

# Stress distribution among periodontally compromised abutments: A comparative study using three-dimensional finite element analysis

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## Abstract

**Aims:** The aim of the study was to evaluate the stress distribution patterns in teeth and supporting structures of fixed prosthesis and design modifications in a fixed prosthesis with either normal or reduced bone support of an additional abutment. Study was also undertaken to disprove Ante's law. **Materials and Methods:** Main models and variations of main models (modification 1, 2, 3, 4, 5, 6, 7, 8) were subjected to 200 N at angulations of 90° and 15° on functional cusps. Results for each loading were obtained as stress distribution color images and numerical values were recorded. A three-dimensional finite element analysis study of variations of normal models was performed using two finite element softwares, namely PRO-Engineer wildfire version 1.0 manufacturer: Parametric technology corporation, Needham, MA 02494 U.S.A. **Results:** When periodontal compromised abutment teeth was splinted with an additional abutment an increase of stress was observed in periodontally compromised abutments so an additional abutment is not required. Eventhough the pericemental area of compromised abutments with an additional abutment (canine) was more than the combined pericemental area of pontics to be replaced, stress generated was more on abutments. This disproves Ante's law. Hence, it may be a reference, but should not be the ultimate criterion in determining the number of multiple abutments. **Conclusions:** When periodontal compromised abutment teeth was splinted with an additional abutment an increase of stress was observed in periodontally compromised abutments so an additional abutment is not required. Even though the pericemental area of compromised abutments with an additional abutment (canine) was more than combined pericemental area of pontics to be replaced, stress generated was more on abutments. This disproves Ante's law. Hence, it may be a reference, but should not be the ultimate criterion in determining the number of multiple abutments.

**Keywords:** Abutment, stress, three-dimensional finite element

## Introduction

A fixed partial denture usually requires the splinting of additional abutments to overcome the loss of bone support of an abutment. It has been contended that splinting of abutments increases their resistance to applied force of teeth and supporting structure. Ante<sup>[1]</sup> suggested that it was unwise to provide a fixed partial denture when the root

surface area of the abutments was less than the root surface area of the teeth being replaced. This has been adopted and reinforced by others as "Ante's law." Ante's law has been a clinical guideline to determine the number of abutments involved in the fabrication of a fixed partial denture. As the edentulous span of a fixed partial denture increased, increasing the number of abutments was recommended. There is insufficient scientific evidence to evaluate the validity of Ante's law.

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The purpose of this study was to analyze the stress levels in the periodontium of fixed partial denture and to predict how the addition of an additional abutment in an fixed partial denture with reduced bone support modifies these stresses and their distribution and also to evaluate the validity of Ante's law.

## Materials and Methods

In this study, a typical fixed partial denture was simulated three dimensionally using the PRO-Engineer wildfire version 1.0 manufacturer: Parametric technology corporation, Needham, MA 02494 U.S.A software. Alveolar bone, periodontal ligament, was also modeled three dimensionally. All vital tissues were assumed elastic, isotrophic, and homogenous. Thickness of the periodontal ligament used in this study was 0.2 mm. Another software IDEAS ver 8.0 manufacturer: International design engineering and services Glasgow G51 1HD Scotland was used for analyzing stress and

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for interpretation in megapascal. Experimental models were created with varying degrees of loss on periodontal support on first premolar and second molar abutments. Four clinical situations were created. They are normal first premolar and 1/3 loss on second molar, 1/3 loss on first premolar and second molar, normal first premolar and 2/3 loss on second molar, 1/3 loss on first premolar and 2/3 loss on second molar. Load distribution was compared among them self with and without the addition of extra-abutment. A canine was added to see if it acts as a splint thereby reducing the stresses and their even distribution.

A typical Pro-E analysis has three distinct steps such as:

Pre-processing and modeling

Processing and meshing

Post-processing and analysis.

Pre-processing involves generation of points along the X-, Y-, and Z-axis of a computer screen which are subsequently connected to obtain a line diagram on a tooth. Connecting of the lines creates areas and volumes are created by areas and volumes were further joined to form an object.

Modeling involves assembling teeth namely mandibular first premolar and second molar without crown preparation and mandibular premolar, second molar with crown preparations restored with a fixed partial denture. Thickness of fixed partial denture was standardized to 0.3 mm. Mandibular first premolar and second molar with extra-abutment canine were also modeled. Surface of each root of tooth was made equal to thickness of periodontal ligaments and roots of each tooth were modeled with alveolar bone. Pre-processed model was subjected to processing by conversion of geometric data into graphical data by finite element software. Elements were present in graphical data. This step is called as meshing. Material properties were incorporated after meshing. Values of enamel, dentin, pulp, alveolar bone, nickel-chromium, were used. Values of Young's modulus in megapascal were given. [Table 1]. Post-processing and analysis is the last stage. Analysis was performed with 200 N occlusal load at angulations of 90° and 15° to mimic clinical conditions. Young's modulus and Poisson's ratio of nickel-chromium alloy of fixed partial denture was used in this study. The values that have been used for periodontal ligament in various finite element analysis (FEA) studies range from 0.07 to 1.750 MPa. Alveolar bone was modeled with the help of the dentulous skull. The properties of these were added to the three-dimensional model during analysis. Lower border of the model was fixed in all directions to resist finite element model for occlusal load.

## Results

Simulated three-dimensional models were loaded with a magnitude of 200 N occlusal load at angulations of 90°

and 15°. Results were obtained as stress distribution colored images and numerical values were recorded. Tables 2 and 3 shows; in normal situations load borne by individual abutments is more compared to when they are connected with prosthesis. The load on each abutment was reduced

**Table 1: Values used for three-dimensional model**

Material properties	Young's modulus	Poisson's ratio
Enamel	83,000 MPa	0.33
Dentin	18,600 MPa	0.31
Pulp	2.03 N/mm <sup>2</sup>	0.45
PDL	50 MPa	0.49
Cortical bone	101000 MPa	0.30
Cancellous bone	250 MPa	0.30
Glass ionomer cement	7560 MPa	0.35
Nickel-chromium alloy	245,000 MPa	0.32

**Table 2: Main model: Without fixed partial denture (on individual first premolar and second molar teeth). Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	47.2	50.4
First premolar	40.5	60.5
Combined	87.7	110.9
Maximum stresses generated	135	202

**Table 3: Main model: Normal first premolar and second molar with fixed partial denture. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	37.2	21.1
First premolar	31.9	27.2
Combined	69.1	48.9
Maximum stresses generated	106	109

**Table 4: Experimental model: Normal first premolar and 1/3 periodontal support removed on second molar. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	116	86
First premolar	130	120
Combined	246	206
Maximum stresses generated	290	344

in both angulations at 15° and 90° (47.2-37.2 N/mm<sup>2</sup> on molar, 40.5-31.9 on premolar at 15° and 50.4-21.1 N/mm<sup>2</sup> on molar, 60.5-27.2 N/mm<sup>2</sup> on premolar at 90°). Hence, fabricating a fixed prosthesis reduces the load on each abutment.

Table 4 shows; between normal premolar and 1/3 periodontal support removed on second molar load transferred to premolar is more because the pericemental area that is intact in molar is less compared to premolar (116 N/mm<sup>2</sup> at 15°, 86 N/mm<sup>2</sup> at 90° on second molar, whereas 130 N/mm<sup>2</sup> at 15°, 120 N/mm<sup>2</sup> at 90°) [Figure 6]. Table 5 shows; when a canine is added to the above model load distribution on individual abutments decreases (116-75.9 N/mm<sup>2</sup> on molar, 130-86.8 N/mm<sup>2</sup> on premolar at 15° and 86-67.9 N/mm<sup>2</sup> on molar, 120-79.2 N/mm<sup>2</sup> on premolar at 90°) [Figure 6a].

Table 6 shows; when second molar and first premolar is 1/3 involved, load taken by premolar is more as compared to molar (for both types of forces at 15° and 90°) [Figure 7]. This situation resembles results normal standard model but at a reduced pericemental area for both abutments. Hence, compared to results of normal standard model combined load taken by abutments is considerably more (351 N/mm<sup>2</sup> + 297 N/mm<sup>2</sup>) as compared combining to normal (69.1 N/mm<sup>2</sup> + 48.9 N/mm<sup>2</sup>). This load distribution (471 N/mm<sup>2</sup> + 317 N/mm<sup>2</sup>) increases if in such situation an extra-tooth is taken up as an abutment (canine).

Table 7 shows; the individual load on each abutment (molar + premolar) is increased when an extra-tooth is added to the above situation at 15° (164-194 N/mm<sup>2</sup> on molar at 15°, 187-191 N/mm<sup>2</sup> on premolar) at 15° and individual load on each abutment (molar + premolar) is decreased when canine is added to the above situation at 90° (137-125 N/mm<sup>2</sup> on molar at 90°, 160-109 N/mm<sup>2</sup> on premolar at 90°) [Figure 7a].

Table 8 shows; when molar is 2/3 involved and normal premolar are subjected to stresses load taken by premolar is more for both types of forces at 15° and 90° when compared with normal model combined stress increased from 69 N/mm<sup>2</sup> to 137.4 N/mm<sup>2</sup> at 15° and 48 N/mm<sup>2</sup> to 95.2 N/mm<sup>2</sup> at 90° [Figure 8]. Table 9 shows; individual load on each abutment (molar + premolar) is increased when extra-tooth is added to the above situation at 15° (77.3-99 N/mm<sup>2</sup> on second molar at 15° and 60.1-119 N/mm<sup>2</sup> on first premolar) [Figure 8a]. It also increased when canine is added to the above situation at 90° (55.5-87 N/mm<sup>2</sup> on second molar 39.7-117 N/mm<sup>2</sup> on first premolar).

Table 10 shows; when 2/3 periodontal support removed on second molar and 1/3 periodontal support removed on premolar, individual load on premolar increased at both the angulations 15° and 90° compared to molar (139 N/mm<sup>2</sup> on second molar whereas 208/mm<sup>2</sup> on first premolar at 15° and

128 N/mm<sup>2</sup> on second molar whereas 171 N/mm<sup>2</sup> on first premolar at 90°) [Figure 9]. Table 11 shows; when a canine is added to the above situation load increased on second molar from 139 N/mm<sup>2</sup> to 190 N/mm<sup>2</sup> at 15° and 128 N/mm<sup>2</sup>

**Table 5: Experimental model: Normal first premolar and canine and 1/3 periodontal support removed on second molar. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	75.9	67.9
First premolar	86.8	79.2
Canine	43.4	45.2
Combined	194.7	189.1
Maximum stresses generated	217	226

**Table 6: Experimental model: 1/3 periodontal support removed on both first premolar and second molar. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	164	137
First premolar	187	160
Combined	351	297
Maximum stresses generated	467	457

**Table 7: Experimental model: 1/3 periodontal support removed on both first premolar and second molar-normal canine. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	194	125
First premolar	191	109
Canine	86.3	83.5
Combined	471.3	317.5
Maximum stresses generated	431	417

**Table 8: Experimental model: Normal first premolar and 2/3 periodontal support removed on second molar. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	77.3	55.5
First premolar	60.1	39.7
Combined	137.4	95.2
Maximum stresses generated	172	159

**Table 9: Experimental model: Normal first premolar and canine and 2/3 periodontal support removed on second molar. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	99	87
First premolar	119	117
Canine	79.3	43.8
Combined	297.3	248.4
Maximum stresses generated	396	292

**Table 10: Experimental model: 1/3 on both first premolar and 2/3 periodontal support removed on second molar. Unit: N/mm<sup>2</sup>**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	139	128
First premolar	208	171
Combined	347	299
Maximum stresses generated	462	757

**Table 11: Experimental model: 1/3 periodontal support removed on first premolar and 2/3 removed on second molar and normal canine**

Abutments	Stresses obtained at 15° and 90° with 200 N load	
	200 N at 15°	200 N at 90°
Second molar	190	165
First premolar	168	124
Canine	105	82.5
Combined	463	371.5
Maximum stresses generated	421	412

to 165 N/mm<sup>2</sup> at 90° whereas on first premolar load decreased (208-168 N/mm<sup>2</sup> at 15° and 171-124 N/mm<sup>2</sup> at 90°) [Figure 9a].

## Discussion

The treatment of partial edentulism with a fixed partial dentures has always been a highly recommended treatment plan. Partial edentulism can be rehabilitated with fixed partial denture if the edentulous site is bounded by sound abutment teeth, which on evaluation satisfy all criteria for a fixed prosthesis therapy. Main criteria are, it should satisfy Ante's law, presence of sound periodontium and area of periodontal ligament attachment to the bone. It is advocated that when supporting bone has been lost because of periodontal disease, teeth involved may have a lessened capacity to serve as abutments. Abutment teeth

are unsuitable because they can be "overstressed" from the additional forces applied to teeth supporting a fixed partial denture. This may be attributed to the resistance to the impact of occlusal forces called as "shock absorber effect" as documented by Carranza, Newman. On the contrary, there is evidence that teeth with compromised periodontal support can serve successfully as the fixed bridge abutments<sup>[2-7]</sup> but clinicians continue to avoid using periodontally compromised abutment teeth.

The degree of periodontal compromise in abutment teeth to be utilized in a fixed partial denture is however, restricted to grade 1 or 2 mobility. Though compromised, abutments are utilized only in a status quo to prevent a further increase in mobility; the redistribution of forces to these teeth through the prosthesis to underlying structure needs an evaluation.

This study evaluates to determine the ratio of load taken up by each abutment when they are connected through fixed partial denture and are involved with varying degrees of loss of periodontium. Study evaluates supporting structures and to how the addition of multiple abutments with either normal or reduced bone support modifies these stresses and distribution. Earlier studies<sup>[2]</sup> were carried out on normal periodontal support, conversely Wylie *et al.*, did studies on fixed partial splints with normal and reduced bone support using a photo elastic model at various levels of periodontal support, but with Photo elastic model it is virtually impossible to proportion the model stiffness in the correct manner. Due to this drawback photo elastic method is considered inadequate to give correct and reliable results about stress distribution. Stress analysis by this method is limited in their scope and are inappropriate in dental structure that are of an irregular form. However, the finite element method is a modern technique of numerical stress analysis and has the great advantage of being applicable to solids of irregular geometry and heterogeneous material properties. So it was chosen to compare the load distribution between abutments with normal and periodontally compromised abutments and also predict how an addition of abutment to either normal or reduced bone support modifies these stresses and their distribution. Application of finite element method in prosthetic dentistry have found in studies.<sup>[8,9]</sup> It is important to keep in mind that finite element method will give results based upon nature of modeling system and for that reason, procedure of modeling is most important.<sup>[10]</sup> Three-dimensional modeling is preferred over two-dimensional modeling as it has significant short comings. The human tooth is highly irregular so it cannot be represented in a two-dimensional space and the actual loading cannot be simulated without taking the third dimension into consideration. Therefore, a three-dimensional modeling within the actual dimensions should be preferred for a reliable analysis.



A fixed prosthesis was designed to replace second premolar and first molar with first premolar and second molar as abutments with the healthy periodontium. The teeth are simulated to be prepared in accordance to standard principles involved in tooth preparation. After preparation fixed prosthesis was cemented to abutments.

Experimental models were created with varying degrees of loss on periodontal support on first premolar and second molar abutments. Four clinical situations were created. They are normal first premolar and 1/3 loss on second molar, normal first premolar and 2/3 loss on second molar, 1/3 loss on first premolar and second molar, 1/3 loss on first premolar and 2/3 loss on second molar, Load distribution among these abutments were compared with normal abutments. They were also compared among themselves with and without the addition of extra-abutment. A canine was added to see if it acts as a splint thereby reducing the stresses and their even distribution.

To this simulated prosthesis a uniform load of 200 N was applied 90° and 15° angulations of tooth to simulate a range of masticatory loads.<sup>[11]</sup> These loads caused stresses in the fixed prosthesis and periodontium which revealed as color coded patterns. The color coded scheme allows visualization and tabulation of stresses at any desired point. As this study deals with periodontium, a reference point was taken at the abutment retainer cemented interface as mentioned in earlier studies.<sup>[11]</sup>

In study model table loading was done before preparation of tooth and also after preparation of tooth with fixed partial denture. Stress distribution and concentrations produced in periodontium of abutment teeth by an occlusal force were decreased by placement of fixed partial denture at 15° (47.2-37.2 MPa on premolar) and 90° loading (50.4-21.1 MPa on molar 60.5-27.2 MPa) Result was in accordance with earlier study.<sup>[1,12]</sup>

In experimental model [Table 4], where molar has lost 1/3 loss of periodontal support and normal premolar as abutments load taken by premolar is more than molar when compared to main model with fixed prosthesis [Figure 6]. In Table 5, where an additional abutment canine is added to normal first premolar and 1/3 loss of periodontal support on second molar, load taken by molar and premolar is shared among three teeth [Figure 6a]. As the pericemental area of abutments is more than tooth being replaced, load on molar and premolar has become less when compared to Table 4. This proves Ante's law.<sup>[13]</sup>

In Table 6 where both the abutments are 1/3 periodontally involved load taken by premolar is more compared to molar for both types of forces these results resemble the main model [Table 3] but with reduced pericemental area [Figure 7]. When compared to results of the main model

with fixed prosthesis combined load taken by abutments is considerably more as compared to normal abutments. Table 7 shows the individual load on each abutment (molar + premolar) is increased when an extra-tooth is added to the above situation at 15° and individual load on each abutment (molar + premolar) is decreased when canine is added to the above situation at 90° [Figure 7a].

In Table 8 where second molar has lost 2/3 loss of periodontal support and normal premolar as abutments second molar is taking up more load than first premolar [Figure 8]. It can be concluded that following increase of alveolar bone loss on second molar in both 1/3 and 2/3 situations with normal periodontal support on premolar load taken by premolar is more. This is because second molar is double rooted and has more surface area than premolar, which has a single root. This is accordance with earlier studies.<sup>[14]</sup>

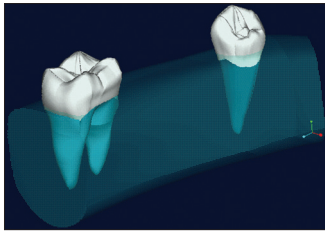
In Table 9 where an additional abutment was added (canine) to normal premolar and 2/3 loss of periodontal support on molar, load on molar and premolar is more and premolar is more although the pericemental area of three abutments are more than teeth being replaced compared to Table 6. This disproves Ante's law [Figure 8a].

In Table 10 where 2/3 loss of periodontal support on molar and 1/3 loss on premolar individual load on molar and premolar increased at 15° and 90° compared to main model [Table 3]. Reduced bone support increased maximum stresses generated in fixed partial denture and supporting structures [Figure 9]. In addition forces applied to supporting bone may be magnified because of greater leverage associated with lengthened clinical crown, which explains the increased stress generated with less periodontal support.<sup>[15]</sup>

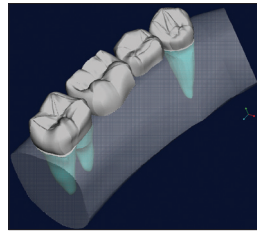
In Tables 9 and 11 when an extra-tooth is added, the individual load on each abutment increased. This is in contradictory to the earlier studies,<sup>[16,17]</sup> where additional abutment decreased maximum stresses generated in periodontium but this is not reliable as it is a two-dimensional finite element study. So splinting an additional abutment did not reduce the maximum stresses in periodontium.<sup>[16-18]</sup>

In Tables 9 and 11 although the pericemental area of abutments is more than the teeth being replaced stress was more when compared without an additional abutment. This disproves Ante's law. Hence, it may be a reference, but should not be ultimate criterion in determining the number of multiple abutments.<sup>[18]</sup>

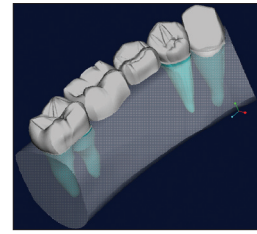
FEA is a numerical tool and any results obtained are extra-polated to a clinical situation unless it is verified more complex and numerical analysis supported by validation experiments are needed to conform the findings. Other parameters such as occlusion should be evaluated.



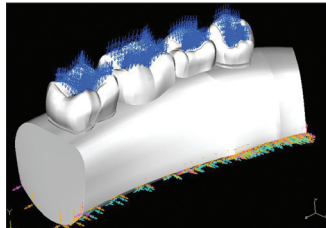
**Figure 1:** Normal first premolar and second molar model without Fixed partial denture



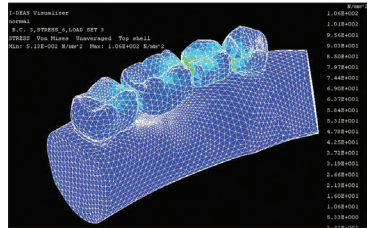
**Figure 2:** Normal first premolar and second molar with Fixed partial denture



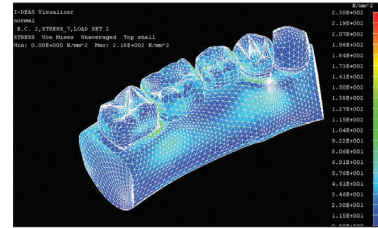
**Figure 3:** Normal first premolar, second molar, and canine with Fixed partial denture



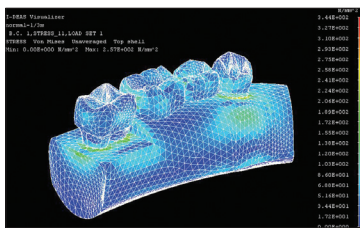
**Figure 4:** Loading



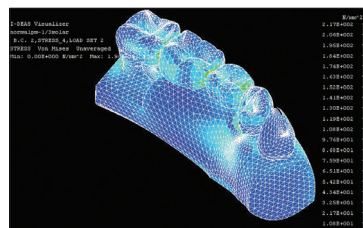
**Figure 5:** Normal model with Fixed partial denture



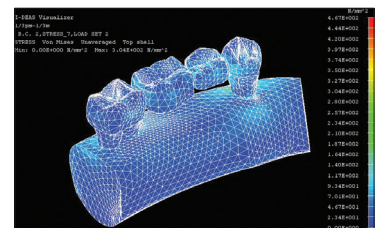
**Figure 5a:** Normal model with Fixed partial denture



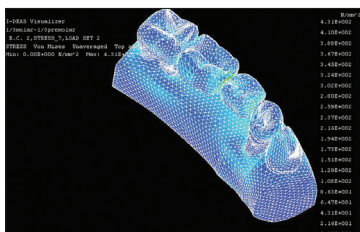
**Figure 6:** Design modification with normal premolar and 1/3 Periodontal ligament removed on second molar



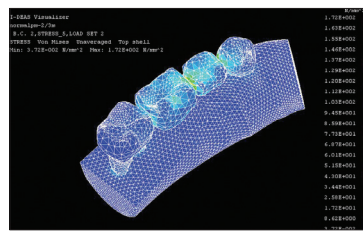
**Figure 6a:** Design modification with normal premolar and 1/3 Periodontal ligament removed on second molar with normal canine



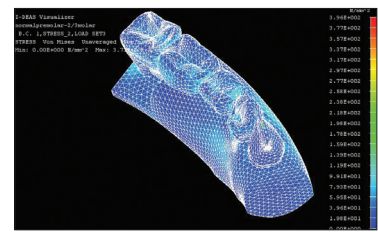
**Figure 7:** Design modification with 1/3 Periodontal ligament removed on premolar and second molar



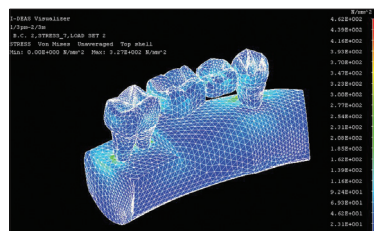
**Figure 7a:** Design modification with 1/3 Periodontal ligament removed on premolar and second molar with normal canine



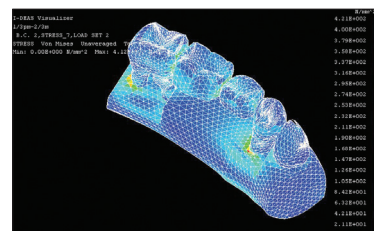
**Figure 8:** Design modification with normal premolar and 2/3 Periodontal ligament removed on second molar



**Figure 8a:** Design modification with normal premolar and 2/3 Periodontal ligament removed on second molar with normal canine



**Figure 9:** Design modification with 1/3 PDL removed on premolar and 2/3 PDL removed on second molar



**Figure 9a:** Design modification with 1/3 PDL removed on premolar and 2/3 PDL removed on second molar with normal canine

## Summary and Conclusion

They were also analyzed to check the validity of Ante's law from the above study it was concluded that:

When fixed partial denture was placed on normal teeth and subjected to loading stress generated was less compared to individual teeth.

When periodontally compromised abutment teeth was splinted with an additional. Abutment stress generated was more due to loss of bone support. In addition, forces applied to supporting bone may be magnified because of greater leverage associated with lengthened clinical crown, which explains the increased stress generated with less periodontal support.

Following an increase of loss of periodontal support on second molar abutment (with normal first premolar) stress concentration of first premolar was more than molar. Although there was loss of periodontal support on both abutments stress concentration of first premolar was more than the molar. This is because of the reason that second molar has two roots and first premolar premolar has one root. Hence, surface area of tooth influences stress concentration.

Although the combined pericemental area of periodontally compromised abutments with an additional abutment (canine) was more than combined pericemental area of pontics to be replaced, stress generated was more on abutments. This disproves Ante's law. Hence, it may be a reference, but should not be the ultimate criterion in determining the number of multiple abutments.

### Clinical implications

Splinting an additional abutment to periodontally compromised abutments is not required when primary abutments has lost 2/3 of periodontal ligament. It is beneficial by splinting additional abutment when primary abutment has lost 1/3 of periodontal ligament.

Ante's law may be a reference, but should not be an ultimate criterion in determining the number of abutments.

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