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# Does the flattening of the curve of Spee affect the chewing force distribution in the mandible? (3D finite element study)

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## Abstract:

**OBJECTIVE:** To search the effects of Curve of Spee (COS) flattening on the stresses and displacement on the different mandible landmarks and lower teeth during posterior teeth loading using three-dimensional (3D) finite element analysis.

**MATERIALS AND METHODS:** Three-dimensional hemi mandibular model was created from real selected mandible. The lower teeth were aligned originally in a curved form with 2.4 mm depth at the cusp tip of the second premolar. Another replica with flat aligned teeth was formed to confirm the analysis by up-righting premolars and molars. A load was applied at mesio-buccal cusp of the lower first molar on both models, and the resultant stresses and displacements on the mandibular landmarks and the lower teeth were tested.

**RESULTS:** Von Mises over the mandible was higher in flat than in curve model. The highest stress levels were detected at the mesio-buccal cusp tip of first molar for flat and curved simulation (5053, 3304) Mpa respectively. Mesio-distally, the teeth displacement was higher in curve model than in flat one. The maximum distal displacement, in flat model, was seen in central and lateral incisors. While, in curve model, the maximum distal displacement was grasped within first and second premolars.

**CONCLUSIONS:** Flattening the COS magnifies the stresses over the whole mandible and reduces lower teeth displacement mesio-distally. We speculated that the readjustment of the COS after orthodontic treatment could reduce the stress and displacements on the lower anterior teeth and decrease the lower anterior teeth crowding relapse.

## Keywords:

Chewing force, curve of Spee, finite element, lower anterior crowding

## Introduction

The Curve of Spee (COS) is an identifying characteristic of normal alignment of the lower teeth which had been observed in the sagittal profile view of the human skulls.<sup>[1]</sup> It was first noted by Graf Von Spee in 1890.<sup>[2]</sup> Recent studies described it, as a curvature extended from disto-buccal cusps of the most posterior teeth to the incisor edge of the central's incisors.<sup>[3]</sup> The literatures

stated that COS developed as a result of the mesial tilting of the long axis of the lower molar teeth incompetence to the efficiency of muscles of mastication.<sup>[4-6]</sup> COS improves food chewing throughout preserving upper and lower teeth contacts during function as it enhances free lower jaw movements.<sup>[2]</sup> Also, COS has a role in facial aesthetic through its enterprise of an esthetical smile.<sup>[7]</sup>

COS was evaluated by two main techniques; the first one: as a radius of inferior portion of circle that extended from anterior border of the Condyle to the buccal cusps of second and

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first molar, and pass to contact the cusp tips of premolars and canine respectively, and terminated on the incisor edge of the two central incisors.<sup>[8]</sup> The second technique of COS evaluation was depending on the arch length and depth of the posterior teeth according to the occlusal plane.<sup>[9]</sup>

However, there is a disagreement about the measurement methodology for COS. Some authors excluded lower incisors during measurements of Spee's curve. As, they are (sometimes) super-erupted, and a raised COS depth was obtained.<sup>[10]</sup>

Recently, with advance technology improvements and the used of three-dimensional (3D) scanner, COS measurement became more easy and accurate by using a digital cast analysis. While, previously all the measurements were obtained from hard study models or their photographs, using a divider, calliper, and a coordinate apparatus.<sup>[11]</sup>

During comprehensive orthodontic treatment, leveling of COS of the mandibular teeth is imperative step to establish proper incisors relation and posterior teeth occlusion, especially for deep bite correction<sup>[12,13]</sup>; however, there are disagreements according to COS leveling techniques used to improve the stability of the orthodontic outcomes.<sup>[14]</sup> Since 1972, Andrews<sup>[15]</sup> advised leveling the COS to a flat plane to assist the construction of an optimal occlusion, regardless of its effects on the mandible or Temporo-mandibular joint (TMJ) or even the lower teeth. As, Kanavakis and Mehta<sup>[16]</sup> found a correlation between the sound in TMJ with the COS flattening.<sup>[16]</sup>

The finite element analysis (FEA) technique has been wildly used to study the dynamics of the stomatognathic system.<sup>[17]</sup> It has a capacity for analyzing the frequency, intensity, direction, duration, and of occlusal forces, also it unable to study mandibular biomechanics and to evaluate deformations, tensions, and displacements that may occur throughout the mandible.<sup>[18,19]</sup> The amazing advantage of this FEA is the study of areas that are impossible to access without any risks to the human.<sup>[17,19]</sup>

Stability of the COS as well as orthodontic outcomes after orthodontic treatment is a matter of arguments.<sup>[1]</sup> As there are no clear clarifications for such relapse. The role of the light continuous force which is produced during daily chewing could be a factor for such deterioration. So, this study was aimed to find out the variations in stresses and displacements after flattening COS, on the mandible and lower teeth during posterior teeth biting, using the FEA.

### Method and Materials

This study is coordinating with the roles of the ethics committee of the college of Dentistry/University of Mosul/Iraq no. 4S/475 in 25/3/2019.

All the necessary procedures for FEA and model construction were carried out as model creations, definitions of the elements form and the properties of the material under load application as well as boundary condition and load application.<sup>[20-23]</sup>

In the current study, 30 skulls for males (judged by three orthodontists to be normal by visual inspections) were examined. Only 10 skulls followed our inclusion criteria, which include: full dentition excluding third molar, class I molar and canine relationships, and without any sever crino-facial abnormalities. The COS of the lower teeth of the 10 selected skulls were measured according to previously authorized methods.<sup>[24-26]</sup> The depth of the bottom of COS was calculated using a Mitutoyo electronic caliper (Mitutoyo, Kawasaki, Japan) as the vertical distance between the deepest cusp tip and occlusal flat plane (a flat metal ruler was seated over the teeth for COS evaluation). The COS line was passed over the mandibular dental teeth extending from the incisal edge of the centrals, passing over the cusp tips of the canine and premolars to touch the mesio-buccal cusp of the lower first molar to the distal cusp tips of the lower second molar [Figure 1]. The average depth of COS for the 10 selected mandibles was 2.4 (± 0.24) mm. The mandible which have a COS depth value near the average (2.4 mm) was selected to be our target model to be use for FEA (The deepest point of it was on the cusp tip of the second premolar). However, this depth value is compatible with previous study.<sup>[27]</sup> Auto cad (2010) Program was used for drawing 3D model of one half of mandible<sup>[23,28]</sup> which was analog to the selected mandible. The previous authorized methods were used to create our 3D model.<sup>[29,30]</sup> All the linear measurements were taken using a Mitutoyo electronic caliper from the selected mandible. The periodontal ligaments were excluded in this study, because of the difficulties in mechanical modeling as well as the complexity of its mesh mathematical calculations.<sup>[31,32]</sup> The first model was

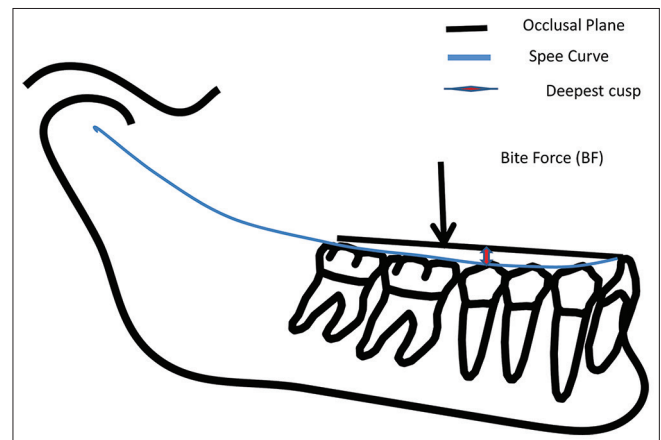


Figure 1: Schematic the curve of Spee extension and its bottom on the cusp tip of the lower second premolar



### Mandibular anatomical landmarks Displacement

Maximum displacement seems to be nearly the same for both models in all three directions. Zero movement was detected in Posterior mandibular condylar (PCo), Anterior mandibular condylar (ACo), and Superior mandibular condylar (SCo). The presentation of X, Y, and Z for displacement depend on how you set your model according to these global coordinate.

### X-displacement

X-displacement was illustrated as antero-posterior (sagittal) movement of mandible, positive value indicate back ward (distally) displacement, negative value specify mesial (forward) displacement. The highest positive X-displacement was seen in the Gonioninferius ( $Go_{inf}$ ) (+0.117, +0.110) mm, Gonion (Go) (+0.112,+0.110) mm for flat and curve simulation respectively, and extended along the inferior border of the mandible. The high value for distal X-movement were observed in Gonion posterior ( $Go_{post}$ ) (+0.099, +0.104) mm and Menton (Me) (+0.078,+0.082) mm for both flat and curve simulations respectively. Moderate positive X-displacements for both models were detected within Posterior border of ramus (Pb) (+0.057, +0.086) mm,

Coronoid (Cor) (+0.052,+0.057) mm, Anterior border of ramus (Ab) (+0.024, +0.046) mm, Pogonion (Pog) (+0.037, +0.065) mm and Central incisor edge (+0.042, +0.026) mm respectively. Less positive X-displacement was noted Supramentale (B) and Infradental (Id). While, negative (mesial) X-displacement was noted in mesio-buccal cusp tip of first molar,  $J_{lat}$  and  $J_{med}$ , as shown in Figures 6 and 7.

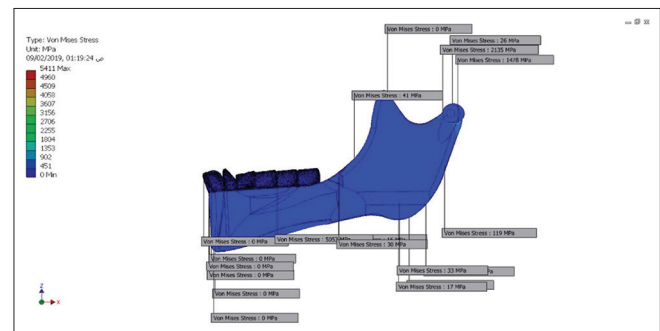
### Y-displacement

Y-displacement specify transverse (in-out) movement, positive value means inward twisting of the mandible. The mandible under masticatory force simulation was bended in inward direction, the highest value in both flat and curve models were noticed inMenton (Me)(+0.257, +0.259) mm and Pogonion (Pog) (+0.237,+0.254) mm respectively. High inward bending was seen in Supramentale (B) (+0.227, +0.230) mm, Infra-dental (Id)(+0.2134,+0.225) mm and central incisor edge (+0.206,+0.213) mm respectively. Moderate Y-displacement for both simulation were detected within mesio-buccal cusp tip of

**Table 2: Maximum Von Mises stress and displacement values for flat and curve models**

Variables	Flat model	Curve model
Von mises (Mpa*)	5411	3452
X-Displacement (mm**)	0.119	0.1187
Y-Displacement (mm)	0.2579	0.26
Z-Displacement (mm)	0.4548	0.4561

\*(MPa) Mega Pascal, \*\* (mm) millimeter



**Figure 4:** Schematic the magnitude and distribution of Von mises stress in flat model

**Table 3: Von Mises stress and displacement in different anatomical landmarks**

Land marks	Flat von mises (Mpa)	Curve von mises (Mpa)	Flat X-displace (mm)	Curve X-displace (mm)	Flat Y-displace (mm)	Curve Y-displace (mm)	Flat Z-displace (mm)	Curve Z-displace (mm)
Posterior mandibular condylar (PCo)	1478	912	0	0	0	0	0	0
Anterior mandibular condylar (ACo)	2135	1370	0	0	0	0	0	0
Superior mandibular condylar (SCo)	26	19	0	0	0	0	0	0
Coronoid (Cor)	0	0	+0.052	+0.057	+0.003	+0.002	0.083	-0.090
Anterior border of ramus (Ab)	41	23	+0.024	+0.046	+0.073	+0.091	0.151	-0.164
Posterior border of ramus (Pb)	119	41	+0.057	+0.086	+0.021	+0.040	+0.006	+0.020
Jlat	30	18	0.050	0.056	+0.100	+0.116	+0.176	+0.198
Jmed	15	2	0.013	0.009	+0.095	+0.086	+0.199	+0.187
Gonion posterior ( $Go_{post}$ )	10	2	+0.099	+0.104	+0.058	+0.074	+0.048	+0.073
Gonion (Go)	5	3	+0.112	+0.110	+0.080	+0.084	+0.080	+0.088
Gonioninferius ( $Go_{inf}$ )	17	4	+0.117	+0.110	+0.088	+0.089	+0.092	+0.098
Menton (Me)	0	0	+0.078	+0.082	+0.257	+0.259	+0.446	+0.443
Pogonion (Pog)	0	0	+0.037	+0.065	+0.237	+0.254	+0.442	+0.447
Supramentale (B)	0	0	+0.005	+0.016	+0.227	+0.230	+0.447	+0.445
Infradental (Id)	0	0	+0.019	+0.005	+0.213	+0.225	+0.444	+0.445
Central incisor edge	0	0	+0.042	+0.026	+0.206	+0.213	+0.450	+0.451
Mesio-buccal cusp tip of first molar	5053	3304	0.007	0.049	+0.147	+0.155	0.300	-0.300

(MP) Mega Pascal, (mm) millimeter



first molar(+0.147,+0.155) mm,  $J_{lat}$  (+0.100,+0.116) mm, and  $J_{med}$  (+0.095,+0.086) mm, Gonioninferius ( $Go_{inf}$ ) (+0.088,+0.089) mm, Gonion ( $Go$ )(+0.080,+0.084) mm, Anterior border of ramus ( $Ab$ )(+0.073,+0.091) mm, and Gonion posterior ( $Go_{post}$ ) (+0.058,+0.074) mm in sequence. Low Y-displacement was seen in Coronoid ( $Cor$ ) and Posterior border of ramus ( $Pb$ ), see Figures 8 and 9.

**Z-displacement**

Z-displacement identify vertical (up-down) movement, positive values pointed to upward movement of the mandible negative values indicate downward displacement. Maximum positive values (upward movement) seen within central incisor edge (+0.450,+0.451) mm, Supramentale (+0.447,+0.445) mm, Infradental (+0.444,+0.445) mm, Pogonion (+0.442,+0.447)

mm and Menton (+0.446,+0.443) mm for both flat and curved models respectively. Highest positive z-displacement seen in  $J_{med}$  (+0.199,+0.187) mm and  $J_{lat}$ (+0.176,+0.198) mm, the high positive displacement detected within  $Go_{inf}$ (+0.092,+0.098) and  $Go$ (+0.080,+0.088) mm, moderate upward movement seen in  $Go_{post}$ (+0.048,+0.073) mm, low values noted within  $Pb$ (+0.006,+0.02) mm respectively for flat and curve simulations. While, negative (downward) Z-movement noted within Coronoid ( $Cor$ ), Anterior border of ramus ( $Ab$ ), mesio-buccal cusp tip of first molar. High downward displacement grasped in mesio-buccal cusp tip of first molar (0.300, 0.3) mm for both models correspondingly. Moderate negative Z-movement values observed in  $Ab$  (0.151, 0.164) mm while Lowest values noted in  $Cor$  (0.083, 0.090) mm for both simulations respectively. See Figures 10 and 11.

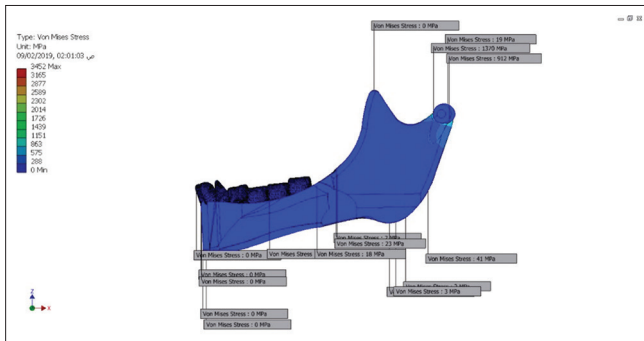


Figure 5: Schematic the magnitude and distribution of Von mises stress in curve plane

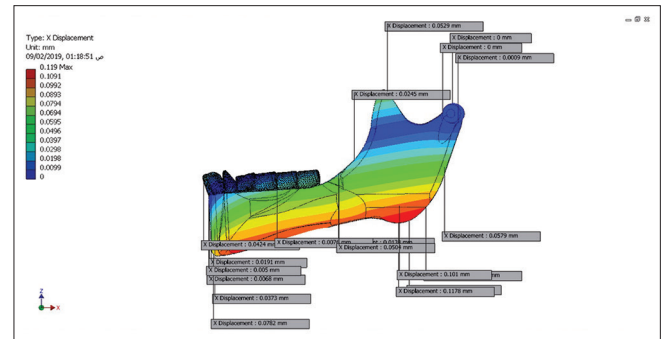


Figure 6: Schematic the magnitude and distribution of X-displacement in flat plane

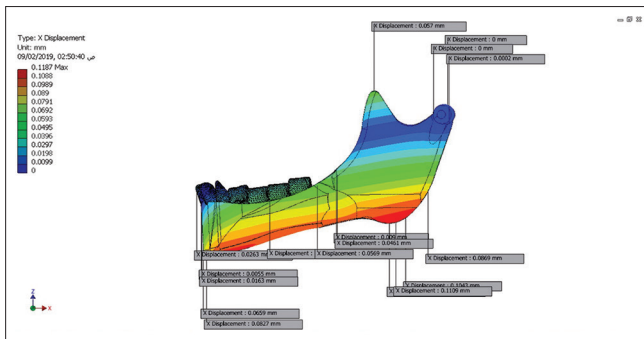


Figure 7: Schematic the magnitude and distribution of X-displacement incurve plane

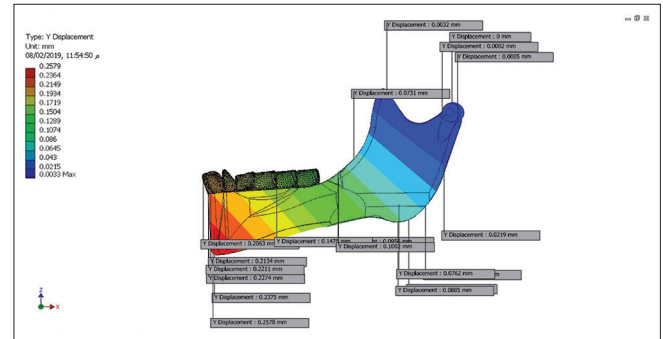


Figure 8: Schematic the magnitude and distribution of Y-displacement in flat plane

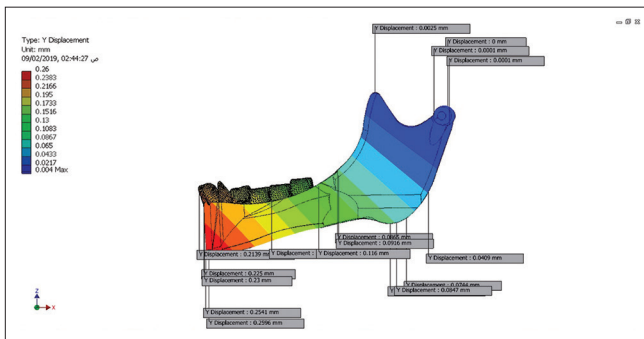


Figure 9: Schematic the magnitude and distribution of Y-displacement in curve plane

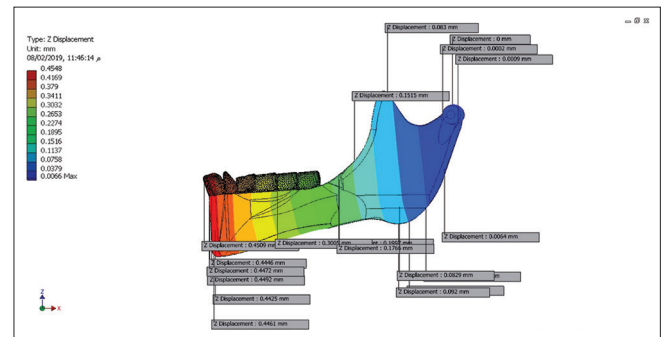


Figure 10: Schematic the magnitude and distribution of Z-displacement in flat plane



force (560 N) over the mesio-buccal cusp of lower first molar was applied.<sup>[35]</sup> In our FE model, the deepest point of the COS was (2.4 mm) which consider normal according to Bayadas *et al.*<sup>[9]</sup> and Ahmad *et al.*<sup>[27]</sup> Although, some authors considered up to 2 mm is normal Spee curve.<sup>[1]</sup> According to Koyama,<sup>[36]</sup> the deepest point of the COS located in the second premolar at the midpoint of the COS, compared with Shannon and Nanda<sup>[1]</sup> which claimed that high percentage of COS bottom located on the mesio-buccal cusp of lower first molar. However, it's positioned moved distally during treatment and retain-back to their mesial position.<sup>[26,41]</sup>

Our hemi mandible model geometry was derived from real physical dimensions taken from the selected desiccated mandible and introduced to the FE program with 922592 nodes and 637,262 elements for more fine details on stress and strain distribution over the jaw.<sup>[42-44]</sup>

In the first curved model, with 2.4mm depth of the COS, the von mises stress was distributed throughout the mandible. The most stress concentration point was predetermined on the mesio-buccal cusp tip of first permanent molar, this consider theoretically true as, this is the point of force application. While, high stress value was observed in the anterior mandibular condylar (ACo) and the posterior mandibular Condylar (PCo), because these are adjacent to our fixation area (mandibular Condyle), as the reaction force appeared in higher stress level, this agree with Basciftci *et al.*<sup>[45]</sup> and Wan *et al.*,<sup>[46]</sup> as they found that the stress accumulation appear at mandibular Condyle, as a result of the mandibular Condyle restraining in the simulation. This considers being representative finding, because the mandibular Condyle is connected to the cranium by several ligaments and muscles that limit the mandible movements during function.

Zero stress values was noted in Menton, Pogonion, Supramentale, Infradental, Central incisor edge and Coronoid, this is again accepted hypothetically because they were far from the point of force application and restriction area (the Condyle), this is once more coordinate with Basciftci *et al.*<sup>[45]</sup> findings; who mentioned that there was no stress accumulation occur in symphysis region as they located away from fixation and stress application points.

It seems that, the flattening of COS is a causative factor for increasing the values of von mises stress all through the mandible, as the PCo, ACo, and SCo stressed higher in flat model than in the curved. This could be related to facts that, the force acts along the long axis of the lower first molar. And according to the geometry of the mandible and the Condyle, the fixed area is subjected to higher stress, unlike in curve case, the force act on

the first molar, which tilted mesially, that could lead to dissipation of the applied force and decrease the amount of stress over the Condyle (fixed area).

Baragar and Osborn<sup>[5]</sup> found a correlation between the Condyle angle (angle formed between the occlusal plane and Condyle slop) with biting angle (which represent the angle between the long axes of the tooth and the direction of the biting force). The biting angle increased in curve condition than in flat COS. As, the first permanent molar tend to tilt mesially. Such mesial inclination is highly increased the efficiency of the biting force. After the flattening of the COS during orthodontic treatment, this biting angle will changed without compensatory changes in the Condyle angle. This could leads to high stress on the Condyle, especially at maximum bite force, as it is correlated to most posterior position of the Condyle to form zero Condyle angles. The continuous over load of the Condyle could lead to bone destruction and damage for the entire joint,<sup>[44]</sup> because the slope of two Condyles are related to occlusal plane in the frontal plane. In the same context, Kanavakis and Mahta<sup>[16]</sup> proclaimed that flattening of COS is a predisposing factor for TMJ sound as Condyle is more posteriorly positioned specially during growth as the posterior teeth less dis-occluded during function, this will increase the load on TMJ during chewing leading to more sounds on it.

This could be explain the high percentage (60%) of recurrence of COS flattening noted by Shannon and Nanda<sup>[1]</sup> and Bayades *et al.*<sup>[9]</sup> as the teeth and mandible tend to establish the most suitable position with less amount of force distributed all around the mandible and lower teeth (see later).

In the same context, the deciduous teeth aligned parallel in flat level. During mandible growth and the permanent teeth eruption, the occlusal plane move downward and posteriorly away from the Condyle and the lower permanent molars teeth erupted with mesial inclination to form the COS.<sup>[47,48]</sup> So, we speculated that the high stress incorporated at the Condyle in primary dentition (flat COS) could be correlated to stimulation of the growth at the Condyle in the early childhood.

### Von mises stress over the lower teeth

The stress over the posterior teeth after COS flattening increased in posterior teeth than in anterior teeth [Table 4]. It is range from 32%, 26%, and 27% in second premolar, first molar and second molar respectively. This high stress over the first molar consider logical as they receive the applied load. The small size of the second premolar as well as its position near the point of applied force could be the responsible for the high stress value act over it. The second molar receive high stress, this could be related to its position related to site of force application and

the bending response of the mandible (see later).<sup>[49]</sup> This finding coordinate with previous conclusions concerning with high percentage of COS relapse and was related mainly to the second molar.<sup>[1]</sup>

While in the anterior teeth, and after the COS flattening, the von mises stress increased to 25%, 23% for central and lateral correspondingly. This could consider as a factor lead to relapse of the mandibular teeth crowding, this could be clarifying by the bending response of the mandible during chewing to overcome the biting force.<sup>[49]</sup> This finding agree with Shannon and Nada<sup>[1]</sup> results, as they conclude a parallel correlation between the COS relapse after flattening and the irregularity index of the lower anterior teeth. In another hand, this finding disagree with Kumara *et al.* conclusions,<sup>[50]</sup> as they found a weak negative correlation between the flat COS and the lower anterior teeth crowding. However, their sample was already present with flat COS. The canine represents the less stressed tooth at 22% to act as a stable guard for the integrity of the lower teeth.

These results are high light the role of the biting force on the relapse of COS after orthodontic treatment. This coordinates with Rozzi *et al.*<sup>[39]</sup> argument on the role of biting force on COS relapse.

Alignment of the teeth in flat plane increased the amount of the von miss stresses distribution over the contact points between each other. The whole, anatomy of the mandible with the Condyle, level of the occlusal plane as well as the angulations of the teeth in sagittal plane are set in a harmony of coordination for biting force distribution. As, the COF is the inferior portion of the radius, that connect the Condyle with the occlusal surface of the posterior teeth and the incisor edge of the anterior teeth.<sup>[41]</sup> So, any changes in this harmony will leads to change in force distribution over the mandible.<sup>[49]</sup> As in our model, the mandible is originally incorporated with mesially tilting of the posterior teeth. After re alignment of the teeth by tip back of the posterior teeth (changes the biting angle) with zero COS depth, it looks that this harmony is interrupted and the amount of stresses applied over the whole mandible is increased with raise in the amount of stresses and displacements with the same quantity of applied force. The mandibular Condyle takes the big responsibility for such alteration, as it consider the joining points that connecting the mandible with the cranial base.

### Teeth displacement

All the teeth were displaced lingually, and this could be due their alignment with lingual inclination in the space to coordinate the upper teeth following the fencing theory.<sup>[51]</sup>

The central and lateral incisors displaced lingually, distally, and superiorly. It seems that the lower anterior teeth were retroclined and compressed to each other during biting in the two models; this could be elucidating by the bending theory of the mandible during biting to overcome the biting force.<sup>[49]</sup> In spite of our model not incorporated the roots of the teeth, our result showed the role of the canine in supporting the teeth alignment as it the less tooth displace distally, this could be related to its position between the centrals and premolars to support the lower teeth alignments as well as in the angle of the hemi lower jaw. The first premolar also followed the anterior teeth in the manner of displacement. Also, the second premolar expressed higher distal displacements with downward shift, as it nearest point of force application (mesio-buccal cusp of the lower first molar). The lower first molar (receptor of the applied force) displaced mesially and downwards. Finally the second molar displace mesially and upwards. This finding support the mandible bending theory, as the lateral ends of the bended object elevated and the nearest points are squeezed and move down ward. This finding agree with previous finding<sup>[49]</sup> as they stated that the teeth is displace under occlusal load. The amount of displacement found by our results differs from their results; however their model was used the upper teeth and lower teeth in occlusal form that could limit free movement of the teeth as in our model.

The range of mesial displacement of the anterior central and mesial surface of lateral was less than in curved plane than in flat one, this could be specified to our model that already has slight crowding in the anterior teeth.

One of the interesting results was that, in the curve model the amount of mesio-distal displacements of the canine, premolars and molars were higher than in the flat one, this could be related the slope of posterior teeth alignment that could permit easily smooth teeth displacement over each other rather than in flat case, to overcome the masticatory forces.

### Limitation of the study

The main limitation of any FEA study could be the incorporation of the roots of the teeth as well as the PDL, which is highly, affects the reliability of the results. As, we dealt only with the crowns of the teeth that were already aligned in curve form and then we altered them in a flat arrangement. The additional limitation of this study is the used of the hemi mandible for force analysis. The use for whole mandible will complicated our mathematical calculations due to the inadequacy the software used in correlations with the numbers of the nodes included in the model. The other limitation could be the fixation of the mandibular Condyle in the FE model that is not harmonizes perfectly with the



normal situation, where it is attached to the cranial base with the ligaments and muscles that permit specific movements during function. The further limitation of this FE study could be the depending on the geometry of the specific mandible, as it is differing from subject to another. Finally, this study excludes the effect of occlusion of the teeth during function on the direction of teeth displacement.

### Clinical implication

This study could be giving us an idea about the importance of the COS on force distribution over the mandible as well as the significance of the re-adjustments of the COS after finishing the comprehensive orthodontic treatments. Re-adjustment of the COS after orthodontic treatments play a role on the eliminations of the stresses over the Condyle and the lower anterior teeth as well as whole the mandible. Other researches could be conducted to search out the most suitable site and depth of COS along with the coordinate of force distributions throughout the mandible to increase the stability of our orthodontic outcomes. Also, the alignments of the teeth in a curve form should be considered during posterior teeth implant, complete denture, and fixed prosthesis constructions.

### Conclusions

1. Flattening the COS by leveling of the premolars and tip back of molars is increasing the stresses over the Condyle, the teeth and the whole mandible.
2. The point of force application (mesio-buccal cusp of lower first molar) stressed 35% less in case of teeth aligned in curve form than in flat situation.
3. Posterior mandibular Condylar (PCo), anterior mandibular Condylar (ACo), and Superior mandibular Condylar (SCo) are stressed about 38%, 36%, 27% more in flat case than in curved model, respectively.
4. The canine is the less displaced and stressed tooth and has a role on the stability of the dental arch whether if the teeth are aligned in flat or curved planes.
5. The mandible is bending under occlusal load.
6. When the force applied on the mesio-buccal cusp of the lower first molar, the second premolar and first molar displace inferiorly while all the other teeth are superiorly displaced.
7. All the mandibular teeth are displaced lingually during function.
8. The premolars and molars are more displaced than anterior teeth, when the teeth aligned in curved than in flat manner in the mesio-distal direction.
9. The central, lateral, canine and first and second premolars displace distally under loading, while the first and second molars displace mesially under the same load for both models.
10. In flat model, maximum distal movement seen within central and lateral contact points. While in curve model, the maximum distal movement grasped within first and second premolars, in mesial and distal contact points.
11. All the lower teeth are displaced mesio-distally in curve model, more than in flat replica.

### Abbreviations

COS: Curve of Spee; TMJ: Temporo-Mandibular Joint; 3D: Three-dimensional; FEA: Finite Element Analysis; ACo: Anterior mandibular condylar; PCo Posterior Mandibular Condyle; SCo: Superior mandibular condylar; Ab: Anterior border of ramus (Ab);  $Go_{post}$ : Gonion posterior; Go: Gonion;  $Go_{inf}$ : Gonion inferior; Me: Menton; Pog: Pogonion; B: Supramentale; Id: Infradental; Cor: Coronoid.

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### Conflicts of interest

There are no conflicts of interest.

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