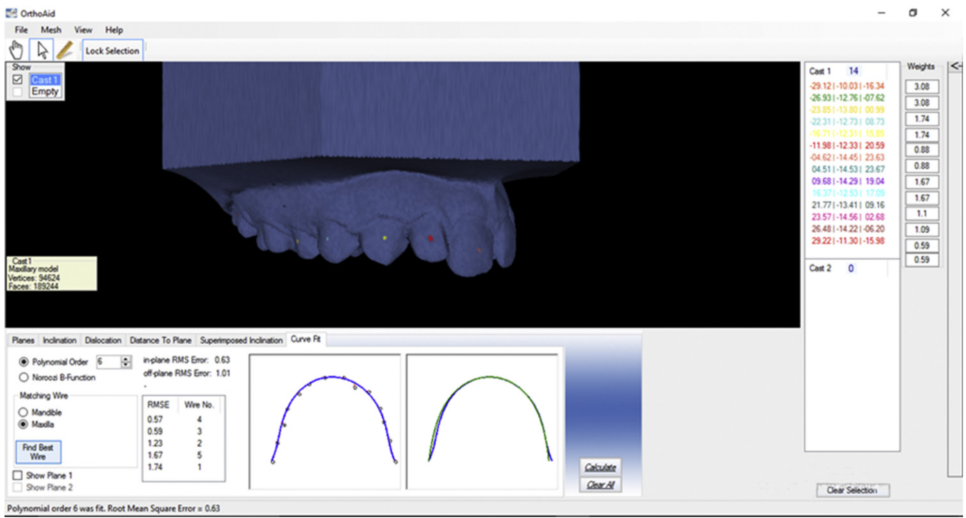

Fig 3. Preform wire selection procedure for a case by the software.

into account by the software because under similar conditions of comparison and use of similar brackets for patients, type of bracket wound not affect the final results.

Eventually, orthodontists were provided with post treatment casts and the archwires best fitting the final cast was also visually chosen by them. The scanned posttreatment casts were also analyzed by the software, and the best-fitted archwire was selected by the software.

Statistical analysis

In this study, the percentage of agreement between the selected archwire at the onset of treatment and the archwire selected by each orthodontist on the final cast of the same patient was calculated. This value demonstrated the agreement between the archwire predicted before treatment with the final postoperative outcome. Using the kappa coefficient, the agreement of this comparison was calculated by considering the selected archwire as a nominal variable (5 preformed wires shown in Figs 1 and 2). Eventually, by reverse engineering of the orthodontists' selection on the cast, the agreement between the results was calculated as a quantitative variable (the RMS value) using the intraclass correlation coefficient (ICC). The numerical value of the difference was reported using Dahlberg's formula. According to the medical literature, kappa >0.6 and ICC >0.75 and smaller Dahlberg values are favorable. The ICC values are interpreted as follows: 0-0.2: weak agreement, 0.3-0.4: fair agreement, 0.5-0.6: moderate agreement, 0.7-0.8 strong agreement and >0.8 almost excellent agreement.[13]

Since the interobserver reliability of the 3 orthodontists who participated in this study had been previously calculated and confirmed on both normal occlusion casts and in use of the software,[9] only the intraobserver reliability of the first orthodontist in use of the software was calculated in the present study. For this purpose, the first orthodontist was requested to select the best-fitted archwire for 10 casts for the second time after a 2-week interval by the digital method. The reliability of qualitative measurements (i.e., type of selected wire) was analyzed using the kappa coefficient while the reliability of quantitative measurements was calculated using ICC. The numerical value of the difference was reported using Dahlberg's formula. Table I presents the intraobserver reliability of the first orthodontist. As shown, the results indicated the effect of changing the variable from nominal to quantitative on increasing the agreement coefficient.

Table I. Intraobserver reliability of the first orthodontist

	Kappa		*ICC*	
Intraobserver reliability	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*
Orthodontist 1	0.500	0.357	0.611	0.835

RESULTS

Table II shows the agreement of archwire selection by each orthodontist on the original plaster casts (conventional method) and final plaster casts. Under ideal conditions, 50% agreement was noted between the selected primary archwire and the fitted archwire on the actual treatment outcome. The numerical values of differences on the casts ranged from 0.425-3.853 mm.

Table II. Agreement of archwire selection by each orthodontist on the primary plaster casts (conventional method) and final plaster casts

	Agreement(%)		*Kappa*		*ICC*		*Dahlberg*	
Initial vs final cast	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*
Orthodontist 1	48	50	0.143	0.150	0.212	0.232	0.535	0.519
Orthodontist 2	49	46	-	0.148	0.022	0.150	0.672	0.525
Orthodontist 3	33	37	0.082	0.141	−0.004	0.345	3.853	0.454

Table III. Agreement of archwire selection by each orthodontist in the software environment on primary and final digital casts

	Agreement(%)		*Kappa*		*ICC*		*Dahlberg*	
Initial vs final cast	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*
Orthodontist 1	55	39	0.325	0.199	0.178	0.308	0.534	0.528
Orthodontist 2	36	51	0.110	0.201	0.081	0.157	0.584	0.540
Orthodontist 3	58	37	0.366	0.202	0.150	0.489	0.505	0.451

Table III shows the agreement of archwire selection by each orthodontist on primary and final digital casts. In the software, this agreement was maximally 58%. The software environment significantly decreased the range of numerical values of the difference between the final results and the primary archwire (0.451-0.584 mm).

Tables IV and V indicate quantitative analysis of comparison of archwire selection between orthodontists in conventional and digital methods. The results revealed that the use of software increased the agreement in archwire selection among orthodontists in almost all cases.

The percentage of agreement among orthodontists on the cast ranged from 39%-58%. The highest agreement was noted between the first and third orthodontists. The mean numerical value of difference at each CBP ranged from 0.357-0.502 mm.

In the software environment, the percentage of agreement ranged from 27%-70% and the values were generally higher. The numerical value of difference also decreased and ranged from 0.310-0.479 mm.

DISCUSSION

Preserving the dental arch form during orthodontic treatment is an important factor in the stability of the treatment outcome.[7] Unplanned contraction or expansion, especially at the intercanine and intermolar regions, can lead to instability.[8,14,15] Thus, correct selection of the primary archwire at the onset of treatment is highly important. Orthodontists often commence orthodontic treatment with NiTi archwires. They often choose the best-fitted wire among the available archwires in their office visually or by use of indices such as the intercanine or intermolar width.[1,11] However, these methods can be associated with a high rate of errors. Evidence shows that selection of archwire only based on the intercanine width can result in up to 6 mm of discrepancy.[16] Also, racial differences that cause variations in dimensions and form of dental arch compared with the available archwires further highlight the significance of proper selection of a preformed archwire that best fits the dental arch.[7,17,18]

Diagnostic software programs can provide accurate information and aid in determining more complex patterns of arch form. In addition, advances in computer analyses enable better definition of arch form individually for each patient. Designing lingual appliances,[19] digital dental alignments,[5] and simulation of orthognathic surgery[10] are among the applications of digital software programs. Several studies have introduced digital software programs to quantify archwire selection and increase the accuracy of orthodontists in this respect. For instance, Nouri et al[9] studied 36 normal occlusion dental casts to assess dental arch form and find the best-fitted archwire using Cast Analyzer X Iranian software. They demonstrated that wire selection by use of the software resulted in a better fit of the wire with the CBPs. Also, the agreement among orthodontists in wire selection is increased by the use of the software. This finding indicated that the software could be used as an adjunct tool for archwire selection. They also showed that under ideal conditions, the curve drawn by the multinomial equation had a 1.4-1.7 mm difference with the corresponding points on the wire, which

Table IV. Quantitative analysis of comparison of archwire selection between orthodontists in conventional method

	Agreement(%)		*Kappa*		*ICC*		*Dahlberg*	
Initial vs final cast	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*
Orthodontist 1 vs 2	57	54	-	0.257	0.352	0.098	0.490	0.502
Orthodontist 1 vs 3	39	43	0.074	0.144	0.486	0.527	0.436	0.357
Orthodontist 2 vs 3	42	58	-	0.382	0.445	0.056	0.447	0.500

Table V. Quantitative analysis of comparison of archwire selection between orthodontists in digital method

	Agreement(%)		*Kappa*		*ICC*		*Dahlberg*	
Initial vs final cast	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*	*Maxilla*	*Mandible*
Orthodontist 1 vs 2	47	35	0.193	0.118	0.353	0.155	0.432	0.487
Orthodontist 1 vs 3	70	49	0.543	0.359	0.683	0.545	0.310	0.384
Orthodontist 2 vs 3	56	27	0.316	0.068	0.448	0.175	0.410	0.479

can result in a 3.5-mm difference in the final position of teeth. This difference is not clinically significant because it can be added to the premolar region of the archwire. According to a previous study, 2-3 mm of expansion in the premolar region does not invade the neutral zone and does not compromise the long-term stability of the treatment outcome.[20,21]

In another study by Carmadella et al.[22] 3 examiners evaluated 20 pairs of dental casts with malocclusion by 2 methods: (1) they first found the best-fitted preformed archwire on dental plaster casts and (2) then selected an archwire on casts scanned by Ortho Analyzer software. They used the best-fit method for assessment of the fitness of wires with the mandibular dental arch. Their results revealed −1.70-4.40 mm difference in the superimposition of wires. Also, they showed accurate superimposition of arch forms on the plaster and digital models. The differences were clinically negligible except in the second molar region.

The current results revealed that the archwire conventionally selected by orthodontists on dental plaster casts had a greater difference with the final arch form of patients, and use of software on 3D scanned casts improved the agreement between the primary and final wire forms. Comparison of the numerical value of difference between the archwire and dental arch of patients revealed that in the digital method, the difference between the primary and final wires was around 0.5 mm, which is clinically negligible.[9] Also, use of digital method informs the orthodontist about the exact numerical value of difference between the existing wires and the patient's dental arch, which leads to more accurate decision making and lower human errors. As shown in our study, the digital method increased the agreement among the orthodontists.

Camardella et al[22] evaluated scanned mandibular casts by the software and achieved an ideal maxillary arch according to the mandibular arch by taking into account 2 mm of overjet. As mentioned earlier, some differences may exist for the coordination of the maxillary and mandibular arches. For instance, Kook et al[23] mentioned that according to a 3D analysis carried out for arch coordination, overjet decreases from the anterior region of the arch (2.3 mm) toward the posterior region (2 mm). One advantage of the software introduced in the present study is that the maxillary and mandibular arches can be evaluated both in occlusion and independently.

In the current study, the RMS was calculated to determine the fitness of wires with the dental arch. The RMS is among the most reliable parameters to compare the curves. By use of the RMS, the difference between the corresponding points on the dental arch and the archwire can be calculated. Similar to the current study, Nouri et al.[9] used the RMS to quantify the subjective data, such that the polynomial curve was drawn and the least distance between the CBPs and the fitted polynomial curve was measured. The RMS was also used to find the best-fitted archwire.

In the current study, a 6-degree polynomial function was used for assessment of dental arch and quantitative evaluations. This selection was based on visual assessment of different polynomial function curves drawn by the software and comparison of the fitness of curves according to the least RMS. Similarly, Trivino et al[24] used a 6-degree polynomial curve for assessment of the mandibular arch form. Memarpour et al[25] reported the optimal accuracy of the 6-degree polynomial function for assessment of primary dental arch form. Polynomial functions of lower degrees cannot accurately visualize the important areas of dental arch such as the anterior curve of the mandibular arch determined by the intercanine distance and alignment of posterior teeth.[13,26,27] Ferrario[28] and Wakabayashi[29] noticed that higher degree polynomial functions provide a more accurate graphical description of dental arch. However, polynomial functions with higher than 6° draw distorted dental arches.[24]

Another important finding of the current study was that changes in dental arch form during orthodontic treatment are not highly predictable. Correction of some malocclusions requires changing of the dental arch form, as observed in many patients. On the other hand, the current results and failure in the prediction of posttreatment dental arch form indicate the presence of some other influential factors in achieving the predicted outcome in an accurate diagnostic set-up. For this reason, it appears that factors other than achieving a normal occlusion should be taken into account in algorithms of prediction of orthodontic treatment outcome. What happens in the clinical setting has 33%-50% agreement on the cast and 36%-58% agreement in the software with the arch form selected by orthodontists at the onset of treatment. This finding has also been confirmed by some other studies on prediction of surgical treatment outcome and outcome of treatment with clear aligners.[6,10,30-34]

CONCLUSIONS

(1) Advances in computer analyses enable a better definition of arch form individually for each patient. The use of a digital method informs the orthodontist about the exact numerical value of difference between the existing wires and the patient's dental arch.
(2) The digital method increases the agreement among the orthodontists in wire selection. Like any other technology, this has a learning curve.
(3) The capacity of predicting the final arch form is still at most 60%, and this indicates that fitting an archwire to selected points on the teeth even based on mathematical equations is not enough for predicting the final arch form of patient after treatment.
(4) Other factors such as biomechanics of tooth movement, the soft and hard tissue limitations, and the biological differences between the patients should be considered in this equation to increase the predictive capacity of this software.

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