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STRESS AND STRAIN DISTRIBUTION IN TEMPOROMANDIBULAR JOINT AFTER MANDIBULAR GROWTH RETARDATION: A THREE DIMENSIONAL FINITE ELEMENT STUDY

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ABSTRACT

Introduction: Angle's Class III malocclusion occurs when lower teeth occlude mesial to their normal relationship or ahead by one premolar width or even more in extreme cases. Etiology of Skeletal Class III malocclusion is considered as multifactorial because of an interaction of both hereditary (genotype) and environmental factors (phenotype). Orthopedic chin cup used in treatment of Class III malocclusion apply force on temporomandibular joint to inhibit or redirect condylar growth. The effects of an orthopedic appliance essentially depend on magnitude and direction of force. Hence, the **purpose of study** was to analyze and compare the stress and strain distribution in temporomandibular joint after growth retardation of the mandible by orthopedic procedure. **Material and Methodology.** a. Construction of the geometric model. b. Conversion of geometric model to finite element model. c. Material Property Data Representation. d. Defining the boundary condition. e. Application of forces. f. Evaluation of stress and strain distribution. **Results & Conclusion.** FEM study reveals changes in stress and strain generation at different anatomical locations after applying force at symphysis region. The pogonion condyle axis is key for direction of forces to induce orthopaedic effects generated by chin cup. However, in clinical situation, study can be utilized for direction planning of chin cup force with anticipated results but magnitude has to be calculated by operator withstanding in physiologic limits of patient. The orthopaedic force can be started with 300 g per side and incrementally increased according to clinical demand, physiologic limits and skeletal age of patient to avoid untoward results of orthopaedic force applied

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Key words: finite element analysis, chin cup, class III, stress & strain on TMJ

INTRODUCTION

Angle's Class III malocclusion occurs when lower teeth occlude mesial to their normal relationship or ahead by one premolar width or even more in extreme cases.

Skeletal Class III malocclusion can be characterized by a) deficiency and/or a backward position of maxilla compared to cranial base and mandible, b) by Prognathism and/or forward position of mandible compared to cranial base and maxilla and c) combination of both. The frequency of Class III malocclusion varies among different ethnic groups. The incidence of this malocclusion in white population has been reported to be 1% to 5% whereas in Asian population incidence ranges from 9% to 19%. Few studies of human inheritance and its role in etiology of Class III malocclusion support the belief that growth and size of mandible are inherited. Thus etiology of Skeletal Class III malocclusion is considered as multifactorial because of an interaction of both hereditary (genotype) and environmental factors (phenotype).[1]

Treatment of Class III malocclusion remains a perplexing problem, particularly in young patients. A number of treatment protocols have been used to address this type of malocclusion, depending upon the localization of etiology i.e. whether fault is in maxilla or mandible. Various treatment protocols include FR-III appliance of Fränkel, orthopedic face mask, reverse activator, reverse twin block and orthopedic chin cup.

The orthopedic chin cup used in the treatment of Class III malocclusion has been recommended in those patients who have a moderately protrusive mandible and a relatively normal anteroposterior position and size of the maxilla. The rationale for a chin cup is to apply force on temporomandibular joint to inhibit or redirect condylar growth. The effects of chin cup force on craniofacial growth—especially that of mandible—have been investigated extensively with cephalometric analyses and animal experiments. The chin cup remains popular because direction of chin cup pull produces favorable treatment effects in sagittal and vertical dimension of the mandible.[2]

It is reported that chin cup force has several orthopedic effects: (1) redirection of mandibular growth, (2) backward repositioning of the mandible, (3) retardation of mandibular growth, and (4) remodeling of the mandible. The effects of an orthopedic appliance essentially depend on magnitude and direction of force. Lighter forces in range of 150 gms bilaterally to higher forces like 1200 gms bilaterally have been studied in literature.

The evaluation of the biomechanical and structural effects of mandibular growth retardation on the TMJ could lead to a better understanding of the exact effects of chin cup treatment using different force values.

Hence, the **purpose of study** was to analyze and compare the stress and strain distribution in temporomandibular joint after growth retardation of the mandible by orthopedic procedure i.e. chin cup; a three dimensional finite element method with following objectives:

1. To evaluate stress and strain distribution along three force vectors of the chin cup orthopaedic procedure i.e. a.) Vector passing through pogonion condyle axis, b.) Vector passing above 30 degrees (+30) to pogonion condyle axis and c.) Vector passing below 30 degrees (-30) to pogonion condyle axis when 600 g of chin cup force is applied bilaterally.
2. To evaluate and compare stress and strain distribution along three force vectors of the chin cup orthopaedic procedure i.e. a.) Vector passing through

pogonion condyle axis, b.) Vector passing above 30 degrees (+30) to pogonion condyle axis and c.) Vector passing below 30 degrees (-30) to pogonion condyle axis when 300 g of chin cup force is applied bilaterally.

3. To compare and correlate the two chin cup forces along the three vectors.

Material and Methodology

Steps involved in the finite element model (fig. 1- fig 5**)**

1. Construction of the geometric model.

The aim was to produce a mathematical model, which represented the biological properties of the TMJ apparatus i.e. condyle, articular disk, glenoid fossa, mandible and teeth. This was represented in terms of points (grids), lines, surfaces (patterns) and volume (hyper patches).

A 10-year-old boy with skeletal Class III, prognathic mandible and favorable growth pattern considered suitable for chin cup therapy was inducted in the study. MRI scans of the patient were procured with a magnetic resonance imaging (MRI) machine, 1.5T magnet and a 3-inch dual surface coil. Frankfort horizontal plane was marked externally and was kept horizontal to the scanning table. The MRI images were obtained in DICOM and JPEG format, comprehensible in MIMICS and the Centricity DICOM MRI viewer. (fig.1) A three dimensional (3D) computer-aided design (CAD) model of the skull was constructed on a highly sophisticated workstation using Centricity DICOM MRI viewer and MIMICS software. Only region of interest like TMJ apparatus which consists of the condyle, glenoid fossa, articular disk and the mandible was extracted from the entire skull. Data from MIMICS was imported into RAPID FORM software to create the surfaces; these surfaces were then exported in IGES (Initial Graphics Exchange Specification) format using HYPERMESH. The anatomic model consists of only surface data. As MRI image failed to capture teeth, anatomic model was used to construct geometric model of mandibular teeth having dimension and morphology found in Wheeler's textbook using ANSYS software. (fig.2)

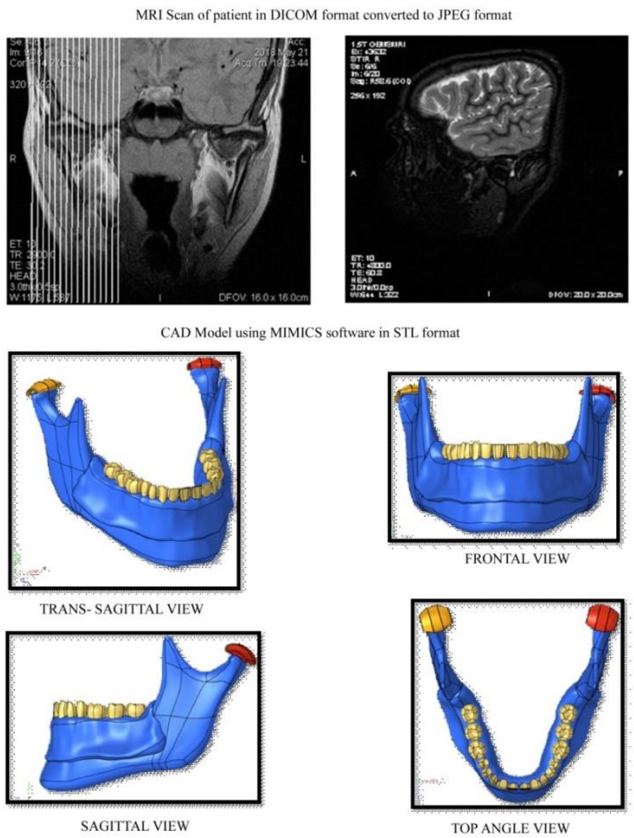


Fig 1: MRI Scan & CAD CAM Models

2. Conversion of geometric model to finite element model

The geometric model was converted into finite element model. In this study, to model the irregular geometry of TMJ apparatus and mandible, tetrahedron shape was selected as finite element. The finite element model generation was achieved with help of ANSYS software. The total numbers of elements used were 7,07,718 and total numbers of nodes used were 1,80,014 with element type 1st order tetra. (fig.2)

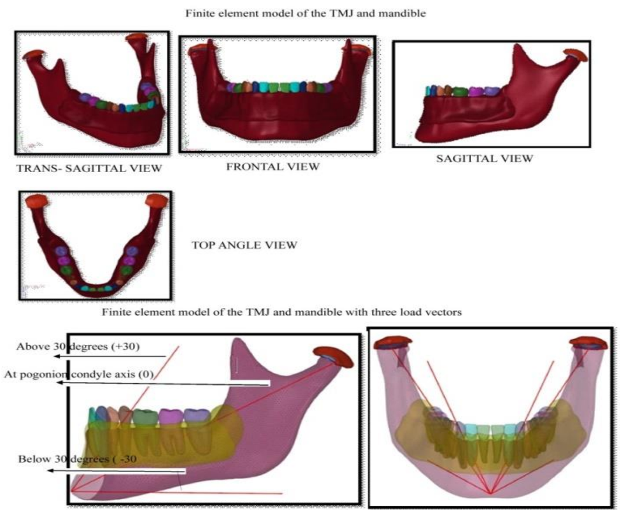


Fig 2: FME model of TMJ & Mandible

3. Material Property Data Representation

Different structures involved in this study include compact bone, articular cartilage and teeth. Entire mandible was assumed to be homogeneous and assigned the material property of compact bone. Glenoid fossa was assigned the material property of compact bone. Small gap between top surface of condyle and inner surface of glenoid fossa represented articular disk and was assigned its material property.

Young's modulus and Poisson's ratio of materials assigned are as follow

Table No. 1:

Material	**Young's modulus (N/mm)**	**Poisson's ratio**
Compact Bone	13700	0.30
Articular Cartilage	0.79	0.49
Tooth	20000	0.30

4. Defining the boundary condition

The model was fixed at superior region of temporal bone to prevent sliding movement of the model.

5. Application of forces (fig.2)

The loading was applied on symphysis region of mandible, and value of loadings was equal to 300 g and 600 g bilaterally. The direction of loading vector was determined as follows

- Vector 1- passing through pogonion – condyle axis
- Vector 2- passing 30 degrees above (+30) pogonion – condyle axis
- Vector 3- passing 30 degrees below (-30) pogonion – condyle axis

6. Evaluation of stress and strain distribution

The analysis was carried out and stress and strain distribution along TMJ apparatus and mandible was evaluated with help of scale as follows

a.) When 600 g of force was applied along-

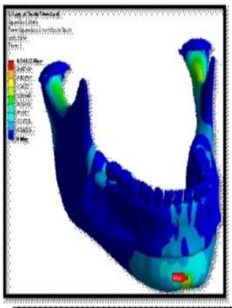
- Vector 1- passing through pogonion – condyle axis
- Vector 2- passing 30 degrees above (+30) pogonion – condyle axis
- Vector 3- passing 30 degrees below (-30) pogonion – condyle axis

b.) When 300 g of force was applied along-

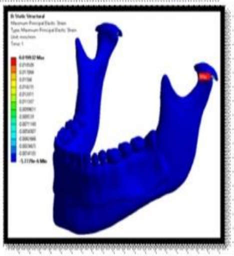
- Vector 1- passing through pogonion – condyle axis
- Vector 2- passing 30 degrees above (+30) pogonion – condyle axis
- Vector 3- passing 30 degrees below (-30) pogonion – condyle axis

FEM analysis was followed by statistical analysis.

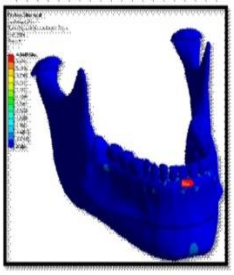
1) Statistical analysis was done by applying Wilcoxon signed rank test to compare 600 g and 300 g of force of chin cup to assess three vectors at different areas of TMJ and mandible.
2) Pearson correlation test was done to correlate 600 g and 300 g of force of chin cup to assess three vectors at different areas of TMJ and mandible.



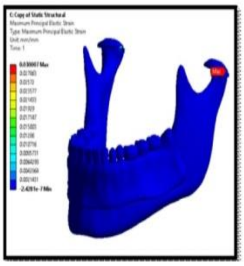
Stress distribution at the TMJ and mandible when 600 g of chin cup force is applied at the chin along the vector passing through pogonion condyle axis.



Strain distribution at the TMJ and mandible when 600 g of chin cup force is applied at the chin along the vector passing through pogonion condyle axis

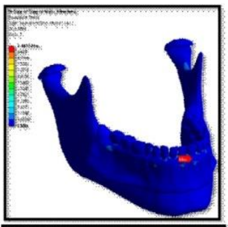


Stress distribution at the TMJ and mandible when 600 g of chin cup force is applied at the chin along the vector above 30 degrees (+30) to vector passing through pogonion condyle axis

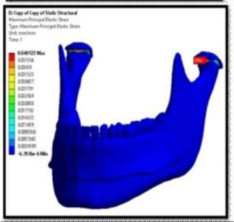


Strain distribution at the TMJ and mandible when 600 g of chin cup force is applied at the chin along the vector above 3 0 degrees (+30) to vector passing through pogonion condyle axis

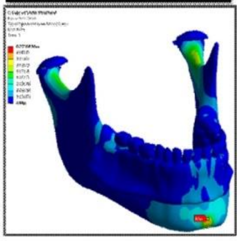
Fig 3: Stress Distribution at TMJ when Force applied



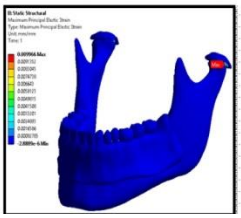
Stress distribution at the TMJ and mandible when 600 g of chin cup force is applied at the chin along the vector below 30 degrees (-30) to vector passing through pogonion condyle axis



Strain distribution at the TMJ and mandible when 600 g of chin cup force is applied at the chin along the vector below 30 degrees (-30) to vector passing through pogonion condyle axis



Stress distribution at the TMJ and mandible when 300 g of chin cup force is applied at the chin along the vector passing through the pogonion condyle axis.



Strain distribution at the TMJ and mandible when 300 g of chin cup force is applied at the chin along the vector passing through the pogonion condyle axis.

Fig 4: Stress Distribution at TMJ when Force applied

RESULTS

TMJ and mandible being a complex three dimensional structure, it was difficult to present the results of finite element analysis due to overwhelming number of choices of values to examine and plot. For this reason, several points on TMJ and mandible at different critical locations were selected i.e. neck of condyle, ramus, symphysis infradentale and articular disk.

A.) 600 g of force applied

1 **Along the vector passing through pogonion condyle axis (**fig. 3 and 4, Table no. 2)-

- Post-processing of FEA depicting stress and strain respectively when 600 g of chin cup force was applied at chin along the vector passing through condyle, A colour scale served to evaluate quantitatively the stress and strain distributions in TMJ and mandible.

- Stress generated at symphysis region was 5.4 x 10^{-1} MPa, neck of condyle was 3.12 X 10^{-1} MPa, ramus was 1.03 x 10^{-1} MPa and infradentale was 1.2x 10^{-1} MPa.
- Maximum stress distribution was at symphysis followed by neck of condyle whereas Minimum stress distribution was at ramus.
- Maximum strain distribution was at articular disk region.

2. Along the vector above 30 degrees (+30) to pogonion condyle axis (fig.3 & fig.4, table no. 2)

- Post-processing of FEA depicting stress and strain respectively when 600 g of chin cup force was applied at chin along the vector above 30 degrees (+30) to pogonion condyle axis, A colour scale served to evaluate quantitatively the stress and strain distributions in mandible and TMJ.
- Stress generated at infradentale was 6.8 X 10^{-1} MPa ,symphysis region was 6.3 X 10^{-1}MPa, neck of condyle was 2.1 x 10^{-1} MPa and ramus was 0.45 x 10^{-1} MPa
- Maximum stress distribution was at infradentale whereas minimum stress distribution was along the ramus
- Maximum strain distribution was along articular disk.

3. Along vector below 30 degrees (-30) to pogonion condyle axis (fig.3 and fig.4 and table no. 2)

- Post-processing of FEA depicting stress and strain respectively when 600 g of chin cup force is applied at chin along vector below 30 degrees (-30) to pogonion condyle axis, A colour scale served to evaluate quantitatively stress and strain distributions in mandible and TMJ.
- Stress generated at infradentale was 7.18 x 10^{-1} MPa, at neck of condyle was 6.3 X 10^{-1} MP, symphysis was 3.5 x 10^{-1} MPa and ramus was 1.48 x 10^{-1} MPa.
- Maximum stress distribution was at infradentale region whereas minimum stress distribution was at ramus.
- Maximum strain distribution was at articular disk.

Table no. 2: Stress distribution in MPa along various areas of TMJ and mandible when 600g of force is applied along three vectors.

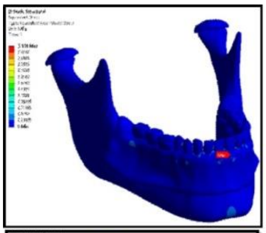
AREAS OF STRESS DISTRIBUTION	VECTORS		
	ABOVE 30 DEGREES	PASSING THROUGH CONDYLE	BELOW 30 DEGREES
NECK OF CONDYLE	2.1 X 10^{-1}	3.12 X 10^{-1}	6.3 X 10^{-1}
SYMPHYSIS	6.3 X 10^{-1}	5.4 X 10^{-1}	3.5 X 10^{-1}
INFRADENTALE	6.8 x 10^{-1}	1.2 X 10^{-1}	7.18 x 10^{-1}
RAMUS	0.45 X 10^{-1}	1.03 X 10^{-1}	1.48 X 10^{-1}

B.) 300 g of force applied (Table No. 3)

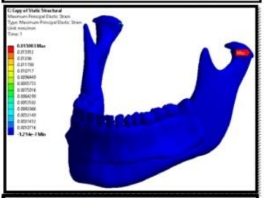
- **Along the vector passing through pogonion condyle axis** (fig.4, fig 5 and table no. 3) –
  - Post-processing of FEA depicting stress and strain respectively when 300 g of chin cup force is applied at chin along vector passing through pogonion condyle axis, A colour scale served to evaluate quantitatively stress and strain distributions in mandible and TMJ.
  - Stress generated at symphysis was 2.7 x 10^{-1} MPa, at neck of condyle was 1.6 X 10^{-1} MPa, ramus was 0.63 x 10^{-1} MPa and infradentale was 0.6 x 10^{-1} MPa.
  - Maximum stress distribution was at symphysis region followed by neck of condyle whereas minimum stress distribution was along infradentale.
  - Maximum strain distribution was at articular disk.
- **Along vector above 30 degrees (+30) to pogonion condyle axis** (fig.4 and fig 5, table no. 3**)-**
  - Post-processing of FEA depicting stress and strain respectively when 300 g of chin cup force is applied at chin along vector above 30 degrees (+30) to pogonion condyle axis. A colour scale served to evaluate quantitatively stress and strain distributions in mandible and TMJ.
  - Stress generated at infradentale was 4.8 X 10^{-1} MPa, at symphysis was 4.0 X 10^{-1} MPa, along neck of condyle was 0.58 x 10^{-1} MPa and ramus was 0.29 x 10^{-1} MPa.
  - Maximum stress distribution was at infradentale whereas minimum stress distribution was seen at ramus.
  - Maximum strain was distributed at articular disk.
- **Along vector below 30 degrees (-30) to pogonion condyle axis** (fig.4 and fig 5, table no. 3)
  - Post-processing of FEA depicting stress and strain respectively when 300 g of chin cup force is applied at chin along vector below 30 degrees (-30) to pogonion condyle axis, A colour scale served to evaluate quantitatively stress and strain distributions in mandible and TMJ.
  - Stress generated at infradentale was 5.2 X 10^{-1} MPa, neck of condyle was 3 X 10^{-1} MPa, along symphysis was 1.8 x 10^{-1} MPa and at ramus was of 0.4 x 10^{-1} MPa.
  - Maximum stress distribution was seen at infradentale region whereas minimum stress distribution was seen at ramus.
  - Maximum strain distribution was at articular disk

Table no. 3: Stress distribution in MPa along various areas of TMJ and mandible when 300g of force is applied along the three vectors.

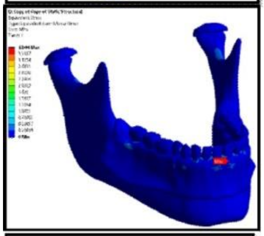
AREAS OF STRESS DISTRIBUTION	VECTORS		
	ABOVE 30 DEGREES	PASSING THROUGH CONDYLE	BELOW 30 DEGREES
NECK OF CONDYLE	0.58 X 10^{-1}	1.6 X 10^{-1}	3 X 10^{-1}
SYMPHYSIS	4.0 X 10^{-1}	2.7 X 10^{-1}	1.8 X 10^{-1}
INFRADENTALE	4.8 X 10^{-1}	0.6 X 10^{-1}	5.2 X 10^{-1}
RAMUS	0.29 X 10^{-1}	0.63 X 10^{-1}	0.4 X 10^{-1}



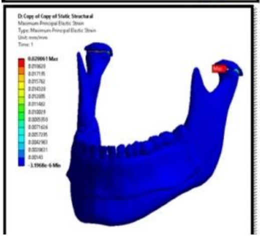
Stress distribution at the TMJ and mandible when 300 g of chin cup force is applied at the chin along the vector above 30 degrees (+30) to vector passing through pogonion condyle axis.



Strain distribution at the TMJ and mandible when 300 g of chin cup force is applied at the chin along the vector above 30 degrees (+30) to vector passing through pogonion condyle axis.



Stress distribution at the TMJ and mandible when 300 g of chin cup force is applied at the chin along the vector below 30 degrees (-30) to vector passing through pogonion condyle axis



Strain distribution at the TMJ and mandible when 300 g of chin cup force is applied at the chin along the vector below 30 degrees (-30) to vector passing through pogonion condyle axis

Fig 5: Stress Distribution at TMJ when Force applied

Statistical analysis (Table No. 4, 5, 6, 7 and Graph No. 1)

- Statistical analysis was done to compare and correlate 2 chin cup forces i.e. 600 g and 300 g applied along 3 Vectors i.e. vector passing through pogonion condyle axis, vector above 30 degrees (+30) to pogonion condyle axis and vector below 30 degrees (-30) to pogonion condyle axis at different areas of TMJ and mandible.
- The data was analysed with Statistical Package for Social Sciences (SPSS) for Windows, version 26.0 (IBM Corp., Armonk, N.Y., USA).
- Confidence intervals were set at 95% and values of $p < 0.05$ were interpreted as statistically significant.
- Wilcoxon signed rank test (table no 4) was applied to compare 600 g and 300 g of force of chin cup to assess three vectors at different areas.
- Pearson correlation test (table no 5,6,7) was applied to correlate 600 g and 300 g of force of chin cup to assess three vectors at different areas

Table 4: Comparison of 2 Chin cup forces i.e. 600 g and 300 g applied along 3 Vectors at Different Areas of TMJ and mandible.

Vectors	Mean	Std. Deviation	Z-value	p-value	Significant
600 g of Force at 30°	0.39	0.312	-1.82	0.06	Non-Significant
300 g of Force at 30°	0.24	0.231			
600 g of Force at 0°	0.26	0.204	-1.82	0.06	Non-Significant
300 g of Force at 0°	0.13	0.099			
600 g of Force at -30°	0.45	0.258	-1.82	0.06	Non-Significant
300 g of Force at -30°	0.26	0.203			

Table no 5: Correlation of 2 Chin cup forces i.e. 600 g and 300 g applied along Vector above 30 degrees (+30) to pogonion condyle axis at Different Areas of TMJ and mandible.

Correlations		600g, + 30 degrees	300g, + 30 degrees
600 g + 30 degrees	Pearson Correlation	1	.984*
	Sig. (2-tailed)		.016
	N	4	4
300g +30 degrees	Pearson Correlation	.984*	1
	Sig. (2-tailed)	.016	
	N	4	4

*. Correlation is significant at the 0.05 level (2-tailed).

Table no 6: Correlation of 2 Chin cup forces i.e. 600 g and 300 g applied along Vector passing through pogonion condyle axis at Different Areas of TMJ and mandible.

Correlations		600g, 0 degree	300g, 0 degree
600g, 0 degree	Pearson Correlation	1	.998**
	Sig. (2-tailed)		.002
	N	4	4
300g, 0 degree	Pearson Correlation	.998**	1
	Sig. (2-tailed)	.002	
	N	4	4

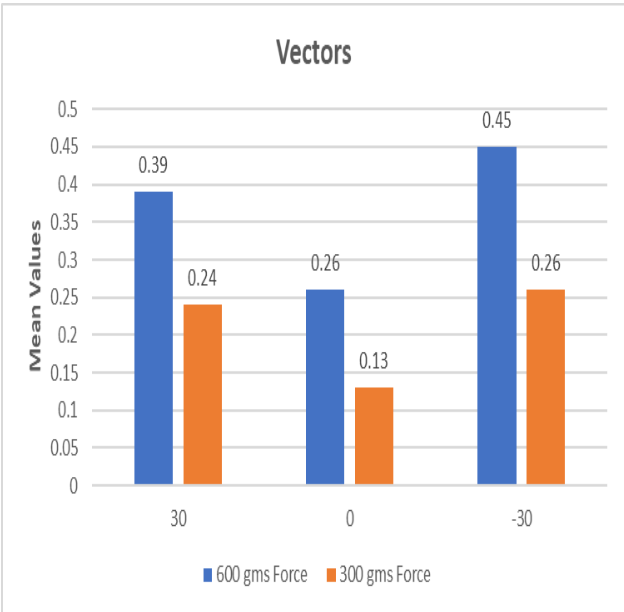
**. Correlation is significant at the 0.01 level (2-tailed).

Table no 7: Correlation of 2 Chin cup forces i.e. 600 g and 300 g applied along Vector below 30 degrees (-30) to pogonion condyle axis at Different Areas of TMJ and mandible.

Correlations		600g, -30 degrees	300g, -30 degrees
600g -30 degrees	Pearson Correlation	1	.951*
	Sig. (2-tailed)		.049
	N	4	4
300g, -30 degrees	Pearson Correlation	.951*	1
	Sig. (2-tailed)	.049	
	N	4	4

*. Correlation is significant at the 0.05 level (2-tailed).

Graph 1: Comparison of Mean Values for 600 and 300 g of Force at Different Areas of TMJ and mandible along three vectors.



Thus, results of this study are as follows

1. Minimum stress distribution at TMJ and mandible was seen at 300 g of force for 0 degree i.e. along vector passing through pogonion condyle axis.
2. Maximum stress at TMJ and mandible was seen with 600 g of force at -30 degrees i.e. along vector 30 degrees below vector passing through pogonion condyle axis.
3. There was no statistically significant difference seen between 600 g and 300 g of force for 3 vectors. However, sample size was too small to give reliable calculation for Wilcoxon signed rank test.
4. There was statistically significant correlation seen between 600 g and 300 g of force for 3 vectors. However, sample size was too small to give reliable calculation for Pearson correlation test.
5. Maximum strain distribution was seen at articular disk for all vectors and force evaluated in this study.

DISCUSSION

The effects of chin cup essentially depend on magnitude of force and direction along which force is applied apart from patient's age, facial skeletal pattern, treatment timing and duration. Chin cup can broadly be classified into two types a) vertical pull chin cup and b) occipital pull chin cup. In vertical pull chin cup direction of force is above condylar head and in occipital pull chin cup force vector passes below condylar head. Vertical pull chin cup is used in patients with steep mandibular plane angles and excessive lower anterior facial heights whereas, occipital pull chin cup are used in patients of mandibular Prognathism.

There has been much debate regarding force magnitude needed to achieve adequate force levels at condyle to retard he mandibular growth. In an overview of chin cup literature, treatment protocols used forces between 200 and 900 g. **Graber**[4-5] proposed that use of force levels similar to that of Milwaukee brace in range of at least 2 pounds (900 g) per side would obtain orthopedic changes. [4] There have been no studies in literature which have attempted to identify minimum amount of force or minimum threshold of force needed to obtain an orthopedic change. A relatively low force magnitude of 150–200 g was utilized by **Thilander**. Higher forces of 400 g were used by **Tanne**[3] **et al. Ritucci and Nanda** investigated effect of a chin cup with 500 g orthopedic force. **Gokalp and Kurt and Tuncer et al** reported use of 600 g. Stronger forces of 1000–1200 g were evaluated by **Deguchi and Kitsugi.** [6]

Katashiba et al. found that use of a chin cup with lighter force, but with a longer wearing time, provided more skeletal correction than use of heavier force for a shorter time. On the other hand, it was reported that a high force was needed to achieve skeletal effects with a chin cup. **Deguchi**[7] **et al.** reported that short-term chin cup treatment showed a significant backward rotation of mandible, while long-term application of chin cup force significantly inhibited growth of ramus height and body length of mandible and showed a significant closing of gonial angle. **Yasser L. Abdelnaby**[8] evaluated dental and skeletal effects of chin cup using two different force magnitude i.e. 300 g and 600 g. He concluded that utilization of either force had same effects except that higher force had a more pronounced effect in reduction of ramus height. Therefore, in this study, two force values i.e. 300 g of force and 600 g of force were used to evaluate stress and strain induced in area of TMJ and mandible followed by chin cup therapy.

From these morphologic changes of mandible, an assumption may be derived that compressive stress on condyle is related to inhibition of condylar growth. To explore association between mechanical stress and bone remodeling, biomechanical studies have been carried out like photo-elastic study, strain gauge and holographic interference technique.

In this study, Finite Element Method (FEM) introduced by Farah J.W et al was applied to assess biomechanical effect produced by chin cup when forces of 300 g and 600 g were applied bilaterally along three vectors.

The FEM results in this study revealed that lowest stress distribution was observed when forces were applied along vector passing through pogonion - condyle axis. In accordance to this FEM study, similar results were found by **Faruk Ayhan Basciftci**[9] where chin cup with 500 g of force was applied in a direction from chin toward the mandibular condyle, coronoid process, and a point anterior to coronoid process. He concluded that force vector passing through condylar head induced lowest stress levels with clockwise rotation of mandible.

On contrary, **Tanne, Tanaka and Sakuda**[10]**,** in their study, when an orthopedic chin cup force of 400 *g* (3.92 N) was applied at pogonion of mandible in directions ranging from -50 ° (below condyle) to 40 ° (above condyle) relative to line connecting pogonion - condyle axis, concluded that 30 ° or 40 ° force is an ideal direction for application of orthopedic chin cup force in terms of biomechanics which produces balanced stress distribution for TMJ components.

In this FEM study, maximum stress distribution was found along vector below 30 degrees (i.e.-30) which was in accordance to results found by **Tanne, Tanaka and Sakuda.**[10] They concluded that when directional angle was around - 50 °, variation in stresses in temporomandibular joint was greatest.

Thus, in this FEM study, it was concluded that as vector moved away from condylar head stress levels increased and biomechanically balanced stress distribution was observed when force vector passed through pogonion - condyle axis.

When chin cup forces were applied along vector passing through condyle, maximum stress distribution was observed along symphysis region, neck of condyle followed by infradentale and ramus. This explains clinical findings of **Hiroshi Mimura, Toshio Deguchi**[11] **and Jose Antonio** that chin cup produces condyle neck compression, slender mandibular neck and symphysis narrowing,

In current study when chin cup forces passed through vector below 30 degrees (i.e. -30) produced maximum stress distribution along infradentale that is area above mid symphysis region. This is in accordance with clinical study of chin cup therapy done by **Maria Chatzoudi et al** [12] which concluded that occipital chin cup affects dentoalveolar area in lower third of face.

As minimum amount of force or minimum threshold of force needed to obtain an orthopedic change is not yet identified in literature, force values used in this study was 600 g and 300 g. Statistical analysis was done to compare and correlate 600 g and 300 g of force of chin cup to assess three vectors at different areas using Wilcoxon signed rank test and Pearson correlation test respectively.

It was concluded that maximum stress and strain distribution was observed when 600 g of force was applied along vector below 30 degree (-30) and minimum stress and strain distribution was observed when 300 g of force was applied along vector passing through pogonion- condyle axis. However, there was no statistically significant difference seen between 600 g and 300 g of force for 3 vectors and two forces along three vectors used significantly correlated. This explains evaluation of **Yasser L. Abdelnaby**[8] where he evaluated dental and skeletal effects of chin cup using two different force magnitude i.e. 300 g and 600 g. He concluded that utilization of either force had same effects except that higher force had a more pronounced effect in reduction of ramus height.

However, **Aubrey Barrett et al** [13] evaluated effectiveness of light-force (150 – 200g) chin cup appliance in correcting skeletal and dentoalveolar components and concluded that light-force chin cup did not produce orthopedic changes in mandible.

Another clinical study was conducted by **Toshio Deguchi, Takao Kuroda Yasuhiro Minoshima, and Tom M. Graber**[14] where effects of short-term and long-term chin cup therapy were studied. They gave chin cups with an orthopedic force of 500 g for 31 months (short-term treatment group) and chin cup force of 250 to 300 g for 86 months (long-term treatment group) which were compared. He concluded that short-term treatment resulted in a slight improvement in ANB angle and Wits appraisal, while long-term treatment resulted in a significant improvement in ANB angle and Wits appraisal, and also suggested to retain changes by wearing the appliance during sleep, with a force of 200 gm applied to center of chin.

Thus, it should be noted that nature of stress distribution is influenced by direction of chin cup and force magnitude. The balanced stress distribution is achieved when chin cup forces are directed through pogonion – condyle axis. The differences in location and magnitude of stress levels with various force vectors call for careful selection of patients and responsible planning and application of chin cup, because the force vector is an important determinant of the orthopedic effects of the chin cup. Also, chin cup should be worn till completion of growth to avoid relapse tendencies.

Higher force magnitude of chin cup for short duration or lower magnitude of chin cup force for longer duration can be worn as corrective therapy to bring about orthopedic or skeletal changes and lower force magnitude can be worn as retentive therapy once the orthopedic changes are achieved to avoid relapse tendency or late mandibular growth.

CONCLUSION

In this FEM study, different amount and direction of force was studied passing through pogonion condyle axis and its adjacent areas at different angulation to evaluate stress and strain distribution at various areas of TMJ and mandible. The results obtained in this FEM study were statistically analyzed and conclusion drawn as follows-

- Minimum stress and strain distribution was observed when forces passed along the axis passing from pogonion to condyle.
- Maximum stress and strain distribution was observed when forces were passed below 30 degrees (-30^0) to the axis passing from pogonion to condyle.
- There was no statistically significant difference seen between 600 g and 300 g of force for the 3 vectors analysed i.e. along pogonion to condyle, above 30 degree (+30) and below 30 degrees (-30).
- There was statistically significant correlation seen between 600 g and 300 g of force for the 3 vectors analysed i.e. along pogonion to condyle, above 30 degrees (+30) and below 30 degrees (-30).
- FEM study reveals changes in stress and strain generation at different anatomical

locations after applying force at symphysis region. The pogonion condyle axis is key for direction of forces to induce orthopaedic effects generated by chin cup. However, in clinical situation, study can be utilized for direction planning of chin cup force with anticipated results but magnitude has to be calculated by operator withstanding in physiologic limits of patient.

- The orthopaedic force can be started with 300 g per side and incrementally increased according to clinical demand, physiologic limits and skeletal age of patient to avoid untoward results of orthopaedic force applied.

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