Effect of Framework in an Implant-Supported Full-Arch Fixed Prosthesis: 3D Finite Element Analysis

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Purpose: The aim of this study was to analyze through a three-dimensional finite element analysis (3D-FEA) stress distribution on four implants supporting a full-arch implant-supported fixed prosthesis (FFP) using different prosthesis designs. **Materials and Methods:** A 3D edentulous maxillary model was created and four implants were virtually placed into the maxilla and splinted, simulating an FFP without framework, with a cast metal framework, and with a carbon fiber framework. An occlusal load of 150 N was applied, stresses were transmitted into peri-implant bone, and prosthodontic components were recorded. **Results:** 3D-FEA revealed higher stresses on the implants (up to +55.16%), on peri-implant bone (up to +56.93%), and in the prosthesis (up to +70.71%) when the full-acrylic prosthesis was simulated. The prosthesis with a carbon fiber framework showed an intermediate behavior between that of the other two configurations. **Conclusion:** This study suggests that the presence of a rigid framework in full-arch fixed prostheses provides a better load distribution that decreases the maximum values of stress at the levels of implants, prosthesis, and maxillary bone. *Int J Prosthodont 2015;28:627–630. doi: 10.11607/ijp.4345*

Several authors regard occlusal loading of dental implants as a critical influence during the surgical healing phase and a factor in its subsequent long-term successful outcome.[1] This is particularly relevant when employing an immediate loading protocol, and prosthodontic design considerations need to be accurately planned to control loading conditions.[2]

The aim of this study was to understand presumed biomechanical advantages associated with the use of or decision not to use framework and the type of framework material employed.

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Materials and Methods

A three-dimensional (3D) edentulous maxillary model was created using customized computer software (FEMAP 8.3, Siemens).

A 3D laser scanner (Range 7 3D Laser Scanner, Konica Minolta) was used to obtain the digital shape of a full-arch fixed prosthesis (FFP). The finite element model was obtained by matching the scan data with a digital skull model. A castable acrylic framework was also scanned to replicate the clinical use of a metal framework for FFP.[3]

Four implants (length: 15 mm) were virtually placed into the maxilla and splinted with an FFP of 12 masticatory units. Prosthodontic cantilevers were avoided. The implant platforms were placed at the level of the canine and the molar area. The distal implants were tilted mesiodistally with a 45-degree inclination, placing them parallel to the mesial wall of the maxillary sinus as explained in previous papers.[4,5]

With all other parameters kept constant, three different configurations were tested: (1) a full-arch acrylic resin prosthesis, (2) acrylic resin veneering material with metal framework, and (3) acrylic resin veneering material with a carbon fiber framework.

The mesh value was 140,000 units. The elastic moduli were equivalent to 103,400 MPa for titanium, 13,700 MPa for cortical bone, 1,370 MPa for cancellous bone, 2,400 MPa for acrylic resin, 125,000 for metal framework, and 40,000 for carbon fiber framework.

Table 1 Von Mises Stress Values (MPa) and Differences in Stress by Resin Configuration (%)

	Compact bone				**Cancellous bone**			
	All acrylic prosthesis				All acrylic prosthesis			
Position	Implant	Bone	Resin		Implant	Bone	Resin	
26	91.46	25.92	12.63		89.48	11.62	12.64	
23	21.59	12.1	0.99		23.37	4.69	1.26	
13	5.1	0.84	0.5		7.45	0.61	1.16	
16	0.64	0.35	0.07		2.49	0.28	0.22	
	Metal framework prosthesis				Metal framework prosthesis			
	Implant	Bone	Resin	Metal	Implant	Bone	Resin	Metal
26	67.52 (−26.18)	16.53 (−36.23)	10.14 (−19.71)	20.43 (+61.76)	66.47 (−25.71)	9.55 (−17.81)	10.13 (−19.86)	20.97 (+65.9)
23	9.01 (−58.27)	5.8 (−52.06)	0.29 (−70.71)	4.98 (+403.03)	10.47 (−55.16)	2.02 (−56.93)	0.63 (−50)	9.7 (+669.84)
13	6.34 (+24.3)	0.71 (−15.48)	0.15 (−70)	3.43 (+586)	10.48 (+40.67)	0.53 (−13.11)	0.25 (−78.45)	5.82 (+401.72)
16	2.37 (+270.31)	1.05 (+200)	0.08 (+14.29)	1.17 (+1,571.43)	7.52 (+202)	0.86 (+207.14)	0.14 (−36.36)	2.33 (+959.09)
	Carbon fiber framework prosthesis				Carbon fiber framework prosthesis			
	Implant	Bone	Resin	Carbon fiber	Implant	Bone	Resin	Carbon fiber
26	71.68 (−21.63)	21.04 (−18.83)	10.25 (−18.84)	20.81 (+64.77)	78.66 (−12.09)	10.34 (−11.02)	10.24 (−18.99)	18.95 (+49.92)
23	12.45 (−42.33)	8.73 (−27.85)	0.1 (−89.90)	3.95 (+289.99)	10.00 (−57.21)	2.81 (−40.09)	0.40 (−68.25)	5.45 (+332.54)
13	4.33 (+15.1)	0.77 (−8.33)	0.06 (−88)	1.79 (+258)	7.98 (+7.11)	0.58 (−4.92)	0.42 (−63.79)	3.76 (+224.14)
16	1.60 (+150)	0.8 (+128.57	0.006 (−91.43)	0.40 (+471.43)	2.50 (+0.40)	0.70 (+192.86)	0.20 (−9.09)	1.11 (+404.55)

An occlusal vertical load of 150 N was applied on the most distal portion on the left side of the prosthesis, and data were analyzed in both compact and cancellous bone. Von Mises stress values of peri-implant bone, implants, and prosthodontic components were recorded. In each test, the highest von Mises value was used for comparison.

Results

Higher von Mises stress values were recorded at the level of the implants (up to +55.16%), of peri-implant bone (up to +56.93%), and of the prosthesis (up to +70.71%) when the full-acrylic resin prosthesis was simulated. The values of stress registered in the model with the metal framework were highly decreased. The carbon fiber framework presented an intermediate behavior between the full-acrylic prosthesis and the one provided with a metal framework.

In compact bone, higher stresses were limited to the bone around the first three or four threads of the implant, while in trabecular bone, stresses were distributed along a greater number of threads up to the apical portion of the implant.

Maximum von Mises values (MPa) are reported in Table 1. Figs 1 to 3 illustrate the results for stress on the prosthesis, framework, implants, and bone.

Discussion

The present computer simulation suggests that a rigid framework is biomechanically advantageous when compared to a full-acrylic resin prosthesis.

The use of a rigid framework allows production of a thinner prosthesis that is resistant to biomechanical stresses. To obtain the same resistance with a full-acrylic prosthesis, a thicker prosthesis is needed and aggressive bone remodeling may be required when a reduced prosthodontic space is available.[4,5]

The numeric results reported in the present study may be regarded as biomechanical indications within the limitations of the model presented, since 3D-FEA models represent a simplification of the investigated structures. In this study, the compact and cancellous

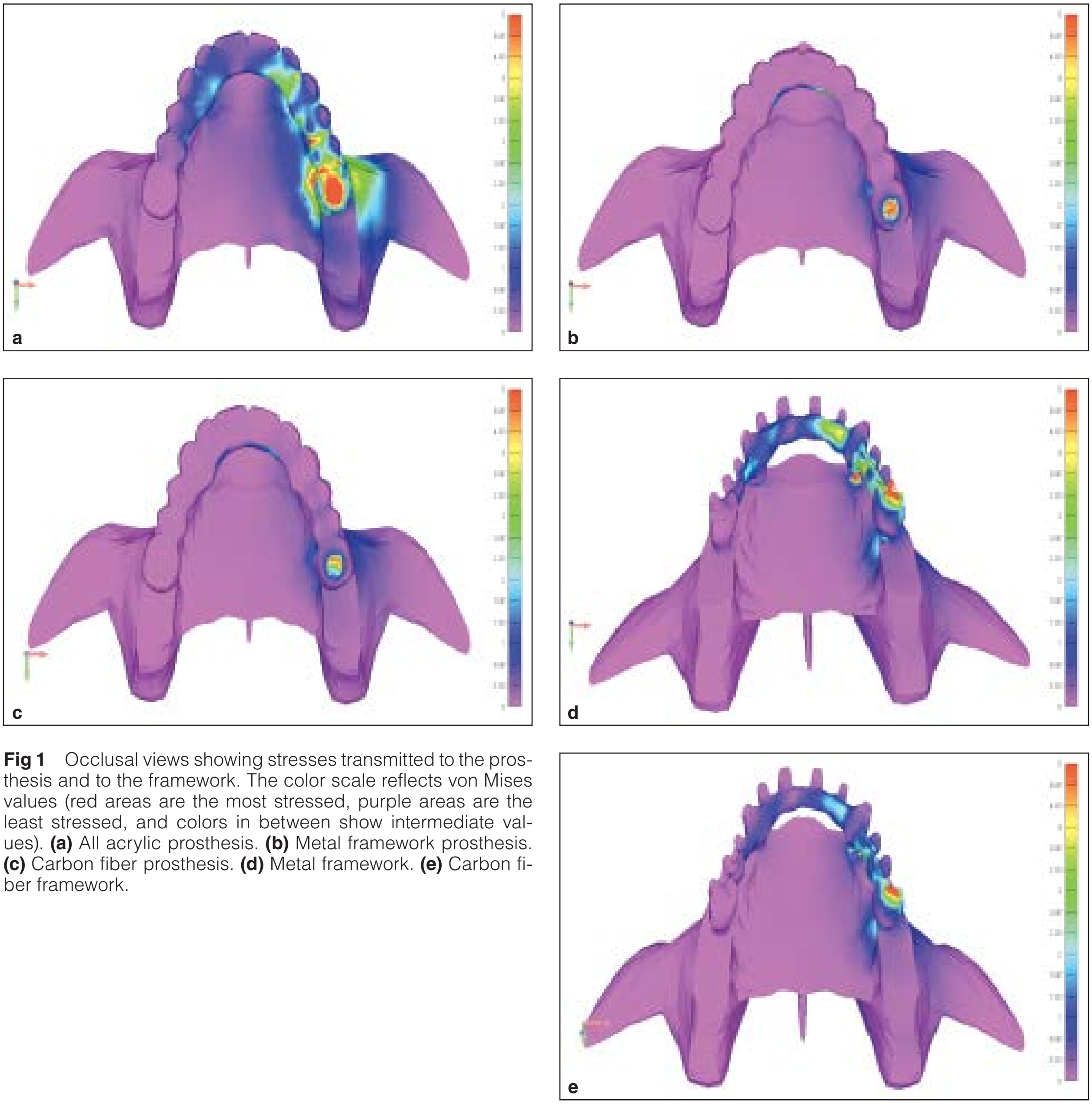

Fig 1 Occlusal views showing stresses transmitted to the prosthesis and to the framework. The color scale reflects von Mises values (red areas are the most stressed, purple areas are the least stressed, and colors in between show intermediate values). **(a)** All acrylic prosthesis. **(b)** Metal framework prosthesis. **(c)** Carbon fiber prosthesis. **(d)** Metal framework. **(e)** Carbon fiber framework.

bone were regarded as isotropic, since anisotropic properties of the maxilla are not yet available in the literature. In addition, the connecting screws at the abutment-implant and prosthesis-abutment interfaces were not modeled and all connections were designed as rigid ones.

Moreover, it should be noted that carbon fiber simulation in the present investigation was simplistic since an isotropic framework was simulated.

Conclusions

The present 3D-FEA suggests that the presence of a rigid framework in full-arch fixed prostheses provides a better load distribution that decreases the maximum values of stress at the levels of implants, prosthesis, and maxillary bone. Carbon fiber frameworks appear to offer promise as a viable alternative to traditional metal frameworks, providing similar stiffness and rigidity.

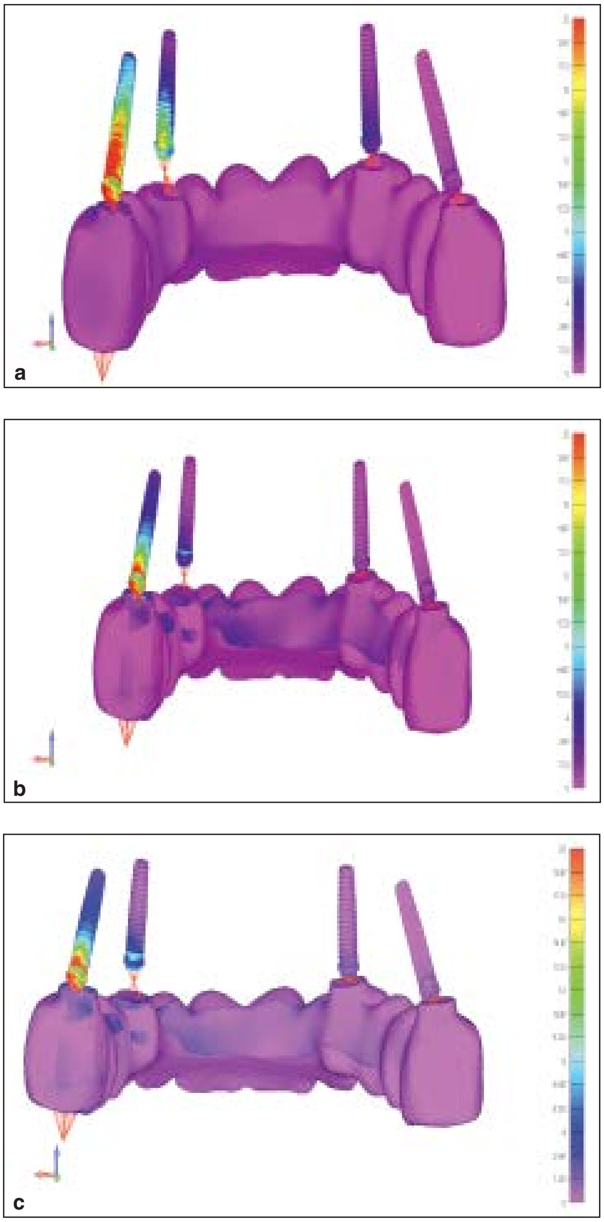

Fig 2 Stresses transmitted to the implants. **(a)** All acrylic prosthesis. **(b)** Metal framework prosthesis. **(c)** Carbon fiber prosthesis.

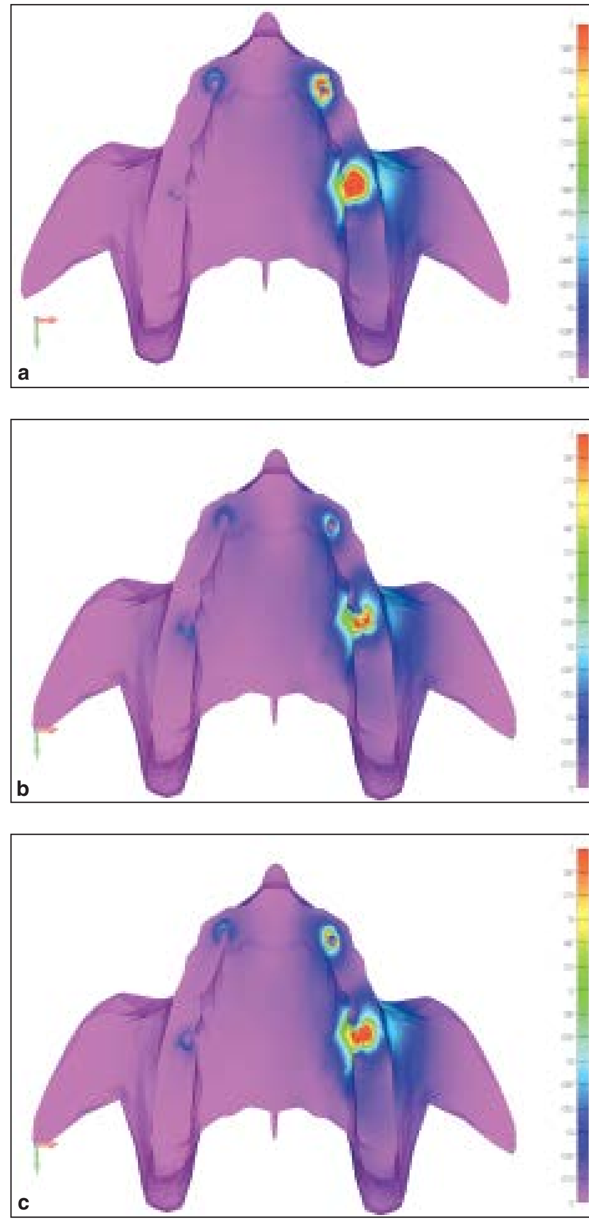

Fig 3 Stresses transmitted to bone. **(a)** All acrylic prosthesis. **(b)** Metal framework prosthesis. **(c)** Carbon fiber prosthesis.

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