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Stress distribution in posterior disc displacement of temporomandibular joint - A 3D fem study

[1]Dr. Archana Mohan, MDS, Post graduate student, Department of Orthodontics, Al Badar Dental College and Hospital Gulbarga-585102

[2]Dr. Chandrika G Katti, MDS, Reader, Department of Orthodontics, Al Badar Dental College and Hospital Naganahalli road, Dariyapur village, near Koranti Hanuman temple Gulbarga, Karnataka, Pin: 585102 India

[3]Dr. Girish Katti, MDS, Professor and Head, Department of Oral medicine and radiology, Al Badar Dental College and Hospital Gulbarga- 585102

[4]Dr. Ashok Kumar Talapaneni, MDS, Professor, Department of Orthodontics, Sibar Dental College, Guntur- 522509 India

[5]Dr. Prasad Konda, MDS, Professor and Head, Department of Orthodontics, Al Badar Dental College and Hospital Gulbarga- 585102

[6]Dr. Syed Shahbaz, MDS, Reader, Department of Oral medicine and radiology, Al Badar Dental College and Hospital Naganahalli road, Dariyapur village, near Koranti Hanuman temple Gulbarga, Karnataka, Pin: 585102 India

Corresponding Author: Dr. Archana Mohan, MDS, Post graduate student, Department of Orthodontics, Al Badar Dental College and Hospital Gulbarga-585102

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Abstract

Objectives: To evaluate stress distribution in Posterior Disc Displacement (PDD) and to compare this with normally positioned disc of healthy Temporomandibular Joint (TMJ), with and without occlusal splint.

Materials and method: TMJ geometry was obtained from Cone Beam Computer Tomography (CBCT) of an adult male volunteer with no history of present or past TMJ disorders to replicate the osseous components and to outline the articular disc, Magnetic Resonance Imaging (MRI) was performed. From these data mandibular condyle and articular fossa eminence of temporal bone contours were delimitated. Three other models were designed considering the presence or absence of occlusal splint in normal and posteriorly displaced disc

Results: 3.31 Mpa (Megapascal) of stress was noted in intermediate zone of the articular disc in a normal TMJ. Reduced stress concentration was noted in the normal TMJ with occlusal splint, with a value of 3.11 Mpa.

Stress value in PDD was observed to be 3.58 Mpa without occlusal splint and was reduced to 3.37 Mpa in PDD model with occlusal spli

Conclusion and clinical significance: PDD generates increased stress in the disc compared to normal TMJ. Use of occlusal splint in PDD model showed significant reduction in stress concentration.

Keywords: Posterior disc displacement, Tempo roman dibular Joint, Disc displacement

Introduction

Temporomandibular joint (TMJ) is a type of synovial joint, formed by articulation of mandibular condyle and temporal bone, which acts as a modified hinge.[1] As a ginglymo-arthrodial joint, it allows for hinging movements in one plane and gliding movements in the other plane.[2]The articular surfaces involved in TMJ are mandibular fossa and articular tubercle of temporal bone, as well as mandibular condyle.[3]

Correct alignment of condyle–disc assembly is important for proper functioning of TMJ .[4] Disc displacement is one of the most common type of TMJ arthropathy.[5] Although precise etiology is not known, microtrauma and systemic factors have been identified as causative factors.[6]

Posterior Disc Displacement (PDD) is defined as "disc displaced posterior to 12 o'clock position on top of the condyle.[7] Clinical symptoms of PDD includes lack of occlusion on affected side, deviation of mandible, pain on palpation, and average mouth opening.[8] Etio pathogenesis of this condition is idiopathic. However, different authors have proposed different predisposing factors, e.g., trauma, forceful wide opening like yawning, lack of anterior prominence of disc, disc adhesion and perforation of disc.[8-12] Though PDD is considered a rare type of disc displacement [8,9] there can be three possible mechanisms of occurrence

1. Stretching of structures limiting posterior displacement of disc.
2. Widening of posterior part of TMJ.
3. Impairment of forward disc movement by adhesion in inferior joint space.
4. Therapeutic approach for treatment of Tempo ro Mandibular Disorder (TMD) includes: Conservative approach and surgical approach. Conservative methods are non-invasive, this involves use of occlusal splints, physical therapy, feedback, acupuncture and short-term pharma cotherapy. Surgical treatments include arthrocentesis, arthroscope, arthroplasty, discectomy, and TMJ reconstruction. [13, 14] The first choice of treatment should be minimally invasive. Surgical management should be considered after unsuccessful conservative therapy .[14]

Occlusal Splint Therapy may be defined as art and science of establishing neuro muscular harmony in masticatory system and creating a mechanical constrain for parafunctional forces with removable appliances. Performance of occlusal splint is based on the mechanism of neuromuscular reflex and decrease in intra-articular pressure in TMJ.[15] Occlusal splints can prevent the existing occlusion from controlling jaw to jaw relationship at maximum intercuspation.[4]

Cone Beam Computed Tomography (CBCT) is considered the best choice for imaging osseous components of TMJ.[16] Magnetic Resonance Imaging (MRI) is the gold standard imaging tool for evaluation of soft tissue components of TMJ and is the best diagnosing modality in disc displacements.[17]

Finite element method (FEM) is a modern mathematical tool where in the shape of complex geometric objects and their physical properties are computer constructed, which has an advantage of being applicable to solids of irregular geometry that contains heterogeneous material properties. Thus, this finite element study helps in determining the stress on TMJ in normal as well as patients with PDD.[18]

The aim of the study is to evaluate stress distribution in PDD and compare it with normally positioned disc of healthy TMJ, with and without occlusal splint.

Materials and method

Ethical Committee approval was obtained from Institutional Ethics Committee prior to start of study. TMJ geometry was obtained from CBCT of an adult male volunteer aged 26 years with no history of present or past TMJ disorders to replicate osseous components and MRI was performed to outline the articular disc.

Scanning Data was obtained as *.stl format from Scanning Centre. This Scanned Data was then imported into Altair Hyper Mesh software. Imported CAD (Computer Aided Design) models were used for finite element simulation. From these images mandibular condyle and articular fossa eminence of temporal bone contours were delimitated (Fig.1a). Upper and lower boundaries of disc were modelled according to upper and lower articular surfaces. It was possible to identify the three parts of articular disc: anterior zone, intermediate zone and posterior zone (Fig. 1b). Meshing details are provided in Table I. Material properties of alveolar bone, articular disc, and periodontal ligament in the model is presented in Table II.

From the model of normal TMJ, three other models were designed considering presence or absence of occlusal splint and presence or absence of posterior displacement of the articular disc. For this purpose, volunteer was subjected to another CBCT with occlusal splint of 2 mm thickness in place. In order to create models with PDD, we considered the concept that 'when the disc is displaced posterior to 12 o'clock position on top of the condyle', this condition is called posterior disc displacement.

Boundary Conditions

Upper temporal lamina was fixed in all degrees of freedom. This in turn generated stress in TMJ which is more realistic and capturing real life scenario. Coefficient of friction value was considered to be 0.0001 between the disc and bony structure. This contact and friction represents joint being lubricated. A model with occlusal splint was found to displace condyle away from articular disc by 0.2 to 0.5 mm forward and downward.

Four FE TMJ models were created:

- TMJ with normal disc position without occlusal splint. (Fig 1c)
- TMJ with normal disc position with occlusal splint.
- TMJ with posterior disc displacement without occlusal splint. (Fig 1d)
- TMJ with posterior disc displacement with occlusal splint.

Results

Stress value in normal TMJ was 3.31 Mpa (Megapascal), with the highest stress observed in the intermediate zone. Stress values were observed to reduce in normal TMJ with the use of occlusal splint, measuring 3.11 Mpa. Although location of stress remained unchanged (Fig 2a, 2b, 2c).

Stress value in TMJ with PDD was observed to be 3.58 Mpa. This shows an increase in stress concentration in PDD when compared to normally placed disc. When the disc was displaced posteriorly, the highest stress was observed between intermediate and anterior zones. Stress values were observed to reduce in PDD with occlusal splint, with stress measuring 3.37 Mpa. (Figure 3a, 3b, 3c) Superior boundary, contacting the glenoid fossa, exhibited lower stresses than those on inferior boundary facing the condyle in both normal as well as PDD model. In our study major type of principal stress seen in the disc was compressive stress (P3) which was found to be higher than tensile stress (P1) in both normal and PDD models. (Fig 4a and 4b,5a and 5b)(Table III).

Discussion

Disc displacement of TMJ is a common non-inflammatory TMD. According to Clark et al and Moloney et al disc displacement is present in about 15%-25 % of patients with TMDs .[19]

Physiologic disc-condyle relationship has an effective intra-articular lubrication mechanism that keeps articular friction coefficient low.[20] An increase in friction coefficient may be due to chronic microtrauma or acute macro trauma directed against TMJ.[21] Microtrauma refers to repetitive minor injuries to TMJ occurring over a long period. Bruxism represents the most frequent cause of microtrauma. Macro trauma caused by an external source that provokes damage to TMJ are often considered to be a risk factor for disc displacement. Macro trauma includes strong blow to mandible, whiplash injury or mandibular hyperextension. [22]

Kirveskari et al mentioned loss of posterior occlusal support as a cause of discal and condylar deformation and degeneration [23] Rubio et al and Alanen et al considered occlusal abnormalities to be a fundamental factor in the onset of TMD symptoms.[24,25] According to Daneile et al, under normal conditions, strong discal ligaments and 'self-seating' wedge shape of the disc prevent any shift movement. For the disc to shift over the condyle, a deformation of its surfaces is needed, together with damage to discal ligaments.[26] Atkinson et al proposed that a steep articular eminence may be an etiologic factor for disc displacement.[27]

In our study, maximum peak of Von Mises stress of 3.31 Mpa was observed in intermediate zone of articular disc in patients with normal TMJ during mastication. Location of stress observed was in the intermediate zone, which is similar to studies conducted on healthy TMJ by Beck et al. [28] Farreira et al in their FEM study perceived stress distribution in anterior, intermediate and posterior zone of disc during mandibular closure, but most critical region of stress concentration was found to be the intermediate zone, which is in concordance with our study. Stress value in their study was exceeding 2 Mpa in intermediate zone [29] which is close to our findings where stress value was 3.31 Mpa in the intermediate zone.

An anatomic study on autopsy material organised by Oberg et al reported maximum pressure concentration in intermediate zone of a normal TMJ disc, which was comparable to our study carried out using FEM. [30]

Yaser et al conducted a FEM study on healthy TMJ to note that stress was distributed equally in all regions of disc that is, anterior, intermediate and posterior zone, which was contrary to our study where stress was observed in intermediate zone. Uniform distribution of stress in the disc in their study could be attributed to the adaptation of disc by acting as a cushion for intraarticular stress conduction.[31] Healthy TMJ exhibits a disc with normal configuration of biconcave shape during mastication.

According to Mori et al the concept of maintenance of shape of disc even after inducing masticatory load could be due to the push back reactionary force exerted by the disc against compressive force induced by condyle on the disc. This property of disc is known as viscoelasticity of the disc. This facilitates stress relaxation and maintains configuration of disc.[32]

But when load on the disc increases due to microtrauma or macro trauma, it can result in loss of viscoelastic property of disc resulting in thinning or perforation of disc causing the disc to displace anteriorly or posteriorly.

In our study on PDD model a stress concentration of 3.58 Mpa was noticed in anterior and intermediate zone of articular disc, to conclude that there was increased stress in PDD when compared to normally positioned disc. This increased stress could be the cause of pain and loss of disc configuration in PDD as described by Wessteson et al .[8]

Exact reason for pain in PDD is unknown. Chiba et al proposed that bone marrow oedema in mandibular condyle could be the cause of TMJ pain in PDD.[9] Afros et al found that sudden inability to achieve occlusion on the affected side and wide mouth opening to be the chief complaint of patients with PDD.[34]

In our model, normal TMJ with occlusal splint demonstrated 3.11 Mpa of stress. Whereas a stress concentration of 3.31 Mpa was noted in normal TMJ without occlusal splint, this shows a reduction of stress by 0.20 Mpa, which varied from the FEM study carried out by Febaine et al where there was no difference of stress in normal TMJ with and without occlusal splint.[29]

In PDD model with occlusal splint, a stress of 3.37 Mpa was concentrated in anterior and inter mediate zone. A maximum stress of 3.58 Mpa was observed in PDD without splint, eliciting a reduced stress of 0.21 Mpa in particular disc of PDD model with occlusal splint.

Reduced stress in both models, that is, normal TMJ model and PDD model with occlusal splint, may be attributed to forward and downward movement of condyle with the use of occlusal splint, which prevents condyle from compressing the disc.

Superior boundary contacting glenoid fossa, exhibited lower stresses than inferior boundary facing the condyle in both normal as well as PDD model**.** This finding did not largely deviate from the result obtained by Rodrigo et al [34] in their FEM study. Increase in the stress in inferior surface may be because of direct compression of inferior surface by the condyle during jaw closure.

An increased compressive stress (P3) was observed compared to tensile stress (P1) in both normal and PDD models (Fig 4, 5)

Indicating that compressive stress exerted by condyle on the disc is more than tensile stress, which was in concordance with statement given by Qihong li et al where the author explained function of disc as combined impact of stretching of ligaments and compression of condyle on articular disc.[5]

P1and P3 was found to be reduced in PDD with splint compared to PDD model without splint. This stress reduction may be the reason for improvement in symptoms associated with PDD.[34]

Studies conducted by Afros et al, Choss gross et al author noted reduction in TMD symptoms in PDD patient after the use of occlusal splint.[33,10] All these finding are in collaboration with the results obtained from our FEM study.

Our result signified that in PDD there was an increased stress concentration in anterior and intermediate zone of the articular disc compared to a healthy TMJ where stress was comparatively less and was noted predominantly in intermediate zone of articular disc. (Fig 6).

Stress magnitude decreased significantly in both normal TMJ and PDD model with the use of occlusal splint. Our FEM study proved the effectiveness of occlusal splint as a treatment modality in PDD cases. Its noteworthy, to assess stress load on TMJ with PDD and to collaborate our findings with clinical manifestations, so that finest treatment protocol could be enforced to the patients.

It is obvious to have better knowledge about diagnosis and treatment agenda of PDD and therefore should be addressed in future studies.

Conclusion

PDD generates increased stress in the disc compared to normal TMJ. Use of occlusal splint in PDD model showed significant reduction in stress concentration.

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Legend Tables and Figures

Table 1: Meshing details

Model	Normal tmj		PDD	
Components	No. of nodes	No. of elements	No. of nodes	No. of elements
Articular disc	8810	42618	8810	42618
PDL	69774	104827	69774	104827
Alveolar bone	55622	286750	55622	286750
Upper temp oral lamina	1638	1540	1638	1540

Table 2: Material properties

Component	Young's modulus (Mpa)	Poisson's ratio(μ)
PDL	0.667	0.49
Alveolar bone	1.37E+04	0.38
Articular disc	16	0.45

Table 3: Results

		Unit Mpa		
Splint	Model	Von Mises stress	Principal stress	
			P1	P3
Without occlusal splint	Normal	3.31	2.20	7.31
	PDD	3.58	1.86	7.62
With occlusal splint	Normal	3.11	2.07	6.87
	PDD	3.37	1.75	7.16

FIGURES AND LEGENDS

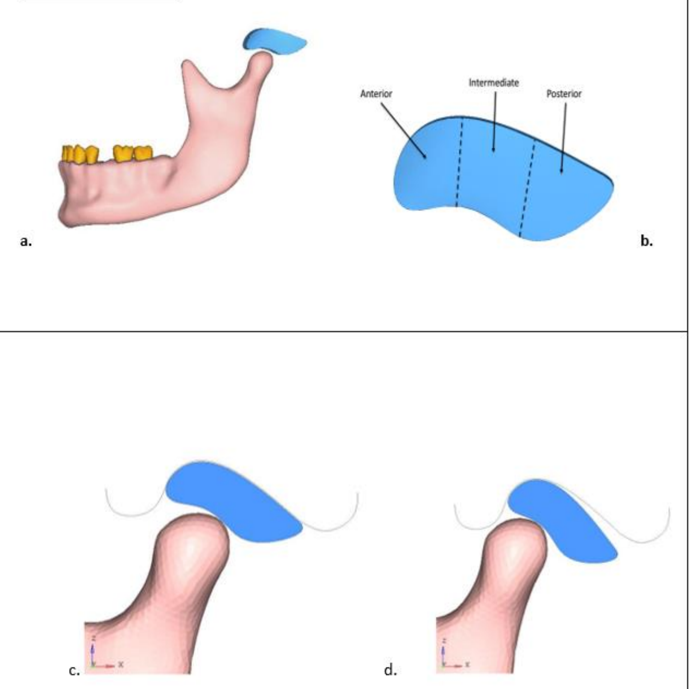

Fig 1

Fig 1: a Simulation of mandibular model, b. Zones of Articular zone, c. Normally positioned disc in TMJ, d. Posteriorly positioned disc in TMJ

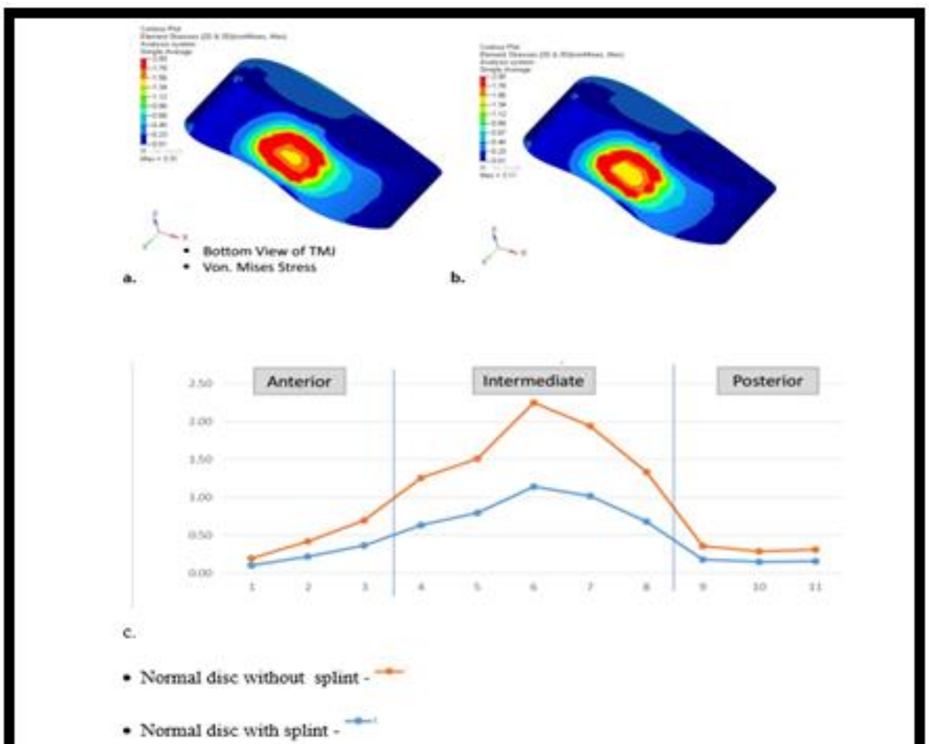

Fig 2

Fig 2: a. Stress concentration in Normal TMJ during jaw closure without and; b. with occlusal splint, c. Zones of stress concentration in normal disc without and with splint.

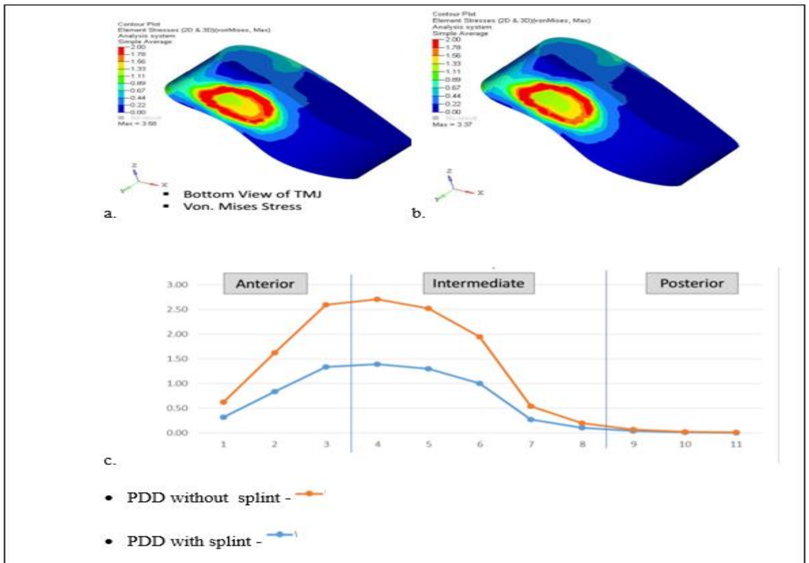

Fig 3

Fig 3: a. Stress concentration in PDD during jaw closure without and; b. with occlusal splint occlusal splint;

c. Zones of stress concentration in PDD without and with splint.

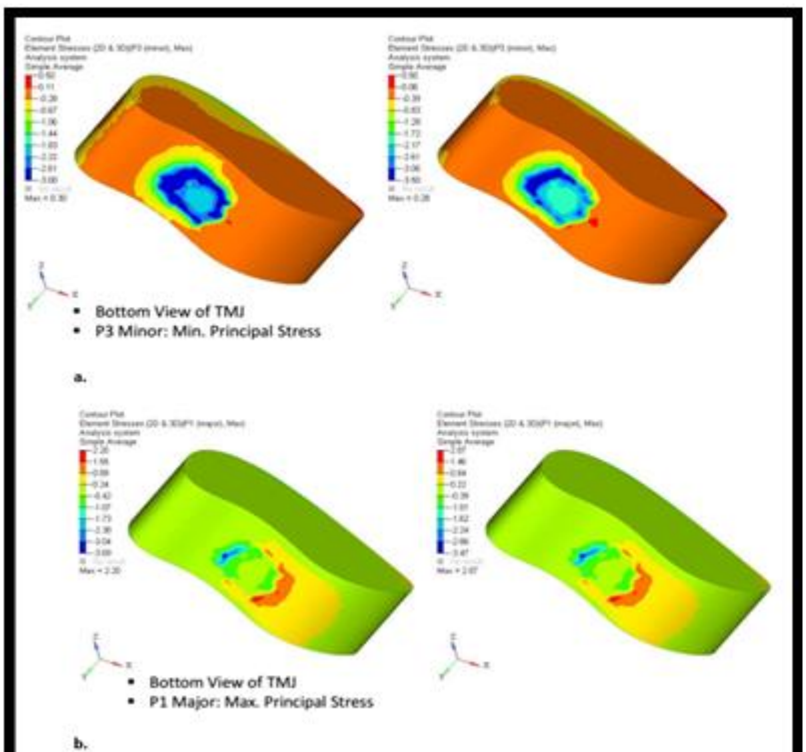

Fig 4

Fig 4: a.P3 on normal TMJ without and with occlusal splint, b. P1 on normal TMJ without and with occlusal splint.

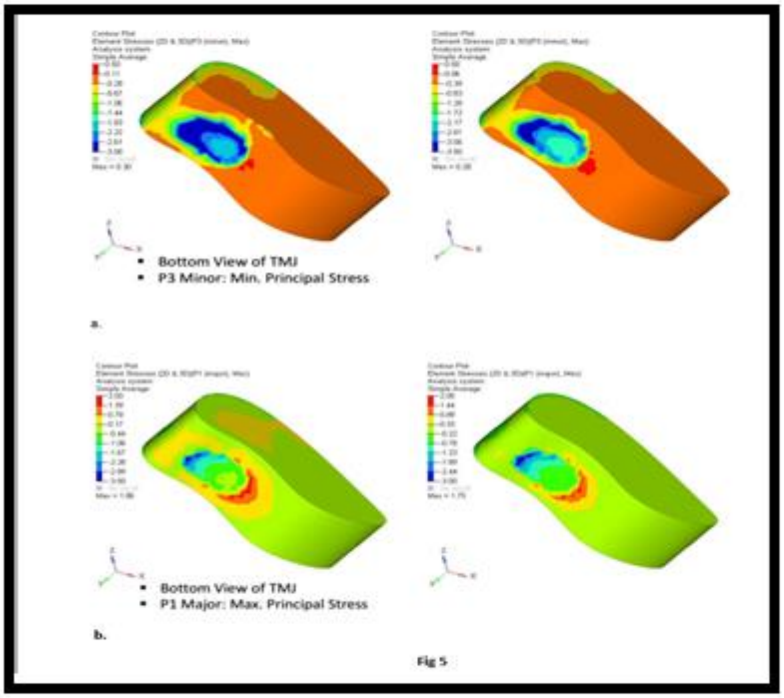

Fig 5: a. P3 in PDD without and with occlusal splint, b. P1 in PDD without and with occlusal splint.

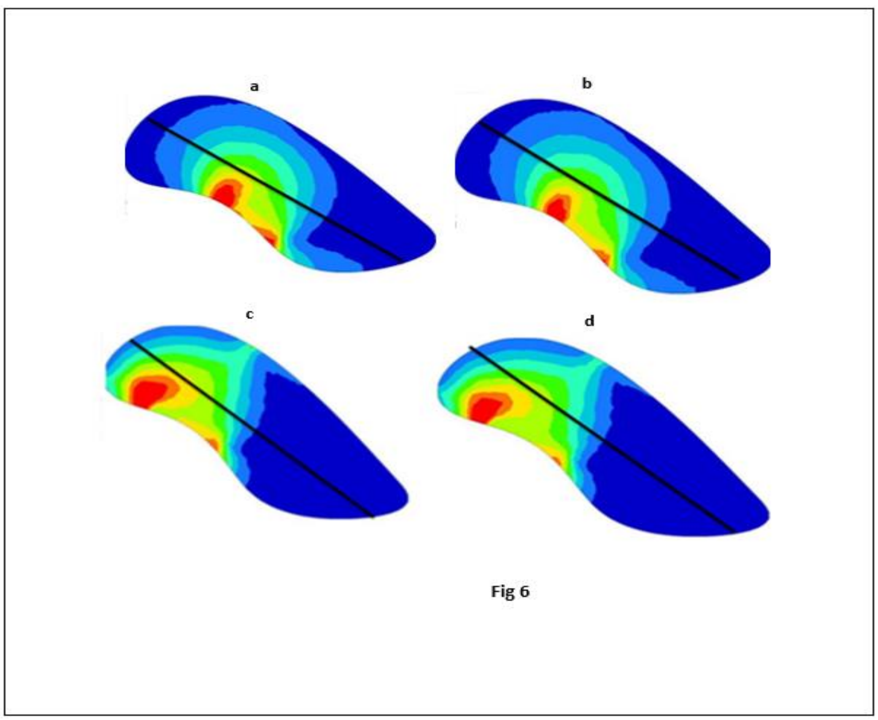

Fig 6: Stress distribution in the articular disc in normal and PDD without and with occlusal splint in anteroposterior direction, a. normal disc without occlusal splint and, b. with occlusal splint , c. PDD without occlusal splint and, d. with occlusal splint.