

# Splinting Effect on Posterior Implants Under Various Loading Modes: A 3D Finite Element Analysis

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**Abstract** - This three-dimensional finite element study compared stresses, intensities and displacements of three mandibular posterior implants restored with cemented crowns (two molars and a premolar in straight line), splinted versus non-splinted. Hundred newton occlusal loads were vertically or horizontally applied, either on one single crown or on all of them. Maximal stresses and implants displacements were higher under horizontal loading. Splinting major effects appeared under single horizontal load with a decrease in stresses (34-49%) and displacements (16-19%) of the loaded crown. Splinting seems more appropriate for implant-supported restorations submitted to frequent single horizontal or oblique loads than vertical ones.

KEY WORDS: Dental implant, Dental prosthesis, Finite element analysis, Mechanical Stress.

## INTRODUCTION

Posterior dental implants are often short ones due to anatomic limitations. They are subjected to high masticatory loads generating stresses which may lead to mechanical or biological issues (such as bone defects or implant failure). The usual rationale for splinting implant-supported prostheses is to favourably distribute the applied forces between the implants, to minimize the transfer of horizontal load to the bone-implant interface and to increase the bone surface area<sup>1</sup>. However, a meta-analysis study failed to show any statistical difference in cumulative survival rate between splinted and non-splinted implant-supported prostheses<sup>2</sup>. No significant difference was either found by Naert *et al.*<sup>3</sup> between splinted and non-splinted implant in their prospective clinical study on partial edentulism. Similar marginal bone loss around single implant restorations and splinted implants have been reported<sup>4</sup>.

Despite the absence of clinical proof, splinting is still assumed to be useful in many cases. Interesting clinical guidelines for splinting implant restorations were proposed by Grossmann *et al.*<sup>5</sup>. According to the authors, the implant should be splinted in the following situations: presence of reduced number of natural occlusal stops, steep anterior guidance, parafunctional oral habits, off-axis/angled implants, implants arranged around an arch, implant-restoration including the canine, edentulous maxilla, and compromised retention/resistance forms of prosthetic components. In other terms, splinting usefulness depends on restoration loading modes.

Finite element analysis (FEA) is a computer-based method used to calculate and visually represent stresses and strains in complex structures, which are subjected to simulated

loads. The calculations require knowledge of the mechanical properties of the materials, such as Young's modulus (E) and Poisson's ratio ( $\nu$ ). This numerical stress analysis technique is widely used today in studying biomechanical problems in dental implantology<sup>6</sup>. Most mechanical FEA about splinting implants were restricted to specific loading.

The hypothesis of this study was that splinting straight line implant-supported restorations is appropriate only under specific forces, and the null hypothesis is that there is no difference between any forms of loading. The aim of this three-dimensional FEA was to determine the stress distribution and displacements of splinted and non-splinted implant-supported prostheses in posterior partial edentulism under different loading modes.

## MATERIALS & METHODS

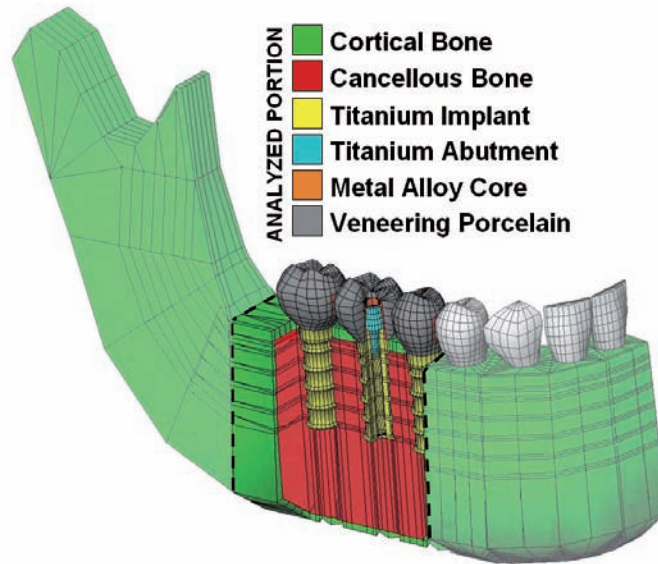
The software package used in this study was CADSPAP® (CADLM, France), French version of SUPERSAP (ALGOR® Interactive Systems, USA). A 3D modelling assuming linear elasticity and isotropy was carried out. The material data (Young's modulus, E; and Poisson's ratio,  $\nu$ ) used in the calculations are presented in Table 1.

**Table 1.** Elasticity Modulus (E, Young's modulus) and Poisson Proportions ( $\nu$ , Poisson's ratio) of the material used, as previously described<sup>24, 25</sup>.

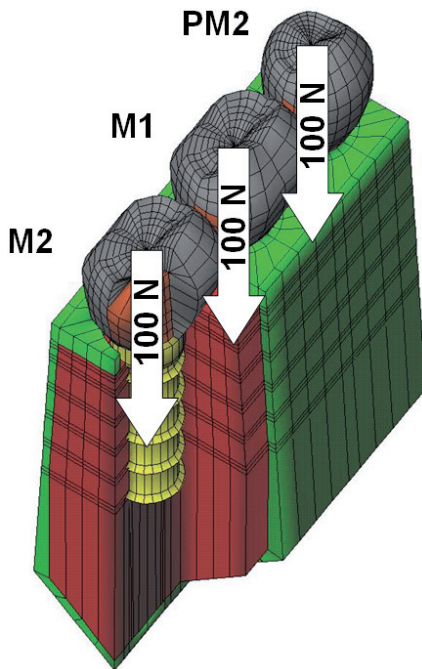
Materials	E (Pa)	$\nu$
Cancellous bone	1.37x10 <sup>9</sup>	0.30
Cortical bone	1.37x10 <sup>10</sup>	0.30
Zinc phosphate cement	1.37 x10 <sup>10</sup>	0.35
Veneering porcelain	6.87 x10 <sup>10</sup>	0.20
Palladium-based alloy	1.15 x10 <sup>11</sup>	0.38
Titanium alloy	1.09 x10 <sup>11</sup>	0.31

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**Figure 1.** Assembled structures for realistic 3D models (selective section). The analyzed portion contained only the second premolar, the first and second molars.



**Figure 2.** Loading mode example (model selective section): The three prosthetic units burdened a vertical 100N force applied at central fossae (B: buccal, L: lingual, stresses in MPa). For this experimental loading, prostheses were successively non-splinted and all splinted together.

An interrupted mandibular arch with distal extensions was designed by finite element modelling (Fig.1) from a scan of a 50 years old male patient. The second premolar (PM2) and the molars (M1 and M2) were lost, and their replacement by implant-supported prostheses was evaluated. The element mesh used in each model consisted of approximately 10,000 elements with a slight refinement of the mesh in the region close to the implants. The models

were approximately 35 mm in height, 35 mm in length mesio-distally and 20 mm in width bucco-lingually. “Generic” dental implants and prosthetic components were modelled. The titanium implants were modelled as cylinders with screw threads. They were assumed to be completely integrated and embedded at their base in the center of a bony structure. They carried a titanium abutment supporting premolar or molar crown (palladium-based alloy core with veneering porcelain). Splinted crowns were linked by the metallic infrastructure (3x3mm connectors) and non-splinted crowns were in contact. Between the cemented parts, zinc phosphate thickness was assumed to be 50  $\mu\text{m}$ <sup>7</sup>. For simplification, the whole implant-supported prosthesis and the surrounding bone were labeled as PM2, M1 or M2, except when a specific component was mentioned.

The nodes of the section surfaces of mandible were constrained in x, y and z directions as the boundary conditions. There was no interference caused by the boundary constraint as the studied region was near the implants.

The splinting effects under 8 loading modes were assessed in the experiment. Vertical or horizontal loads were applied at central fossae (Fig.2). The single-loading mode applied a single force at one unit (PM2, M1 or M2). For the multiple-loading mode, all the three prosthetic units were subject to a force (PM2, M1 and M2). The magnitude of each force was 100 N. For each experimental loading, the prostheses were successively non-splinted and all splinted together. The three restorations (PM2, M1 and M2) were supported by 4x10mm implants, which were installed along a straight line at the centre of the bone piece.

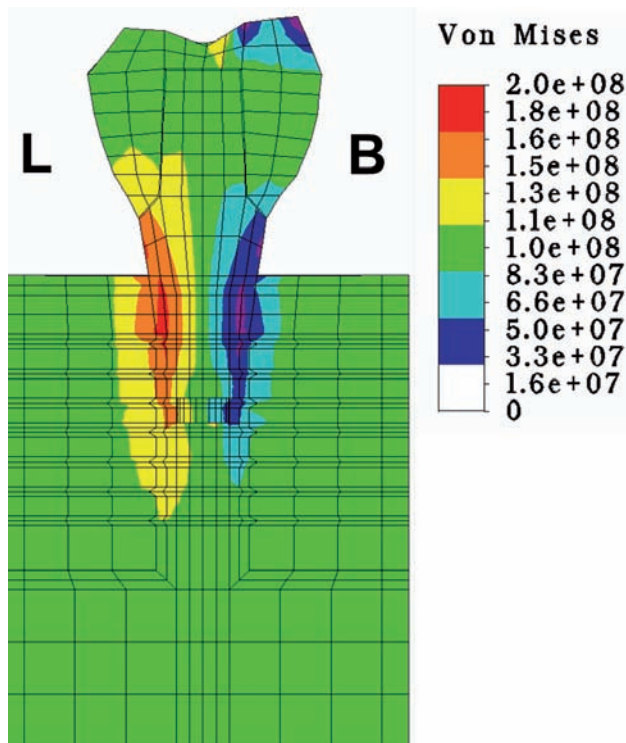
The von Mises equivalent stress distribution within implants and surrounding bone was calculated. The stress distribution was represented as iso-areas (ranges of intensity) showing mean stresses in Pa. Red and orange indicated high-intensity stresses, purple and blue indicated low-intensity stresses. Implant displacements were measured in the cervical area.

**Table 2.** Von Mises stresses in splinted and non-splinted implants models under vertical loadings.

Models		Implant stress (10 <sup>6</sup> Pa)			Abutment stress (10 <sup>6</sup> Pa)			Cortical bone stress (10 <sup>6</sup> Pa)			Cancellous bone stress (10 <sup>6</sup> Pa)		
		PM2	M1	M2	PM2	M1	M2	PM2	M1	M2	PM2	M1	M2
Vertical loading on PM2, M1 and M2	Non-Splinted	20,82	19,73	20,18	8,97	10,56	10,53	8,55	8,14	8,30	20,83	19,73	20,19
	Splinted	20,46	20,37	19,88	8,93	10,68	10,52	8,36	8,41	8,13	20,46	20,37	19,88
Vertical loading on PM2	Non-Splinted	18,64	3,93	1,99	8,90	1,20	0,19	8,12	5,56	1,60	18,64	3,92	1,99
	Splinted	16,90	6,64	3,37	9,55	2,68	1,58	7,89	4,9	2,16	16,90	6,65	3,37
Vertical loading on M1	Non-Splinted	4,40	13,86	3,25	0,78	10,35	0,57	5,09	7,58	3,83	4,40	13,86	3,25
	Splinted	6,02	9,11	6,35	5,75	9,66	3,65	5,25	5,82	6,35	6,02	9,11	5,13
Vertical loading on M2	Non-Splinted	1,99	3,22	18,74	0,20	0,95	10,49	1,77	4,66	8,00	1,99	3,23	18,74
	Splinted	3,36	5,96	17,13	2,21	2,30	10,39	1,94	4,00	7,54	3,37	5,96	17,13

**Table 3.** Von Mises stresses in splinted and non-splinted implants models under horizontal loadings.

Models		Implant stress (10 <sup>6</sup> Pa)			Abutment stress (10 <sup>6</sup> Pa)			Cortical bone stress (10 <sup>6</sup> Pa)			Cancellous bone stress (10 <sup>6</sup> Pa)		
		PM2	M1	M2	PM2	M1	M2	PM2	M1	M2	PM2	M1	M2
Horizontal loading on PM2, M1 and M2	Non-Splinted	70,12	63,69	65,32	36,88	30,59	30,65	56,14	52,13	51,72	70,12	63,7	65,32
	Splinted	70,69	63,73	66,82	35,18	31,61	31,26	54,47	52,93	53,45	70,69	63,73	66,82
Horizontal loading on PM2	Non-Splinted	53,11	21,35	10,19	36,23	3,64	0,65	50,93	18,53	4,36	53,11	21,35	10,19
	Splinted	34,9	30,51	14,47	24,09	16,97	8,09	32,80	30,51	14,47	34,90	22,42	14,38
Horizontal loading on M1	Non-Splinted	21,30	46,26	18,61	2,02	29,47	1,62	12,06	42,24	8,48	21,30	46,26	18,61
	Splinted	23,27	23,48	21,55	12,48	14,80	10,26	16,06	21,46	17,39	23,27	23,48	21,55
Horizontal loading on M2	Non-Splinted	10,32	19,49	49,52	0,64	2,82	30,16	5,36	14,20	45,52	10,32	19,49	49,52
	Splinted	13,84	25,74	32,60	8,96	16,41	20,92	10,34	25,74	31,55	13,84	20,83	32,60



**Figure 3.** Stresses distribution example: a single horizontal force on PM2. The stress distribution was represented as iso areas showing mean stresses in Pa. Red and orange indicated high-intensity stresses, purple and blue indicated low-intensity stresses.

## RESULTS

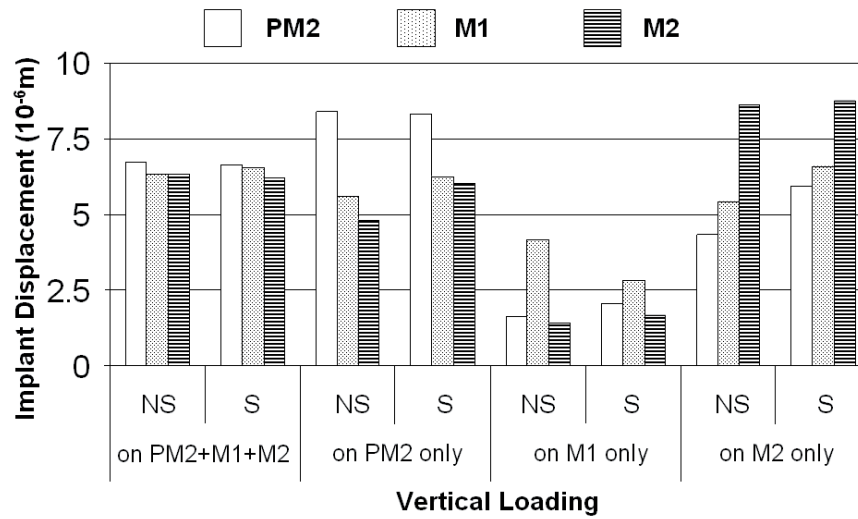
### Distribution

Maximal Von Mises stresses in implant components were located on the collar for all models under all loading modes. Bone maximal Von Mises stresses were also located in the crestal area.

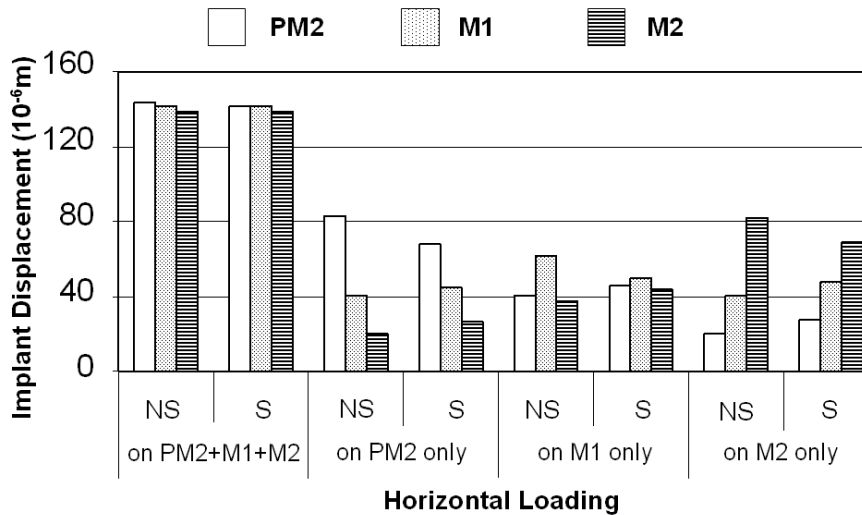
### Splinting effect on loading mode

In the vertical multiple loading mode, stresses were very similar for non-splinted PM2, M1 and M2, and small differences were attributed to rebound effect (Tab.2). Maximal stresses recorded in implants and cancellous bone were very similar. They were moreover approximately twice higher than in implant abutments and cortical bone. Implants displacement was estimated to be around 6.5µm (Fig.4). Splinting prostheses did not modify the range of maximal stresses or displacements.

The vertical single loading modes exhibited different results according to the loaded prosthesis. When central M1 was loaded, splinting was associated with -34.3% stresses in M1 implant and surrounding cancellous bone, but with an increase in PM2 and M2 (mean +56.7%; Table 2). M1 displacement was lower when splinted (-32.3%) and the other values were higher (mean +23.3%). When PM2 or M2 was loaded, splinting was associated with only -9.0% stresses in the loaded implant and surrounding cancellous



**Figure 4.** Displacement in splinted and non-splinted implants models under vertical loadings (NS: non-splinted, S: splinted).



**Figure 5.** Displacement in splinted and non-splinted implants models under horizontal loadings (NS: non-splinted, S: splinted).

bone, and with an important increase in the other values (mean +73.1%). Loaded implant displacement remained stable, and those of other implants were increased (mean +24.0%; Fig.4).

The horizontal multiple loading mode was associated with increased stresses (mean +306.5%; Tab.3) and displacements (+2090.8%; Fig.5) when compared with the vertical multiple loaded model. Stresses and displacements were very similar for splinted or non-splinted PM2, M1 and M2.

The horizontal single loading modes exhibited different results according to the loaded prosthesis. When M1 was loaded, splinting was associated with -49.2% stresses in M1 implant and surrounding cancellous bone, and with a low increase in PM2 and M2 (mean +12.5%; Tab.3). Displacement was lower for M1 (-19.3%) and higher for the others (mean +15.7%; Fig.5). When PM2 or M2 was loaded, splinting was associated with -34.2% stresses in the loaded

implant and surrounding cancellous bone, and with an increase in the others (mean +29.8%). Displacement was lower for the loaded prosthesis (-16.3%) and higher for the others (mean +24.5%).

## DISCUSSION

Finite Element Analysis (FEA) has proved to be an accurate and convenient tool for predicting the mechanical behaviour of prosthodontics layouts<sup>8-11</sup>. The program used in this investigation has several limitations considering the unrealistic simulation of the structure's material properties. This static study assumes that the bone is homogeneous, linear-elastic and isotropic. It does not take into account materials fatigue due to repeated loading and the complexity of masticatory forces. The masticatory system has the capability to produce bite forces in several directions. The magnitude and direction of applied forces influence the

resulting stress distribution<sup>12</sup>. Our applied forces were not oblique, even if it would have been more realistic: it was decided to separate the axial and lateral components to clarify the result analysis. Although the forces investigated lacked the complexity of the loading which occurs in the oral environment, the findings are of value when comparing the alternative designs of the investigated structures. The main purpose was to compare biomechanical behaviour rather than report absolute values for displacements and stresses of the system. Cement thickness was assumed to be standardized. Layer variations would have been time consuming and of little interest in this displacement comparative study. Between the sealed parts, the cement thickness was assumed to be 50 µm<sup>7</sup>. The use of different luting agents with different elastic moduli has been shown to have a minor effect on the resulting stresses in FEA. The effect of different thicknesses of these luting agents is even smaller<sup>13</sup>. However, the mastication forces and the tooth/bone interface are dynamic. It is consequently impossible to reproduce all the details of natural behaviour. Finite element analysis can not determine criteria for acceptability of stress levels, but enables comparison of different models and quantifies the risk in each of them. Focus was on von Mises equivalent stresses, as it makes the study comparable with related publications. These shearing stresses are the common mode of illustration for areas where plastic strains are potentially taking place.

Maximal stress distribution is interesting for locating potential implant fracture or bone resorption. Our study suggests important bone compressive stresses around the implant neck. The cervical area is critical because of the concentration of high-intensity stresses, especially when implants are subjected to lateral forces. This result corroborates other *in vitro* studies using FEA or other methods<sup>8-11</sup>. High stresses are associated with bone remodelling resulting in osseointegration<sup>14</sup> or surrounding bone loss<sup>15</sup>. Implant stability and success rate depend on this potential remodelling<sup>16</sup>. Repeated stresses lead to fatigue of implant components, reduce their long-term resistance, and lead to a higher risk of biomechanical complications<sup>17</sup>. However FEA can not take into account such fatigue events but does suggest clinical location of potential implant components fracture, bone resorption or crown unscrewing<sup>18</sup>.

High stresses occurred in straight line implants under oblique loading. This preliminary study focused on loading modes and clarified other *in vitro* studies. Photo-elastic studies have reported conflicting results<sup>19</sup>. Abu-Hammad *et al.*<sup>20</sup> made a similar 3D finite element modelling analysis, but focusing on offset placement. Their models described three splinted titanium implants of 4-mm-diameter and 10-mm-long osseointegrated portions submitted to 100N loads. Loads were directed vertically or horizontally on two implants simultaneously. Their conclusions on straight line implants conditions were consistent with our study. Loading the peripheral implant always resulted in higher stresses than loading the middle implant. Moreover, the lowest compressive stress values were recorded under vertical loading conditions, while the highest values were recorded under horizontal loads. Bergkvist *et al.*<sup>21</sup> produced a 3D FEA with implants modelled as cylinders (4.1 x 12 mm) both splinted or not splinted to a curved parallelepipedic prosthesis. They studied one-stage surgery in the treatment of the edentulous maxilla with immediate splinting

of the implants with a fixed provisional prosthesis. The bite force was set to 300 N, 10° diagonally from the rear, and one was subjected to a vertical load. They concluded that splinting dental implants strongly reduces stress levels in the surrounding bone tissue, especially when the implants were exposed to an angled force. If this result is consistent with our study, their implants were not in a straight line placement.

Cantilevers, long spans, eccentric loading, and short abutments caused by limited interarch space are all indications to splint the crowns on the implants<sup>5</sup>. This choice cannot be systematic as splinting is associated with some possible complications. Furthermore, the laboratory aesthetic treatment of embrasure morphology is often more difficult to manage if implants are splinted. Some authors suggested that prosthetic crown splinting had biomechanical advantages and could raise the success rate because the occlusal forces could be shared through splinted crowns, thus decreasing the bone peak-stresses<sup>22, 23</sup>. Occlusal considerations are decisive in the choice of prosthetic splinting: a good anterior guidance allows posterior teeth disocclusion. This reduces posterior chewing forces which are predominantly vertical forces.

Although this FE study needs clinical verification, it still provides insight into the mechanical interest of the implant splinting. In future studies, FEM could also be of interest to use in analyses of the relative influence of various clinical parameters on splinting, such as implant offset, angulations, diameter, length, vertical interarch space or abutment height.

## CONCLUSIONS

This FEA study shows that there is a reduction in stresses and displacements when posterior implants undergo a single horizontal loading.

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