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

Minal Sanjay Kumthekar, Pronob Kumar Sanyal, Shivsagar Tewary
Department of Prosthodontics and Crown and Bridge, School of Dental Sciences, KIMS-DU, Karad, Maharashtra, India

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

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

\[
\text{Frictional resistance} = f \cdot S \cdot V \cdot n
\]

- \( S \): Surface area
- \( V \): Speed of the body
- \( f \) and \( n \): Coefficients dependent on the length and roughness of the surface.

The surface area (\( S \)) was calculated for each design for each length using the following formula: surface area = Length of the surface in contact \( \times \) height of the component. The velocity (\( V \)) used was 72 \( \mu \), 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.
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. 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 [5] [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. 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 [6].

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. [14] It is essential

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     |

Table 2: Descriptive statistics for force among the four groups

| 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  |

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

| 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  |

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

| 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  |             |              |                |

Multiple comparisons

| (I) Group                  | (J) Group       | Mean difference | 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 | -7.2490938 | 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
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Table 5: Comparison of frictional resistance among the four groups by analysis of variance followed by Tukey’s post hoc test

| 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

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

| (I) group          | (J) group          | Mean difference (I-J) | SE       | Significant (P) | 95% CI Lower bound | 95% CI 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

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

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

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

Figure 8: Graphical representation of frictional resistance at various lengths among the four groups
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.[9] 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.

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Conflicts of interest

There are no conflicts of interest.

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