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Website: www.jorthodsci.org
DOI: 10.4103/jos.JOS_45_20

# Accuracy of three different customized lingual orthodontic appliance systems in achieving predicted results on maxillary anterior teeth: A Retrospective Cohort Study

Floyd Fernandes, Ravindranath V. Krishnan<sup>1</sup>, Vivek Patni<sup>1</sup> and Nikhilesh Vaid<sup>2</sup>

## Abstract:

**OBJECTIVE:** To comparatively evaluate the ability of three different customized lingual appliance systems in achieving predicted results with respect to the mesiodistal crown tip, labiolingual crown inclination, in–out position of Maxillary permanent anterior teeth, and Maxillary arch form.

**METHODS:** Three commercial houses: Incognito, iLingual 3D, and Lingual matrix were analysed in this study. The final sample size consisted of 42 cases. Fourteen digital prediction and posttreatment models of the maxillary arch were provided by three orthodontic offices each using a different system. Discrepancies between the prediction and posttreatment model in mesiodistal tip, labiolingual inclination, in–out position of anterior teeth, and arch form were analyzed.

**RESULTS:** Incognito displayed the highest accuracy in all parameters except for in–out positioning. Lingual Matrix showed greater precision in achieving planned mesiodistal positions than labiolingual inclination while it was just the opposite for iLingual 3D. All three systems proved to be clinically reliable in achieving the predicted in–out positions of permanent Maxillary anterior teeth.

**CONCLUSION:** These systems were considerably accurate in achieving planned treatment goals with minute deviations from the predicted value.

## Keywords:

Accuracy, appliances, customized, digital models, FEM, lingual

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Submitted: 31-Jul-2020  
Revised: 23-Aug-2020  
Accepted: 25-Feb-2021  
Published: 04-Aug-2021

## Introduction

Lingual orthodontics is a means of correction of dental malocclusion using efficient biomechanical principles.<sup>[1,2]</sup> By streamlining mechanics to correct a malocclusion and keeping operator preferences in perspective, customized lingual orthodontics has made treatment planning specific.<sup>[3]</sup> Digital prediction models can be constructed to provide a template for the final tooth position that is to be achieved clinically. New customized systems have emerged

to that have accurately produced clinically acceptable results.<sup>[4-6]</sup> Such systems warrant further analysis to determine factors that increase their accuracy.

Studies have been performed to quantify orthodontic tooth movement.<sup>[7-9]</sup> The use of anatomic landmarks as reference,<sup>[10]</sup> finite helical axis system,<sup>[7,8]</sup> and surface to surface registration using the best fit method<sup>[9]</sup> have produced valid results. The current study uses digitally constructed planes for reference and geometric nodes each with a specific co-ordinate while quantifying

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**How to cite this article:** Fernandes FS, Krishnan RV, Patni VJ, Vaid N. Accuracy of three different customized lingual orthodontic appliance systems in achieving predicted results on maxillary anterior teeth: A Retrospective Cohort Study. *J Orthodont Sci* 2021;10:15.

orthodontic tooth movement. The planes provide a fixed reference to which geometric nodes of digital models can be superimposed using their co-ordinates. Since each system has its own digital software, a common compatible platform can be used to evaluate and compare them.

The null hypothesis was that there was no difference in the accuracy of the three systems in predicting the clinical outcome of their respective cases.

### Aim of this study

After the considerations above this study was conducted to evaluate and compare the ability of three different customized lingual appliance systems in achieving simulated predictions with respect to the mesiodistal crown tip, labiolingual crown inclination, in-out position of Maxillary permanent anterior teeth and Maxillary arch form.

## Materials and Methods

The sample was collected from three Orthodontic offices in Mumbai, Maharashtra, India. The inclusion criteria were simulated prediction and posttreatment digital models created for cases treated using Incognito (3M- Unitek, Monrovia, Calif, USA), iLingual 3D (iLingual 3D, Mumbai, India), Lingual Matrix (Lingual Matrix, Mumbai, India); permanent Maxillary teeth. The exclusion criteria were simulated prediction and posttreatment digital models created by a software other than that for Incognito, iLingual 3D, Lingual Matrix; teeth other than the permanent Maxillary teeth. Mesiodistal tip, labiolingual inclination, and in-out position of the Maxillary anterior teeth were measured; the posterior teeth were included in the arch form analysis.

The sample size was estimated considering the difference in group means to be 20%, the power of the study as 80%, a 95% confidence interval, a ratio of sample size as one, and a significance level set at 5%. The initial sample size consisted of 44 patients. After applying the exclusion criteria, the final sample size was 42 (23 Male, 19 Female). The demographics are given in Table 1. The records of 14 cases from each commercial house Incognito, iLingual 3D, and Lingual Matrix were included. The observers were blinded from the analysis and interpretation of data.

Two sets of digital models were available for each patient: Posttreatment digital models obtained on the

day of bracket de-bonding and prediction models made on digital malocclusion models before orthodontic treatment began. Posttreatment digital models were obtained using a TRIOS 3shape scanner (3Shape A/S, Copenhagen, Denmark). The models poured in Class IV die stone (ultrarock, Kalabhai Karson Pvt Ltd, Mumbai, Maharashtra, India; Orthokal, Kalabhai Karson Pvt Ltd, Mumbai, Maharashtra, India) were scanned with a Rexcan III white light scanner (Solutionix and Medit, Seongbuk-gu, Seoul, Korea) with ezScan software for iLingual 3D records and a 3Shape Desktop scanner for the posttreatment records of Lingual Matrix and Incognito systems. The die stone was manipulated according to the manufacturer's instructions before pouring it into the impression made of polyvinyl siloxane putty and light body (Zhermack SpA, Badia Polesine, Italy; 3M™ ESPE™, 3M India Ltd., Bangalore, India).

The software used for constructing digital prediction models was Treatment Management Portal (TMP™) by 3M Unitek. Models were oriented in space using the occlusal plane as reference to a true vertical and horizontal plane. The occlusal plane was constructed in the X-Y plane using standard surface creation tool available in HyperMesh. All scanned models were aligned perpendicular to global Z-Axis in the co-ordinate system. The bottom surface of both models was oriented parallel to the horizontal plane. The surfaces were simplified to 50,000 points using the Qslim 2.0 tool and then cleaned to delete the gingival tissue. The prediction model was then registered to the posttreatment model using Hyperworks 13.0 software (Altair, Troy, Michigan, United States) to combine both models in the same coordinate system [Figure 1]. Since surface to surface registration of final orthodontic digital models to planned setup models is reproducible, the registration process was repeated five times per patient, rendering five relative positions of the prediction to the posttreatment models.<sup>[9]</sup> Prediction and posttreatment dental arch forms were compared pair-wise.

The long axis of each tooth was constructed by joining the center of the incisal edge for Incisors and cusp tips for Canine designated as point A to the centroid of the clinical crown designated as point B [Figure 2a and b]. The centroid of the crown was obtained by using RBE3 Rigid elements in HyperMesh.

Point A was projected normal to the horizontal surface which created a new point C and a straight-line AC was

**Table 1: Descriptive statistics for Demographic data**

Variable	Incognito	iLingual 3D	Lingual Matrix	P
Age (Years)	28 (6.3)	29.5 (9.8)	27.5 (9.5)	0.462 <sup>**</sup>
Duration of Treatment (Months)	20.5 (8.8)	17 (8)	18.5 (11.5)	0.194 <sup>**</sup>
Gender (%Female)	57%	50%	28.50%	0.278 <sup>§§</sup>
Extraction (%Yes)	0%	7%	14%	0.231 <sup>§§</sup>

<sup>††</sup>Kruskal Wallis test, <sup>§§</sup>Chi square test (Likelihood ratio). <sup>\*\*</sup>P<0.05 – Significant, <sup>††</sup>P<0.001 - Highly significant

constructed. The angle formed by lines BA and AC was then measured [Figure 2c]. This process was done on both the prediction and posttreatment models. A frontal view was used to measure mesiodistal tip while a lateral view was used for measuring labiolingual inclination.

The midmost tips of the six maxillary anterior teeth were marked as nodes. A circle was constructed by “Circle-Center” tool available in HyperMesh. The radial distance between the center and each node at a tooth tip was measured [Figure 3]. This was done for the prediction and posttreatment models. The difference in value was presented as the in-out measurement.

The arch line was plotted by connecting nodes on cusp tips and incisal edges. The prediction and posttreatment models were superimposed in same co-ordinate system. A grid was generated around these arch lines [Figure 4]. A common score was calculated for each arch form depending on intersections, overlapping, and crossing over between these two lines [Table 2]. The final score

was presented as a percentage between the sum of scored values against total number of blocks.

The Statistical software IBM SPSS statistics 20.0 (IBM Corporation, Armonk, NY, USA) was used to analyze the data. Descriptive and inferential statistical analyses were carried out in the present study. The results on continuous measurements were presented as Median (Interquartile range). The level of significance was fixed at  $P = 0.05$  and any value less than or equal to 0.05 was statistically significant. The power of the study was 80% and was uniform throughout. Based on the results of normality test (Kolmogorov–Simonov and Shapiro–Wilk test), it was concluded that the data did not follow the normal distribution, hence non-parametric test were used. Kruskal–Wallis test was used to find the significance of study parameters between three or more groups. Mann–Whitney U test was used to find the significance of study parameters on a continuous scale between two groups.

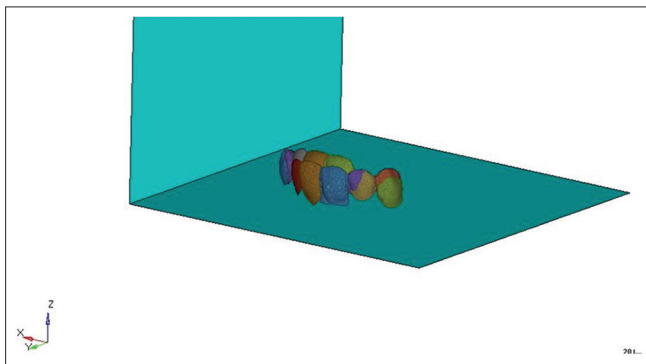
## Results

Incognito displayed the highest accuracy in all parameters except for in-out positioning [Figures 5-8]. Lingual Matrix showed greater precision in achieving planned mesiodistal tip than labiolingual inclination while it was just the opposite for iLingual 3D [Figures 5 and 6]. There was negligible difference between the ability of all three systems in achieving planned in- out tooth positions ( $P \leq 0.001$ ) [Figure 7].

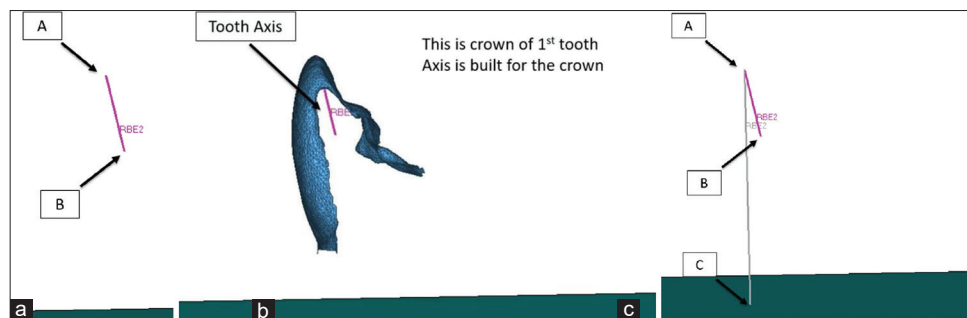
Each system had variations in the final position of the Maxillary teeth. In the Incognito system, the permanent Maxillary Right Lateral Incisor showed the most accurate mesiodistal tip expression while the permanent Maxillary Right Lateral Incisor showed the least accurate expression ( $P \leq 0.001$ ) [Table 3]. The permanent Maxillary Left Lateral Incisor showed the most accurate labiolingual inclination expression while the permanent Maxillary Left Canine showed the least accuracy ( $P \leq 0.001$ ) [Table 3]. For in-out position the permanent Maxillary left Lateral Incisor showed the least accurate expression ( $P > 0.001$ ) [Table 4].

**Table 2: Arch form scoring index**

Value assigned	Arch form attribute
1	Blocks with >50% of both lines overlapping
0.5	Blocks with <50%->0% of both lines intersecting
0	Blocks with no intersection by both lines, yet both lines remain in same block



**Figure 1:** The Digital model surfaces simplified to 50,000 points using the Qslim 2.0 tool and then cleaned to delete the gingival tissues



**Figure 2:** (a). Construction of the long axis of each tooth. (b). The centre of the incisal edge for Incisors and cusp tips for canine designated as point A and the centroid of the clinical crown designated as point B. (c). Construction of an angle for measuring mesiodistal tip and labiolingual inclination

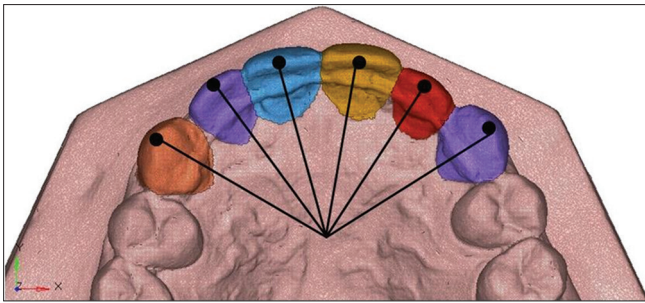


Figure 3: Constructing Radii (Occlusal view)

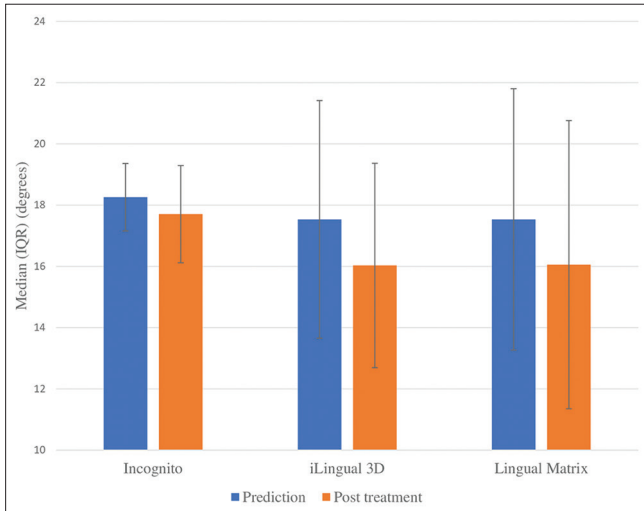


Figure 5: Comparison of the prediction and post treatment values of Mesiodistal tip between the three customized lingual appliance systems

In the iLingual 3D system, the permanent Maxillary Left Canine showed the most precise mesiodistal tip ( $P \leq 0.001$ ) and in-out position ( $P > 0.001$ ) expression [Tables 3 and 4]. The least accurate mesiodistal tip and labiolingual inclination was expressed by the permanent Maxillary Right Central Incisor ( $P \leq 0.001$ ) [Table 3]. The permanent Maxillary Right Canine showed the most accurate labiolingual inclination expression ( $P \leq 0.001$ ) [Table 3]. The permanent Maxillary Right Lateral Incisor showed the most amount of difference in its in-out position comparisons ( $P > 0.001$ ) [Table 4].

In the Lingual Matrix system, the Maxillary Right Central Incisor showed the most amount of discrepancy in its mesiodistal tip and labiolingual inclination comparisons ( $P \leq 0.001$ ) [Table 3]. The permanent Maxillary Right Lateral Incisor showed the least amount of difference for mesiodistal tip and labiolingual inclination comparisons ( $P \leq 0.001$ ) [Table 3]. The permanent Maxillary Left Canine showed the least amount of difference for in-out position comparisons ( $P > 0.001$ ) [Table 4].

Incognito showed the highest accuracy for reproducing the predicted maxillary arch form followed by

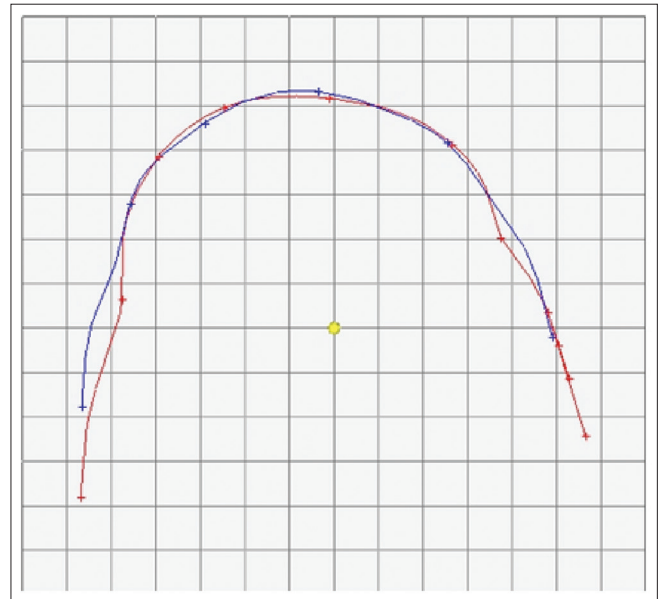


Figure 4: Generation of a grid around Maxillary arch lines to quantify the accuracy arch form prediction

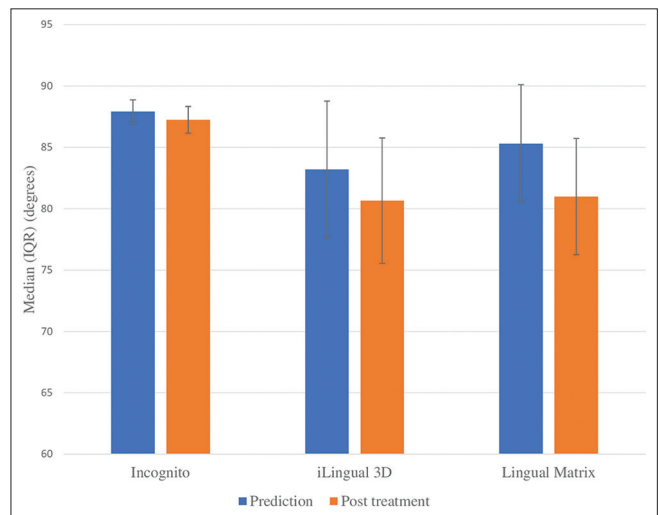


Figure 6: Comparison of the prediction and post treatment values of Labio-lingual inclination between the three customized lingual appliance systems

iLingual 3D and Lingual Matrix in that order [ $P \leq 0.001$ ] [Table 5].

## Discussion

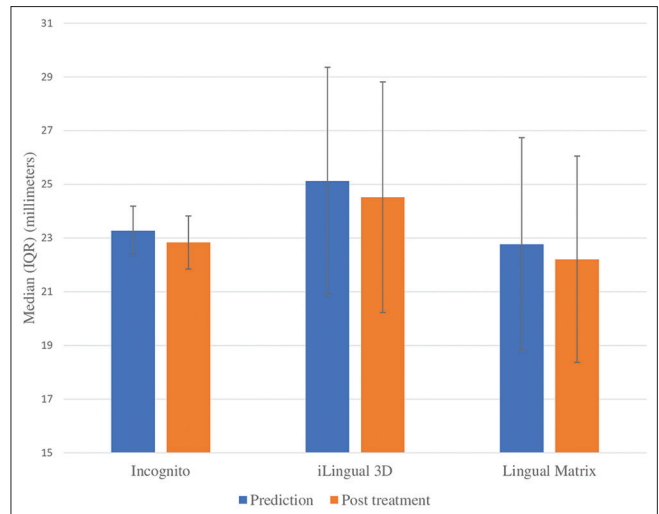
The aim of this study was to compare the predictive ability of three customized systems namely Incognito, iLingual 3D, and Lingual Matrix. Digital models obtained from scanned Polyvinyl siloxane impressions were measured reliably and accurately.<sup>[11,12]</sup> The null hypothesis of this study was that there was no difference in the predictive ability of the three systems.

Ideally the prediction and posttreatment models should completely match in all planes of space. Hence a plane

**Table 3: Comparison of the mesiodistal tip and labiolingual inclination among the three customized lingual appliance systems using Kruskal Wallis test**

Tooth No.	Incognito		iLingual3D		Lingual Matrix		Chi Square Value	Mann Whitney- U	P (Kruskal Wallis test)	
	Median (Degrees)	Interquartile range (Degrees)	Median (Degrees)	Interquartile range (Degrees)	Median (Degrees)	Interquartile range (Degrees)				
<b>Mesiodistal Tip</b>										
*R1	0.5200	1.82499	1.8700	1.71000	2.6200	1.19500	20.422	<0.001 <sup>††</sup>	0.029 <sup>**</sup>	<0.001 <sup>††</sup>
†R2	0.4100	0.37000	1.5200	2.98750	1.5200	2.50750	14.608	<0.001 <sup>††</sup>	0.002 <sup>**</sup>	1.000
‡R3	0.5200	0.27749	1.7950	1.62750	2.1250	1.42500	11.929	0.011 <sup>**</sup>	0.002 <sup>**</sup>	0.250
§L1	0.5550	0.17250	1.3700	1.18500	1.7350	0.93250	16.624	0.022 <sup>**</sup>	<0.001 <sup>††</sup>	<0.001 <sup>††</sup>
¶L2	0.5550	0.21000	1.4900	1.30500	1.9750	1.63000	12.015	0.013 <sup>**</sup>	0.002 <sup>**</sup>	0.147
∥L3	0.4849	0.40499	1.2250	1.08000	1.5500	1.24000	16.286	0.011 <sup>**</sup>	<0.001 <sup>††</sup>	0.069
<b>Labiolingual inclination</b>										
*R1	0.6057	0.21989	2.6807	1.98244	4.9907	1.52183	26.685	<0.001 <sup>††</sup>	<0.001 <sup>††</sup>	0.005 <sup>**</sup>
†R2	0.5907	0.23737	2.2857	1.71621	3.6064	1.11483	22.201	0.004 <sup>**</sup>	<0.001 <sup>††</sup>	0.032 <sup>**</sup>
‡R3	0.6343	0.14297	1.6393	0.99733	4.5107	3.65481	24.859	0.010 <sup>**</sup>	<0.001 <sup>††</sup>	<0.001 <sup>††</sup>
§L1	0.5921	0.21228	2.2521	1.57947	4.1486	1.52404	26.358	<0.001 <sup>††</sup>	<0.001 <sup>††</sup>	0.007 <sup>**</sup>
¶L2	0.5736	0.09896	2.1086	1.46713	3.6579	1.51068	19.852	0.033 <sup>**</sup>	<0.001 <sup>††</sup>	0.032 <sup>**</sup>
∥L3	0.6900	0.26652	1.8479	1.15226	4.2343	2.65764	22.309	0.010 <sup>**</sup>	<0.001 <sup>††</sup>	0.009 <sup>**</sup>

\*R1: Permanent Maxillary right Central Incisor, †R2: Permanent Maxillary right Lateral Incisor, ‡R3: Permanent Maxillary right Canine, §L1: Permanent Maxillary left Central Incisor, ¶L2: Permanent Maxillary left Lateral Incisor, ∥L3: Permanent Maxillary left Canine. \*\*P<0.05 Significant, ††P<0.001 - Highly significant



**Figure 7: Comparison of the prediction and post treatment values of In-out position between the three customized lingual appliance systems**

of reference can be constructed using any three digital landmarks with the models registered using the same coordinate system. The error in measuring discrepancy between surface to surface registration of digital models is negligible ( $P \leq 0.001$ ).<sup>[13]</sup>

Age, sex, and duration of treatment had no influence on the outcome of treatment ( $P \leq 0.001$ ). Another study reports the same: Grauer<sup>[9]</sup> (2010) reported that demographics were not co-related with the discrepancy between the predicted and posttreatment result or the severity of malocclusion and treatment needed. The sample did not represent any particular malocclusion. A customized appliance is considered specific to each case in its design; hence a notion can have developed that relatively simpler cases or cases requiring simpler biomechanics may conclude in a position closer to the prediction made than a case requiring complex biomechanics. Given that over correction is planned into the appliance and the overall treatment plan, the term “customized” cannot be limited to the design of the appliance alone for the biomechanics themselves must be tailored to bring about desired Orthodontic tooth movement in accordance with the treatment plan. The very process of making a prediction model must take into consideration appliance design and sound biomechanical principles along with biologic limitations. This holistic plan is a customized plan and the appliance used, a customized appliance in its true sense. Thus, regardless of the type of malocclusion, the customized appliance is designed to produce results that almost match the prediction model if not completely mimic it. There were no fixed patterns of prescription expression based on type of malocclusion or biomechanics used. Unlike non-customized appliances, the norm for one case may not be that for another when using a customized system. While a fixed template of norms is considered for

**Table 4: Comparison of the in-out position among the three customized lingual appliance systems using Kruskal Wallis test**

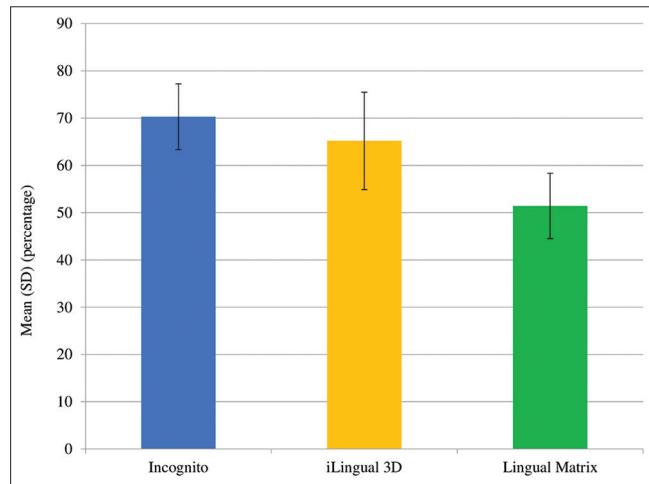
Tooth No.	Incognito		iLingual 3D		Lingual Matrix		Chi Square Value	Mann Whitney-U		P (Kruskal Wallis test)	
	Median (mm)	Interquartile range (mm)	Median (mm)	Interquartile range (mm)	Median (mm)	Interquartile range (mm)					
*R1	1.0613	2.14909	0.5393	0.13071	0.7403	1.23865	3.008	0.462	0.102	0.260	0.222
†R2	1.0471	2.15250	0.5550	0.15570	0.5634	0.27477	1.640	0.190	0.382	0.963	0.441
‡R3	1.0629	2.28439	0.5121	0.18560	0.4752	0.25151	0.777	0.872	0.566	0.369	0.678
§L1	1.1354	2.41166	0.5400	0.16474	0.5607	0.18681	0.046	0.854	1.000	0.854	0.977
¶L2	1.1385	2.37786	0.5321	0.17725	0.5493	0.22510	0.326	0.646	0.613	0.890	0.849
¶¶L3	0.9799	1.78663	0.4629	0.12493	0.4436	0.23273	1.424	0.433	0.250	0.678	0.491

\*R1: Permanent Maxillary right Central Incisor, †R2: Permanent Maxillary right Lateral Incisor, ‡R3: Permanent Maxillary right Canine, §L1: Permanent Maxillary left Central Incisor, ¶L2: Permanent Maxillary left Lateral Incisor, ¶¶L3: Permanent Maxillary left Canine. \* $P < 0.05$  - Significant, † $P < 0.001$  - Highly significant

**Table 5: Comparison of the arch form accuracy among the three customized lingual appliance systems using ANOVA test**

Group	Sample size (n)	Median (%)	Interquartile range	F	P
Incognito	14	70.6900	13.88	19.800	<0.001**
iLingual 3D	14	65.7500	17.46		
Lingual Matrix	14	50.0000	9.95		
Total	42	62.7000	17.79		

\*\* $P < 0.05$  - Significant, † $P < 0.001$  - Highly significant

**Figure 8:** Comparison of the accuracy of the clinical reproducibility of the predicted maxillary arch form of the three customized lingual appliance systems using ANOVA test

the former, floating norms will be a more appropriate approach for the latter.

According to Wiechmann<sup>[44]</sup> (2003), the finishing process is affected by inaccurate bracket positioning, inaccurate archwire fabrication, and torque play. In customized systems, the whole bracket base is manufactured to conform to the lingual surface of a tooth. Virtual bracket positioning further enhances placement accuracy. Incognito system uses CAD/CAM technology to manufacture brackets and archwires making it completely unique to each case.<sup>[4]</sup> Incognito uses robotic arms to bend superelastic wires accurately.<sup>[15]</sup> This technique is more precise as compared

to manual wire bending.<sup>[16]</sup> iLingual3D and Lingual Matrix brackets are made using CAD/CAM technology as well. The archwires are preformed.<sup>[4]</sup> Errors could occur during the indirect tray transfer procedure, direct bonding or rebonding procedure; during archwire fabrication or archwire modification or a combination of these factors. Human error is inherent in direct bonding even though the brackets have extended customized bases.<sup>[14]</sup> Indirect tray transfers may reduce chair side time but bracket positioning may still be erroneous.

### Mesiodistal crown tip

Mesiodistal tip is manifested earlier than inclination as the alignment and levelling of teeth take place. Therefore, it is considered a more important aspect than labiolingual inclination.<sup>[17,18]</sup> There was no specific pattern of mesiodistal tip expression for any tooth when the three systems were compared. However, individual extremes for certain teeth were observed. The ribbon arch system provides less control over tip expression. This could explain the discrepancies between planned and achieved tooth positions. However, archwire and bracket slot interactions, archwire properties too could contribute to said discrepancies. Incognito's anterior tip bar brackets (3M, Bad Essen, Germany) have an increased slot width to increase control over tip expression. Incognito was within 1° of its planned position. iLingual 3D was within 3° of its planned position; it used tandem slots<sup>[4]</sup> to refine its tip expression. Lingual Matrix was within 1.5° of its planned position. Power ties, anterior tip bar brackets, and tandem slots seem like innovative measures capable of accurate tip expression.

### Labiolingual crown inclinations

iLingual 3D showed greater accuracy in achieving planned labiolingual inclinations of teeth than their mesiodistal positions. Since the iLingual 3D appliance harbors a 0.016 × 0.022" TMA (Titanium Molybdenum Alloy) finishing wire in a 0.016 × 0.022" slot,<sup>[4]</sup> the expected difference between the predicted and posttreatment labiolingual inclination would be negligible if not least among the three systems. It was within 2° of its planned inclination. The Lingual Matrix system used

a 0.017 × 0.025" TMA wire in a 0.018 × 0.025 slot in its finishing stages for most cases. Thereafter, any sagittal dental discrepancies were dealt with while using a 0.016" TMA wire. This system was within 3.6° from its planned labiolingual inclination. The cross-section of the finishing wire is a contributing factor to achieving accurate labiolingual inclination. Other factors like moment to force ratio, point of application of force, undermining resorption must be taken into account while simulating predictions as these factors may invariably affect the final labiolingual inclination expression. Incognito system used a full dimension 0.018 × 0.025 TMA wire in a 0.018 × 0.025 slot during its finishing stages. It was within 1° of its planned inclinations. A difference was found between all three systems ( $P \leq 0.001$ ). This could be because of variations around the bracket slot dimension, termed as the tolerance limit of the manufacturer which tends to increase the play.<sup>[19]</sup> The archwires fabricated have dimensions that are never greater than nominal values, and bracket slots have values slightly greater than nominal values which facilitate easier wire insertion and removal. This provides adequate depth to allow correct positioning in the slot.<sup>[20]</sup> If the bracket slots are found to be smaller than desired on post-production inspection, they are enlarged using precision broach tools; if the slot is too large, the bracket is discarded and a new one is made.<sup>[14]</sup> Rounding of the wire edges could reduce the expression of labiolingual inclination too.<sup>[21]</sup> Given that these circumstances were present in all three systems, robotic wire bending could be the deciding factor. It may provide for more accurate expression of tip and labiolingual inclination since Incognito was the most accurate in both aspects.

Considering the wide biological variation, individualized bracket prescriptions based upon current tooth position and the outcome desired are a means to accurately achieve predictable results. A non-customized straight wire appliance uses smaller diameter wires in the brackets to avoid any undesirable changes. This is determined by the position of the cortical plates. Play between the wire and the slot would not allow complete expression of the prescription. A customized appliance, however, could allow relatively more predictable wire expression because of relatively less play between wire and slot when compared to non-customized appliances.

### In-out tooth position

All three systems were within a millimetre of achieving planned in-out tooth positions. Statistically, CAD/CAM technology is highly accurate in appliance design and production. Stress is laid on the word technology because it is now apparently a crucial factor in designing systems with accurate bracket positioning, more so in the in-out dimension as this study has found. Since the bracket base conforms to the lingual surface, it is the slot that is machined in accordance with the desired prescription.<sup>[14]</sup>

This brings the wire even closer to the lingual surface and the centres of resistance than it does in a conventional lingual system, thereby exerting more control over in-out position of teeth. Interestingly, the permanent Maxillary Left Canine showed the least amount of discrepancy between its prediction and post treatment in- out position in all three systems.

### Maxillary arch form

Incognito had a clinical accuracy of above 70% in achieving the planned Maxillary arch form. iLingual 3D and Lingual Matrix systems adequately achieved their Maxillary arch form predictions as well. Grauer<sup>[9]</sup> (2010) found the mesiodistal translational discrepancies to be small with most of the sample within 1 mm of the planned position. The differences in arch form had minimal effect on the mesiodistal position of a tooth. He reported that the molars were in a more constricted position while the incisors were in a more proclined position and that arch form change was not entirely achieved by the final wire. A possible explanation could be that dental arch expansion is proportional to the arch wire expansion until a threshold is reached after which a greater torsional stiffness of the wire is needed.<sup>[22]</sup> The last wire used in over two-third of patients in that study was a rectangular TMA wire.<sup>[22]</sup> The torsional stiffness of this wire is around 40% of the rigidity of a similarly-sized stainless steel wire.<sup>[22]</sup> Hence the arch may not arrange itself completely according to the shape of the final wire.

Several developments have led to the formulation of Orthodontic treatment with the outcome planned even before the appliance has been fabricated. The ability to visualize, analyse, and modify treatment outcomes and possibilities using digital algorithms has increased the potential of Orthodontists in achieving predictable results consistently. All three systems studied herein have achieved planned tooth positions with minor deviations from the predicted values. Thus, all three systems have a clinically reliable prediction software and appliance design.

### Limitations of this study

A factor that can be included in future studies in enamel wear. Co-ordinates plotted on the occlusal plane are subject to changes in microns because of factors like enamel wear.<sup>[23]</sup> The difference between points plotted on an everchanging surface, no matter how small will interfere with the process of superimposition. The methods used in this study can be further be validated using a larger sample size.

Only the crowns of teeth were used in this study. Given the high anatomic variability of the angle between the visible crown and the covered root, the teeth remain partially analyzed.

The remainder of the dentition and inter-arch relationship can be further analyzed. Rotational and vertical discrepancies can be evaluated and compared in addition to the parameters already studied herein. The effect of the duration of finishing stage of treatment, number of arch wires changed, frequency of appointments are factors that can be studied in relation to the clinical reproductive potential of the predicted outcome when comparing all three systems. An in-depth analysis and comparison of the effect robotic and manual wire bending on these systems can be done.

## Conclusion

1. Incognito, iLingual 3D, and Lingual Matrix clinically reproduced the predicted mesiodistal tip, labiolingual inclination, in-out positions of the permanent Maxillary anterior teeth and the Maxillary arch form with an acceptable degree of accuracy. All three systems differed by a small degree in achieving treatment objectives.
2. All three customized lingual appliance systems have room for further refinement in various aspects. The operator element and biological variation among patients must be considered when setting up treatment goals digitally as they will influence the outcome. Given the results of this study it seems there is still a need for manual wire bending and settling elastics to achieve the planned position of teeth despite the advances in digital treatment planning and customized appliance fabrication.
3. The application of a prediction software has made visualizing the outcome of treatment possible right at the stage of examination and diagnosis. The unexplored potential of such fore sight is what the future holds in store for customized lingual appliance systems in the field of Orthodontics.
4. Given the results of this study the null hypothesis was rejected.

## Financial support and sponsorship

Nil.

## Conflicts of interest

There are no conflicts of interest.

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