Original Article

Comparative evaluation of frictional resistance of extracoronal attachments of different designs and lengths in fixed partial denture: A finite element analysis

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Abstract

Aim: The purpose of the study was to evaluate the frictional resistance and the vertical force required to achieve the frictional resistance for different length and designs of extracoronal attachments used in fixed partial denture (FPD).

Setting and Design: Finite element analysis.

Materials and Methods: Four different designs and five different lengths (3 mm, 3.5 mm, 4 mm, 4.5 mm, and 5 mm) of extracoronal attachments for FPD were selected from different manufacturers. Three-dimensional models of all the samples were simulated using Catia V5 software. The properties were incorporated to the software to simulate the clinical conditions. The frictional resistance and the vertical force required to achieve frictional resistance were analyzed using ANSYS workbench 15.0 finite element software.

Statistical Analysis Used: ANOVA and Tukey's *post hoc* test.

Results: The mean microhardness of the Variolink N resin cements were significantly higher than Panavia SA ones ($P < 0.001$). Variolink N cements exhibited lower sorption/solubility than Panavia SA resin cements ($P < 0.05$). The ceramic shade had a significant influence on the microhardness of both cements ($P < 0.001$) but had no significant effect on the sorption/solubility of resin cements ($P > 0.05$).

Conclusion: Interposition of monolithic zirconia decreases the microhardness of resin cement especially Panavia SA. The microhardness decreased in Variolink N with the increase in the chroma saturation of ceramics. However, in Panavia SA, it was altered by the shades. For both cements, there were no statistical differences between the sorption/solubility. There was a reverse correlation between microhardness and water sorption/solubility of both cements.

Keywords: Attachments, fixed dental prosthesis, force, frictional resistance, length and design of attachment

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Submitted: 12-Dec-2019, **Revised:** 08-Feb-2020, **Accepted:** 04-Jun-2020, **Published:** 29-Jan-2021

INTRODUCTION

An extracoronal attachment is a prefabricated attachment where the retentive components are positioned outside the normal contour of the abutment tooth.[1] It is commonly used in situations of pier abutment teeth to manage the stress distribution in fixed partial dentures (FPDs).

Access this article online

Quick Response Code:

Website:
www.j-ips.org

DOI:
10.4103/jips.jips_463_19

How to cite this article: Kumthekar MS, Sanyal PK, Tewary S. Comparative evaluation of frictional resistance of extracoronal attachments of different designs and lengths in fixed partial denture: A finite element analysis. J Indian Prosthodont Soc 2021;21:99-106.

The choice of attachments in FPD depends on the design, length, material, position of attachment, and the periodontal condition of the healthy abutment teeth.

Pier abutment used in rigid FPDs can act as a fulcrum and can cause retention failure of terminal retainer of FPD due to the tensile forces action away from the fulcrum.[2,3] During function, the maximum occlusal force is concentrated at the region of connectors and in the cervical region of the prostheses near the edentulous ridge.[2] Management of stress concentration at connectors is significant for long-term prognosis. The use of nonrigid connectors was suggested to reduce the risk of failures. The selection of appropriate attachment for the particular clinical conditions is a challenge. In addition, the knowledge on frictional resistance and force required to simulate the physiological tooth movement of various attachments is vital in clinical selection.

Frictional resistance is the force which opposes the movement of one body over the other. The estimation of frictional resistance is essential for the understanding and the use of nonrigid connections/attachments in FPD. Few studies have determined these values. Direct clinical measurement of frictional force and stress distribution at these intraoral locations is difficult and not practical. Finite element method (FEM) is an acceptable and established method to determine the frictional resistance attachment used in FPD.

The study was designed with null hypothesis of that there is no significant difference in frictional resistance and in the vertical force for various extracoronal attachments used in FPD. The objective of the study was to evaluate the frictional resistance and the vertical force required to achieve frictional resistance between different lengths of Vario-Soft 3 conical bridge, Preci-Vertix standard, Preci-Vertix P, and PH Conix-PH Intrax attachments.

MATERIALS AND METHODS

The present study was approved by the institutional ethical committee (Ref No. KIMSDU/IEC/09/2018). Four different designs and five different lengths (3 mm, 3.5 mm, 4 mm, 4.5 mm, and 5 mm) of semiprecision extracoronal attachments for FPD [Figures 1 and 2] were selected from different manufacturers [Table 1].

Three-dimensional (3D) models of attachments were created with real dimensions and features using Catia V5 software (Dassault Systemes, French Company) [Figure 3]. All materials of the models were isotropic and homogenous. Twenty models were made of five lengths (3 mm, 3.5 mm, 4 mm, 4.5 mm, and 5 mm) for each of the four design attachments. The models were transferred to ANSYS workbench 15.0 software (Swanson Analysis Inc., Houston, PA, USA) to perform the finite element analysis. All the models were divided into small elements. Each element was considered to be interconnected at a number of discrete

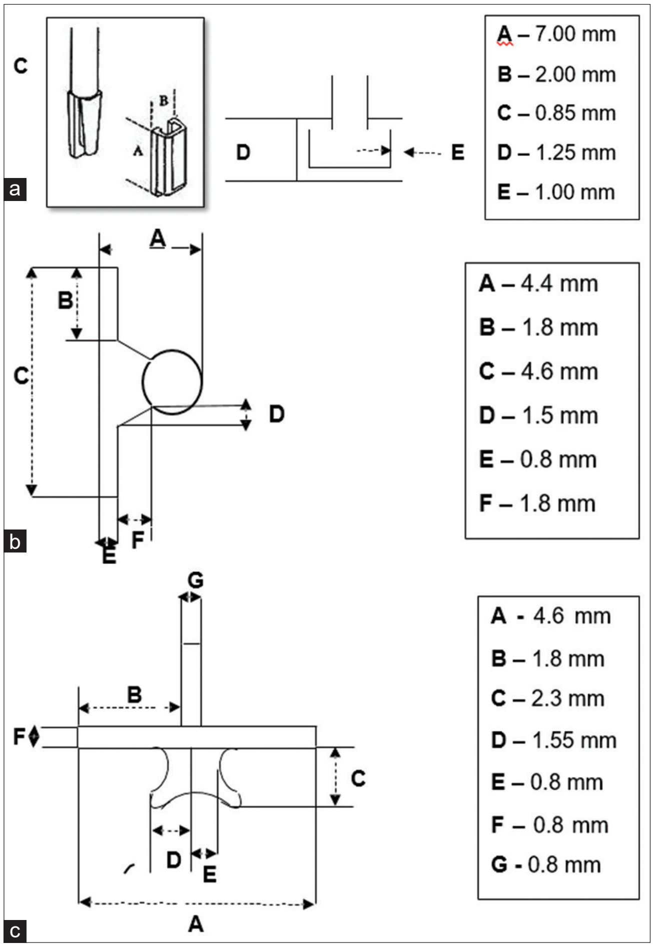

Figure 1: Schematic representation of all attachment designs: (a) PH Conix-PH Intrax, (b) Preci-Vertix standard and Preci-Vertix P (45° inclination), (c) Vario-Soft 3 conical bridge

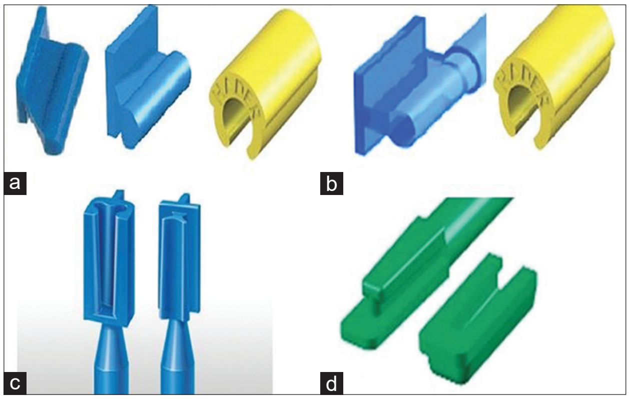

Figure 2: Different designs of attachment (male and female components): (a) Preci-Vertix P, (b) Preci-Vertix standard, (c) Vario-Soft 3 conical bridge, (d) PH Conix-PH Intrax

nodes. The models were meshed, and the maximum von Mises stresses was determined. The model was fixed at the posterior side. The attachment was designed to clinical situation with fixed matrix and movable patrix. The material properties were incorporated to the models to simulate the clinical situation. The coefficient of friction was fixed between the matrix and patrix of the attachment. ANSYS software provides quantitative von Mises stress and pattern of stress distribution with different colors and aids in calculation of frictional resistance [Figure 4]. Frictional resistance was calculated using the following formula:

Frictional resistance = f. S. Vn
- S: Surface area
- V: Speed of the body
- f and n: Coefficients dependent on the length and roughness of the surface.

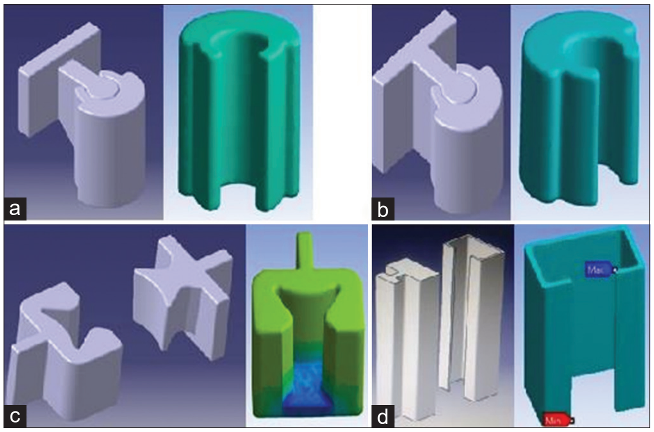

Figure 3: CAD designs of all the four attachments (male and female components): (a) Preci-Vertix P, (b) Preci-Vertix standard, (c) Vario-Soft 3 conical bridge, (d) PH Conix-PH Intrax

The surface area (S) was calculated for each design for each length using the following formula: surface area = Length of the surface in contact × height of the component. The velocity (V) used was 72 µ, and the Poisson's ratio used was 0.25 (f and n) which was constant for all designs and lengths. The data of force and frictional resistance for all attachments of varying lengths were recorded and statistically analyzed by ANOVA one way and Tukey's *post hoc* test.

RESULTS

The descriptive statistics for force and frictional resistance for all designs are listed in Tables 2, 3 and Figure 5. The mean force values were as follows: 10.077 N for Vario-Soft 3 conical bridge, 7.124 N for Preci-Vertex standard, 12.762 N for Preci-Vertix P, and 4.172 N for PH Conix-PH Intrax [Table 2 and Figure 5]. The mean values recorded in Preci-Vertix P was highest among all attachments [Figure 6]. The mean value for frictional resistance [Table 3] was 8.992 N for Vario-Soft 3 conical bridge, 6.730 N for Preci-Vertex standard, 2.420 N for Preci-Vertix P, and 4.892 N for PH Conix-PH Intrax [Figures 7 and 8]. The results [Tables 4 and 5] were statistically significant ($P < 0.05$).

DISCUSSION

The results rejected the null hypothesis of the study. A significant difference was found in frictional resistance

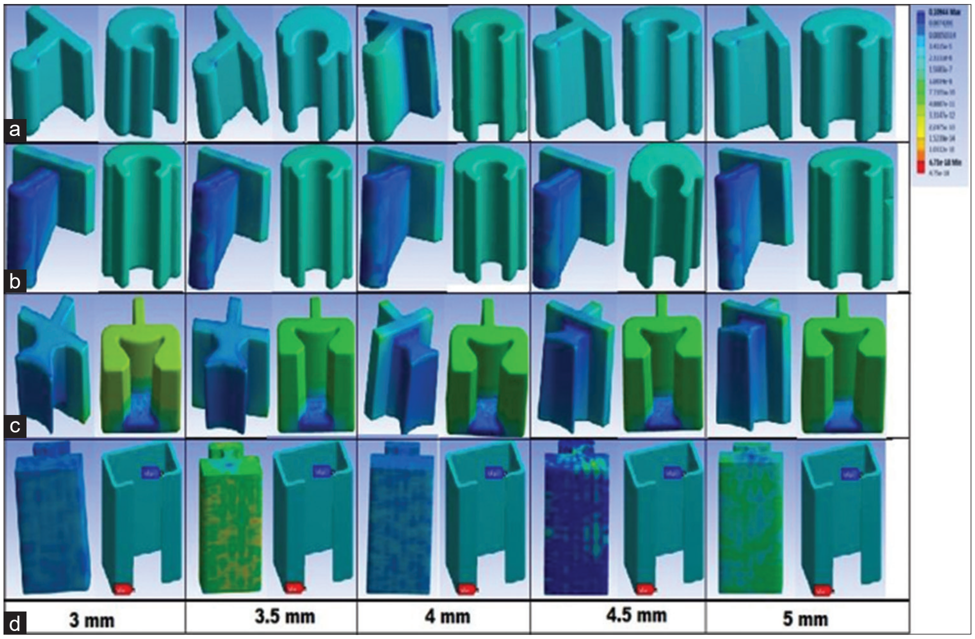

Figure 4: Finite-element analysis for all designs for all lengths: (a) Preci-Vertix standard, (b) Preci-Vertix P, (c) Vario-Soft 3 conical bridge, (d) PH Conix- PH Intrax

and vertical force between the various designs and the lengths of the attachments.

The abutment teeth that support the FPD move within physiological limits during the functional forces. The type of prosthesis, arch curvatures, and position and type of abutment teeth are significant in determining the movement of teeth.[5] In situations of conflicting movements, particularly in long-span FPD, the stresses generated are less accepted by the abutment teeth and it significantly affects the periodontal health of the teeth[6] [Figure 9]. In addition, the tensile forces generated between the retainer and the abutment create extrusive force, especially on the terminal abutments. It can lead to break in marginal seal, caries, and loss of retention.[7] Lin *et al*. reported that a nonrigid connector reduces the stress on abutment teeth and the use of a nonrigid connector has been suggested in the literature to reduce the destructive stresses transferring to the abutment teeth.[8]

Table 1: Details of attachment designs with their respective symbolic representation

Name of attachment	Company name	Symbol
Vario-Soft 3 conical bridge	Bredent, Senden, Germany	D1
Preci-Vertix Standard	Ceka, Waregem, Belgium	D2
Preci-Vertix P	Ceka, Waregem, Belgium	D3
PH Conix-PH Intrax	Microtecnor, Buccinasco, Italy	D4

The biomechanics of attachment varies with the system. The attachment designs permit different movements between the component parts and can modify the stress distribution to the abutment teeth.[9] The results of this study exhibit that the force increases with the moment of the attachment. The resultant force should ideally match the physiological tooth movement to avoid debonding of the terminal abutments. The vertical force and frictional resistance are directly proportional to the length of the attachment or abutment teeth. The increased force and frictional resistance cause increased attachment wear and can make it ineffective in its function. The increased stress leads to the sequalae of clinical failure of abutment and prosthesis.[10] It is essential

Table 2: Descriptive statistics for force among the four groups

Descriptive statistics					
Group	*n*	Minimum	Maximum	Mean	SD
Vario-Soft 3 conical bridge	5	6.0540	12.8340	10.076720	2.5847980
Preci-Vertix standard	5	5.2871	8.5538	7.124260	1.2628737
Preci-Vertix P	5	7.0000	17.0400	12.762000	4.0319747
PH Conix-PH Intrax	5	3.3035	5.5560	4.171500	0.9066244

SD: Standard deviation

Table 3: Descriptive statistics for frictional resistance among the four groups

Descriptive statistics					
Group	*n*	Minimum	Maximum	Mean	SD
Vario-Soft 3 conical bridge	5	6.4000	11.3440	8.991720	1.9248955
Preci-Vertix standard	5	5.0500	8.4100	6.730000	1.3281566
Preci-Vertix P	5	1.9600	2.8800	2.420000	0.3636619
PH Conix-PH Intrax	5	3.6690	6.1150	4.891900	0.9669455

SD: Standard deviation

Table 4: Comparison of force among the four groups by analysis of variance followed by Tukey's *Post hoc* test

ANOVA					
Force	Sum of squares	df	Mean square	*F*	Significant (*P*)
Between groups	206.374	3	68.791	10.853	<0.001*
Within groups	101.419	16	6.339		
Total	307.793	19			

*Statistically significant. ANOVA: Analysis of variance

Multiple comparisons						
Dependent variable: Force Tukey's HSD						
(I) Group	(J) Group	Mean difference (I-J)	SE	Significant (*P*)	95% CI	
					Lower bound	Upper bound
Vario-Soft 3 conical bridge	Preci-Vertix standard	2.9524600	1.5923196	0.286	−1.603198	7.508118
Vario-Soft 3 conical bridge	Preci-Vertix P	−2.6852800	1.5923196	0.362	−7.240938	1.870378
Vario-Soft 3 conical bridge	PH Conix -PH Intrax	5.9052200*	1.5923196	0.009*	1.349562	10.460878
Preci-Vertix standard	Preci-Vertix P	−5.6377400*	1.5923196	0.013*	−10.193398	-1.082082
Preci-Vertix standard	PH Conix -PH Intrax	2.9527600	1.5923196	0.286	−1.602898	7.508418
Preci-Vertix P	PH Conix -PH Intrax	8.5905000*	1.5923196	<0.001*	4.034842	13.146158

*The mean difference is significant at the 0.05 level. CI: confidence interval, HSD: Honest significant difference, SE: Standard error

Table 5: Comparison of frictional resistance among the four groups by analysis of variance followed by Tukey's *post hoc* test

ANOVA

Frictional dimension	Sum of squares	df	Mean square	*F*	Significant (*P*)
Between groups	116.471	3	38.824	23.758	<0.001*
Within groups	26.146	16	1.634		
Total	142.616	19			

*Statistically significant. ANOVA: Analysis of variance

Multiple comparisons

Dependent variable: Fictional dimension Tukey's HSD

(I) group	(J) group	Mean difference (I-J)	SE	Significant (*P*)	95% CI	
					Lower bound	Upper bound
Vario-Soft 3 conical bridge	Preci-Vertix standard	2.2617200	0.8084835	0.056	−0.051367	4.574807
Vario-Soft 3 conical bridge	Preci-Vertix P	6.5717200*	0.8084835	<0.001*	4.258633	8.884807
Vario-Soft 3 conical bridge	PH Conix -PH Intrax	4.0998200*	0.8084835	0.001*	1.786733	6.412907
Preci-Vertix standard	Preci-Vertix P	4.3100000*	0.8084835	<0.001	1.996913	6.623087
Preci-Vertix standard	PH Conix -PH Intrax	1.8381000	0.8084835	0.146	−0.474987	4.151187
Preci-Vertix P	PH Conix -PH Intrax	−2.4719000*	0.8084835	0.034*	−4.784987	−0.158813

*The mean difference is significant at the 0.05 level. HSD: Honest significant difference, SE: Standard error, CI: confidence interval

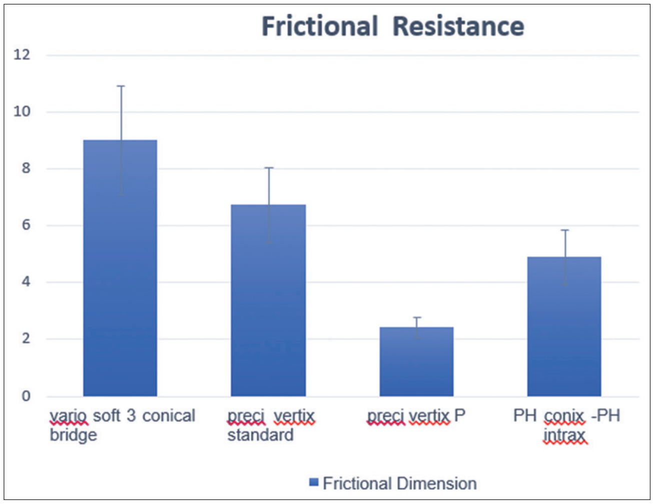

Figure 5: Graphical representation of descriptive statistics for frictional resistance among the four groups

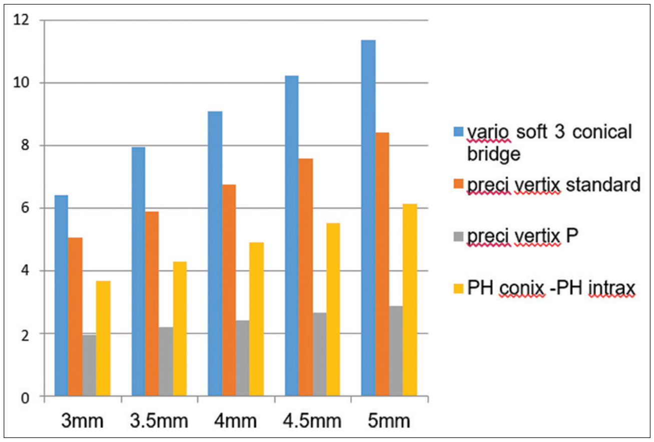

Figure 7: Graphical representation of force at various lengths among the four groups

to select an attachment with ideal frictional resistance that matches the physiological tooth movement and transfer the forces that are acceptable to abutment teeth.[11]

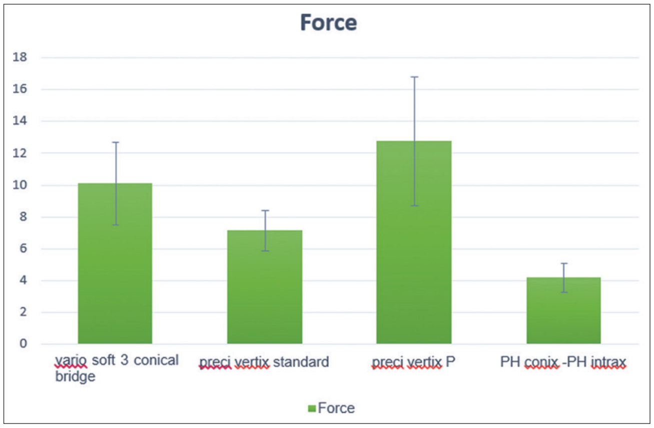

Figure 6: Graphical representation of descriptive statistics for force among the four groups

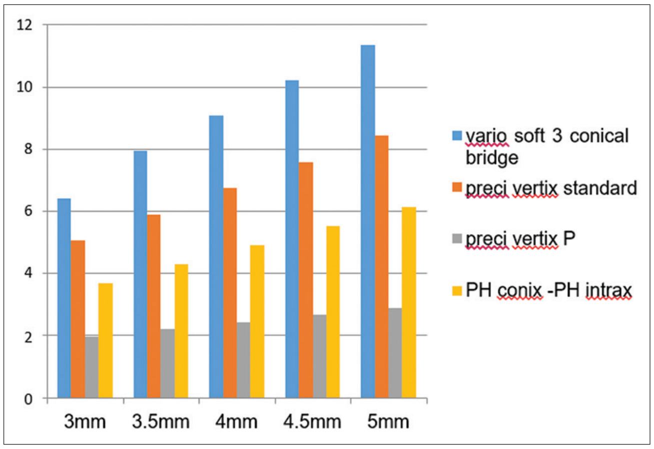

Figure 8: Graphical representation of frictional resistance at various lengths among the four groups

The movements in attachment can occur in both horizontal and vertical directions.[12,13] It is essential that these movements are within the physiological limits of periodontal ligament. Since the frictional resistance increases with vertical movement, the attachment

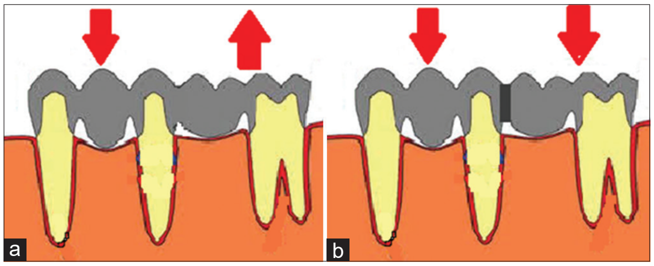

Figure 9: Effect of long-span fixed dental prosthesis with and without the use of attachments on force application: (a) without the use of attachment, (b) with the use of attachment

selection is predominant with vertical movement and less consideration is provided to horizontal movement.[14-16]

FEM has been proven to be a useful tool in investigating complex *in vitro* and *in vivo* investigations. It is more accurate and it is influenced by the model geometry, number of nodes, elements, and input properties.[17,18] FEM has limitations of *in vitro* study design and cannot be equated to actual clinical situation. It requires technical expertise to design and execute the study.[19,20] 3D models were designed with Catia V5 software. The frictional resistance and the force were analyzed using ANSYS workbench 15.0 software. ANSYS Fluent software reduces the converging time compared to that of other software.

The movement of attachments should match the movement of tooth to achieve the optimal health of abutment teeth. It is essential to select appropriate design and length of attachment for particular position of teeth in the arch. The results of the study exhibited highest frictional resistance for Vario-Soft 3 conical bridge followed by Preci-Vertix standard and PH Conix-PH Intrax and Preci-Vertix P. The vertical force was greater in Preci-Vertix P, followed by Vario-Soft 3 conical bridge, Preci-Vertix standard, and PH Conix-PH Intrax. Clinically, if the more movement was anticipated, higher friction resistance attachment has to be selected and vice versa for lower physiological movement.[1] The anterior teeth comparatively have higher tooth movement that mandates strong frictional resistance attachment while the posterior teeth has lower movement that demands weaker frictional resistance attachment [Figure 9]. In any situations, the ideal length of attachment should be between 3 and 5 mm to achieve the optimum function. In addition, these lengths aid in preventing gingival inflammation by achieving minimum 2 mm space to between the gingival floor of attachment and marginal gingiva.[21]

The results of the study aid in clinical selection of the attachment in accordance with the length of the abutment teeth, frictional resistance, and estimated forces. If the length of abutment is greater than 5 mm, Preci-Vertix P is preferred for anterior teeth, Preci-Vertix standard or PHConix-PH Intrax for premolar, and Vario-Soft 3 conical bridge for molar. If the length of the abutment is <5 mm, attachment with more frictional resistance should be selected. Vario-Soft 3 conical bridge for anterior and posterior teeth can be ideal to balance the movement and force generated within abutments. The study has a major limitation of *in vitro* study design. Future clinical studies with long-term follow-up are essential for wider clinical acceptance.

CONCLUSION

The force and frictional resistance increase with the length of the attachment. Highest frictional resistance was observed in Vario-Soft 3 conical bridge and force is highest in Preci-Vertix P.

Acknowledgment

The authors thank CADD Centre for their support in terms of CAD/CAM and Mr. Muzzamil Shekh and Mr. Rahul Magdum for their engineering support in analysis.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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