OPEN ACCESS
Saudi Journal of Oral and Dental Research
Abbreviated Key Title: Saudi J Oral Dent Res
ISSN 2518-1300 (Print) |ISSN 2518-1297 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Original Research Article

Comparative Evaluation of Compressive Stresses on the Periodontal Ligament Adjacent to Two Differently Angulated Miniscrew Implants (MSIs)

Dr. Vanessa Varghese[1*], Dr. Shrinivas V Ashtekar[2], Dr. Rahul S Deshpande[3], Dr. Pravin S Shetty[4], Dr. Jagadeesh P Gajapurada[5], Dr. Anilkumar Biradar[6]

[1]Post graduate resident, Department of Orthodontics and Dentofacial Orthopedics, Vasantdada Patil Dental College and Hospital, Sangli, Maharashtra, India
[2]Professor, Department of Orthodontics and Dentofacial Orthopedics, Vasantdada Patil Dental College and Hospital, Sangli, Maharashtra, India
[3]Professor and Head of Department, Department of Orthodontics and Dentofacial Orthopedics, Vasantdada Patil Dental College and Hospital, Sangli, Maharashtra, India
[4]Professor, Department of Orthodontics and Dentofacial Orthopedics, Vasantdada Patil Dental College and Hospital, Sangli, Maharashtra, India
[5]Professor, Department of Orthodontics and Dentofacial Orthopedics, Vasantdada Patil Dental College and Hospital, Sangli, Maharashtra, India
[6]Professor, Department of Orthodontics and Dentofacial Orthopedics, Vasantdada Patil Dental College and Hospital, Sangli, Maharashtra, India

DOI: 10.36348/sjodr.2021.v06i06.002 | **Received:** 23.04.2021 | **Accepted:** 31.05.2021 | **Published:** 04.06.2021

***Corresponding author:** Dr. Vanessa Varghese

Abstract

Aim: The aim of our study was to assess and observe the changes in Maximum von Mises stresses in relation to force application during miniscrew placement at two different insertion angles in proximity of PDL under varying magnitudes of load and locations. ***Methods:*** Patient specific finite element models of the area of interest involving maxillary 1st molar and 2nd premolar were developed using computed tomography images. An Miniscrew implant surface model derived from micro-computed tomography was placed at three different levels away at regular intervals from the PDL of the premolar. Finite element analysis was conducted with 45 and 90-degree angle on the MSI, with a loading force of 100g and 200g, at a distance of 1mm,1.5mm and 2.0mm from the PDL. Maximum von Mises stresses was calculated at each distance. To explain compressive stress by proximity, load magnitude and different insertion angle stepwise multiple regression models was conducted. ***Results:*** The multiple regression models explained the variation of MPa and included all three factors: proximity, load magnitude and angulation. The regression model showed significant interaction between the three factors, proving that lesser angulation & load magnitude and implant position far away from the 2nd premolar PDL could be associated with minimal amount of stresses generated and decreased effect on roots. ***Conclusion:*** To safeguard the adjacent roots and periodontal ligament structures the MSI should be placed at 90-degree angulation, with a loading force of 100g and at 2mm from the 2nd premolar's PDL to produce minimum compressive stresses.

Keywords: miniscrew implant, PDL, force, angulation, proximity, stress, survival, CBCT, CAD/CAM, OptiStruct

INTRODUCTION

Orthodontic miniscrew implants (MSIs) have been commonly used in orthodontic clinical practice as temporary anchorage devices. Various orthodontic treatments and tooth movements have become effectively achievable with less or no loss in anchorage [1].

Mini-implants are being extensively used in orthodontic treatment. A new ground of possibilities has been opened for treatment before the concept of absolute anchorage has become available to us in the form of mini-implants. The small size and ease of placement have made mini-implants user-friendly; also, they are more relatively comfortable for the patient. The main concerns with mini-implants are the failure rate and potential trauma to the surrounding structures and the consequences of the damage [2]. Park et al, Chung et al. and Ohnishi et al. [3] have stated that, titanium mini-screws placed into alveolar bone have been used as absolute anchorage and led to favourable treatment outcomes; however, some researchers have experienced loosening of the screws.

Various factors affecting the stability of orthodontic mini-implants have been researched. Failures were noted among screws contacting roots, which is one of the possible complications when placing miniscrews around the periodontal ligament area [4]. Motoyoshi et al. [3] developed tapered orthodontic miniscrews (T-type screws), which can endure immediate loading and can be used clinically. However, even these screws show mobility and failure in clinical scenario, and their effectiveness has not been sufficiently investigated.

Bone density and soft-tissue health directly affect implant stability [3]. Practically, it is not possible to measure the stresses in the PDL in vivo directly. The finite element method is supposed to be a reliable and non-invasive technique to measure stresses in the PDL. Recent advances in computational technology allow finite element simulations of bone specimens to be very close to reality by constructing finite element models based on specimen specific geometries and properties [5]. In essence of this techniques, a computed tomography (CT) image of the patient is obtained and used to produce patient specific bone geometry and CT-voxel-based bone mechanical properties.

The stresses generated by placement and loading are very important factor for stability of miniscrew implant (MSI) during orthodontic treatment thereby affecting the success of the treatment. Hence, the aim of our study was to assess and observe the changes in Maximum von Mises stresses (MPa) in relation to force application during miniscrew placement at each insertion angle in proximity of PDL under varying loading magnitudes and locations.

METHODOLOGY

A scanned Cone beam computed tomography data of normal adult occlusion was collected from the CBCT centre. With the help of ADVANCED CAD TECHNOLOGY software and machine a CAD/CAM model of the Dentos miniscrew (Seoul, South Korea) was generated (Figure 1) and maxillary arch was generated (Figure 2). The patient was keenly selected without any systemic disease or syndrome. In the patient scan, one side (right) was used to develop the finite element model. The side with greater interradicular width between roots of maxillary 1st molar and 2nd premolar was the area of interest. We used the CT images to construct a 3D (three-dimensional) model of the area of interest as mentioned above with their PDLs, roots, cortical and cancellous bone surrounding the segment.

Fig-1: CAD/CAM model of the Dentos miniscrew

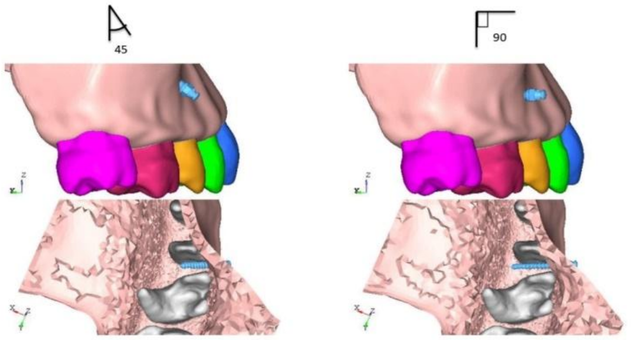

Fig-2: CAD/CAM model of the maxillary arch with miniscrew angulated at 45 and 90 degrees

The tapered miniscrew was used for 3D surface model using a micro CT image of a MSI. The dimension of miniscrew is mentioned in (Table 1). The miniscrew 3D model was then integrated into each of the anatomical sections at 2 different angulations and 3 different distances from premolar PDL (Figure 2,3). The 12 resultant 3D models were analysed using the finite element method.

Table-1: Dimensional details of the mini-screw

Screw Type	Model Code	External diameter	Internal diameter	Length of Threaded Part	Pitch	Length of Tapered Part
Tapered	SH 1312-08	1.30mm	0.80mm	8mm	0.60mm	6.60mm

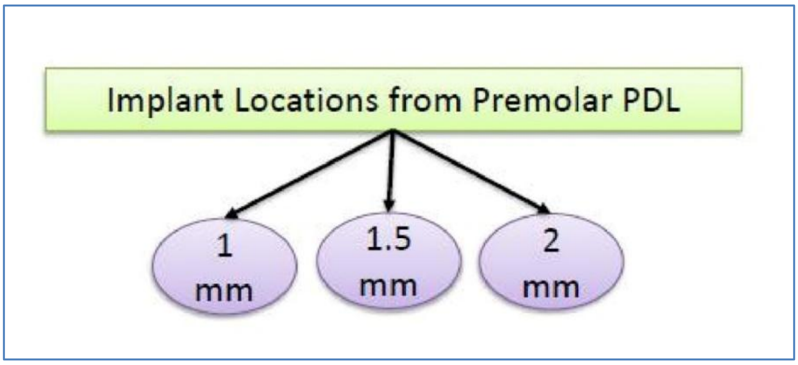

Fig-3: 3 different distances from premolar PDL

Every individual model of 12 sections were discretized with tetrahedral elements FEA pre-processing by using Altair Hyper Mesh (Altair Engineering Inc. Troy, Michigan, United States) and concentrated to a roughly 400,000 number of nodes and 17,00,000 number of elements. The elastic modulus for each element of bone was calculated from the CT images obtained were calculated as per a reference protocol from elsewhere [6]. Average peak elastic modulus for the periscrew bone was 1.37E±0.4 MPa. The Poisson ratio was considered to be 0.38 for the bony elements. Young's modulus and Poisson ratio for other components in the model are mentioned in (Table 2). Force application on the head of MSI in 45 degrees and 90 degrees angulation. The nodes on cutting faces of the bone were set at the specific angulation. The finite element models were checked using Altair OptiStruct software during pre-processing for finite element calculation. Then, the stress in Maximum von Misesstresses (MPa) around the premolar PDL area was calculated at two loading force of 100g and 200g equalling to 48 calculations were obtained by using FEA Post-processor software Altair HyperView.

Table-2: Details regarding the components and the variables

Component	Young's Modulus (MPa)	Poisson's Ration
Teeth	20000	0.3
Periodontal Ligament (PDL)	0.05	0.49
Alveolar bone	1.37E+04	0.38
Cortical bone	2000	0.30
Cancellous bone	200	0.30
Stainless Steel	210000	0.30
Titanium	110000	0.342

Multiple logistic regression models were constructed to explain the absolute peak compressive stress in the PDL area by proximity to screw, loading magnitude and at different insertion angle.

RESULTS

The stepwise multiple regression models yielded a variation in compressive stress in PDL. Maximum von Mises stresses (MPa) after force application at each insertion angle are mentioned below (Table 3,4) (Figure 4,5). Stress in Roots & Cortical dropped by steady 11% across all 3 distances.

Table-3: Maximum von Misesstresses (MPa) after force application of 100g during miniscrew placement at each insertion angle

Stress in MPa						
	1.0mm from PDL of Premolar		1.5 mm from PDL of Premolar		2.0 mm from PDL of Premolar	
	45 Deg.	90 Deg.	45 Deg.	90 Deg.	45 Deg.	90 Deg.
Roots	0.094	0.080	0.086	0.075	0.071	0.062
PDLs	0.001	0.001	0.001	0.001	0.001	0.000
Cortical Bone	1.640	1.404	1.575	1.378	1.559	1.364
Cancellous bone	0.099	0.072	0.093	0.069	0.092	0.068

Table-4: Maximum von Misesstresses (MPa) after force application of 200g during miniscrew placement at each insertion angle

Stress in MPa						
	1.0mm from PDL of Premolar		1.5 mm from PDL of Premolar		2.0 mm from PDL of Premolar	
	45 Deg.	90 Deg.	45 Deg.	90 Deg.	45 Deg.	90 Deg.
Roots	0.199	0.178	0.183	0.164	0.150	0.134
PDLs	0.002	0.001	0.001	0.001	0.001	0.001
Cortical Bone	3.490	3.120	3.350	2.995	3.317	2.965
Cancellous bone	0.210	0.160	0.197	0.150	0.195	0.149

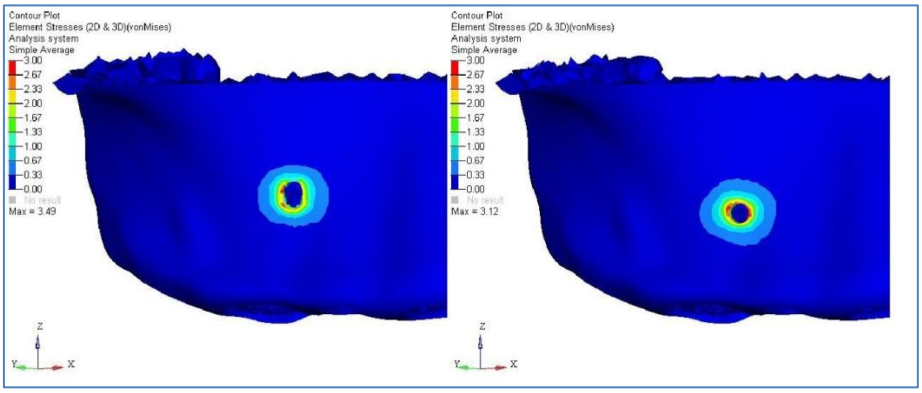

Fig-4: Maximum von Mises stresses (MPa) after 100g of force application at each insertion angle

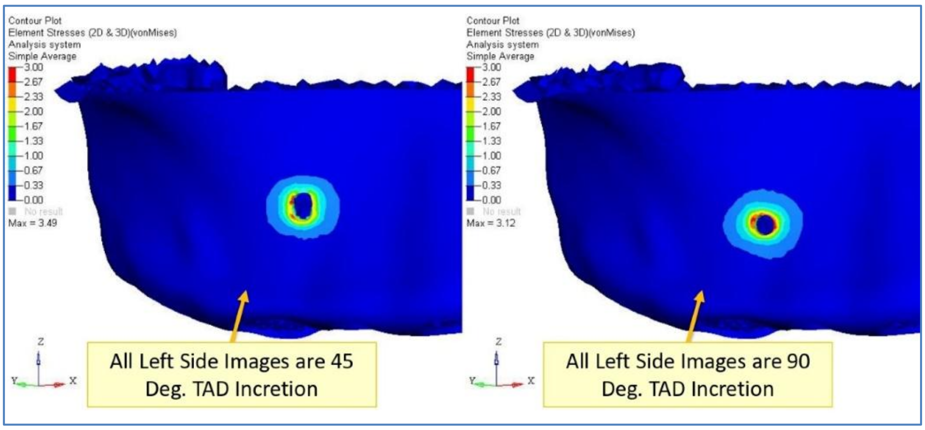

Fig-5: Maximum von Mises stresses (MPa) after 200g of force application at each insertion angle

Stress in Cancellous Bone increased by 27% and 25% whereas, it increased steadily by 24% across all 3 distances from PDL after force application of 100g and 200g respectively (Table 5,6). Comparing distance, it is clear that as we move away from PDL stress reduces in Root, PDL & Bone. Stress in Root drops from 0.094 to 0.071MPa with 100g of force and 0.199 t0 0.150 with 200g of force as we shift implant from 1.0mm to 2.0mm (for 45 Degree.). Similar pattern is observed for 90 degree. It was observed that 45 Degree Implant angulation & 1.0mm distance from PDL has highest stress levels in all parts (Roots, PDL & Bone), while at 90 Degree Implant insertion angulation & 2.0 mm distance from PDL has the least stress value in all parts (Roots, PDL & Bone).

Table-5: Percentage of Maximum von Misesstresses (MPa) after force application of 100g during miniscrew placement at each insertion angle

Implant Length		**1.0mm from PDL**			**1.5 mm from PDL**			**2.0 mm from PDL**		
Miniscrew	Structure	45 Deg.	90 Deg.	45-90%	45 Deg.	90 Deg.	45-90%	45 Deg.	90 Deg.	45-90%
Tapered	Roots	0.094	0.080	14%	0.086	0.075	12%	0.071	0.062	12%
	PDLs	0.001	0.001	16%	0.001	0.001	14%	0.001	0.005	14%
	Cortical bone	1.640	1.404	14%	1.575	1.378	13%	1.559	1.364	13%
	Cancellous bone	0.099	0.072	27%	0.093	0.069	25%	0.092	0.068	25%

Table-6: Percentage of Maximum von Misesstresses (MPa) after force application of 200g during miniscrew placement at each insertion angle

Implant Length		1.0mm from PDL			1.5 mm from PDL			2.0 mm from PDL		
Miniscrew	Structure	45 Deg.	90 Deg.	45-90%	45 Deg.	90 Deg.	45-90%	45 Deg.	90 Deg.	45-90%
Tapered	Roots	0.199	0.178	11%	0.183	0.164	11%	0.150	0.134	11%
	PDLs	0.002	0.001	0%	0.001	0.001	0%	0.001	0.001	0%
	Cortical bone	3.490	3.120	11%	3.350	2.995	11%	3.317	2.965	11%
	Cancellous bone	0.210	0.160	24%	0.197	0.150	24%	0.195	0.149	24%

DISCUSSION

Conventional methods of providing anchorage were with the help of tooth borne or extra oral appliances, however miniscrew implants provided infinite anchorage by its varying nature. Orthodontic miniscrew implants have been gaining popularity because of their simplicity of placement and removal, minimum cost, and minimal need for patient compliance. The clinical effectiveness lies in their ability to maintain close bone contact, thus resisting reactive orthodontic forces [7]. However, other than these factors there is a need to understand how these MSI's can affect the PDL and roots of adjacent tooth. So, the current study will help us elucidate how these MSI's should be placed in order to protect these structures.

Kim et al. [8] found in their study that when the mini-implant was placed less than 1 mm from the PDL, external root resorption occurred. Although no direct contact was made and there was presence of bone between the implant and the root, resorption still occurred. It is recommended that at least a 1-mm space should be left between the mini-implant and the root surface during placement of mini-implants. Lee et al. [9] who noticed an increased incidence of root resorption when the MSI-root distance was less than 0.6 mm. It is also clear from this study that; as the distance (2mm) of implant insertion increases from PDL we get lesser amount of stress generated. The failure rate of mini-implants varies from 6.6 to 16.1%, which is higher than that of dental implants (3%) and other temporary anchoring devices, such as miniplates (2.6 to 7. 3%). The mechanism that leads to mobility and, eventually, to the clinical failure of mini-implants is still unknown [10].

Based on linear extrapolation, peri-implant bone strain data were found to fall below the pathological overload threshold of 3000 $\mu\varepsilon$, as defined by Frost's bone mechanostat theory. Strain dissipation to distant sites appeared to be an effective mechanism by which bone resorption [11]. Generally, a 200g force is used in orthodontic treatment for retracting a canine. However, a range of 100-200g is suggested to be sufficient [12]. Therefore, in this study 100g and 200g of force magnitude were assessed. In our study a force magnitude of 100g showed lesser compressive stresses in the PDL which will offer better stability to the MSIs.

The angulation of MSI placement also plays an important role in stability. Woodall N et al. [12] conducted a study on screw placement orientation at 30º, 60 º and 90 º and concluded that placing the miniscrew at 90º angle to the alveolar process provided greater anchorage resistance and less cortical bone stress compared to 30º and 60 º angle. In our study we have compared 45 º and 90 º angulation and have found the similar result, where the 90 º angulation provided minimal compressive stresses in the PDL.

In this study we have tried to replicate and prove that bone properties when calculated using CT images with collaboration with Altair Optistruct software rather than conventional methods. However, the limitation of the current study was that it was performed by software by not considering the biological events occurring in the bone. The combination of the results of this study along with various animal studies will help us confirm these findings.

CONCLUSION

There is a plethora of factors that mark the amount of compressive stresses generated by a miniscrew implant such as the angulation, force magnitude, and distance of the MSI to the PDL. The conclusion of this study was, to safeguard the adjacent roots and periodontal ligament structures, the MSI should be placed at 90-degree angulation, with a loading force of 100g and at 2mm from the 2nd premolar's PDL to produce minimum compressive stresses.

REFERENCES

1. Abdulnabi, Y., Albogha, M. H., Abuhamed, H., & Kaddah, A. Non-surgical treatment of anterior open bite using miniscrew implants with posterior bite plate. Orthod Waves. 2017;76(1): 40-5.
2. Kim, H., & Kim, T. W. Histologic evaluation of root-surface healing after root contact or approximation during placement of mini-implants. Am J Orthod Dentofacial Orthop. 2011; 139(6): 752-60.
3. Yano, S., Motoyoshi, M., Uemura, M., Ono, A., & Shimizu, N. Tapered orthodontic miniscrews induce bone–screw cohesion following immediate loading. Eur J Orthod. 2006; 28(6): 541-6.
4. Chen, Y. H., Chang, H. H., Chen, Y. J., Lee, D., Chiang, H. H., & Jane Yao, C. Root contact during

insertion of miniscrews for orthodontic anchorage increases the failure rate: an animal study. Clin oral implants research. 2008;19(1): 99-106.
5. Chen, G., Schmutz, B., Epari, D., Rathnayaka, K., Ibrahim, S., Schuetz, M. A., & Pearcy, M. J. A new approach for assigning bone material properties from CT images into finite element models. J Biomech. 2010; 43(5):1011-5.
6. Albogha, M. H., Kitahara, T., Todo, M., Hyakutake, H., & Takahashi, I. Maximum principal strain as a criterion for prediction of orthodontic mini-implants failure in subject-specific finite element models. Angle Orthod. 2016; 86(1): 24-31.
7. Papageorgiou, S. N., Zogakis, I. P., & Papadopoulos, M. A. Failure rates and associated risk factors of orthodontic miniscrew implants: a meta-analysis. Am J Orthod Dentofacial Orthop.2012; 142(5): 577-95.
8. Kim, H., & Kim, T. W. Histologic evaluation of root-surface healing after root contact or approximation during placement of mini-implants. Am J Orthod Dentofacial Orthop.2011; 139(6): 752-60.
9. Lee, Y. K., Kim, J. W., Baek, S. H., Kim, T. W., & Chang, Y. I. Root and bone response to the proximity of a mini-implant under orthodontic loading. Angle Orthod. 2010; 80(3): 452-8.
10. Daokar, S. S., & Agarwal, G. Orthodontic Implant Failure: A Systematic review. Int J Oral Implantol Clin Res.2016;7(1): 1-6.
11. Kan, J. P., Judge, R. B., & Palamara, J. E. In vitro bone strain analysis of implant following occlusal overload. Clin Oral Implants Res. 2014;25(2): e73-e82.
12. Woodall, N., Tadepalli, S. C., Qian, F., Grosland, N. M., Marshall, S. D., & Southard, T. E. Effect of miniscrew angulation on anchorage resistance. Am J Orthod Dentofacial Orthop. 2011; 139(2): e147-e52.

