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Do erupted third molars weaken the mandibular angle after trauma to the chin region? A 3D finite element study

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Abstract. It has been suggested that third molars increase mandibular fragility because they do not contribute to its strength. For ethical reasons, a human study design that would permit the elucidation of this interference is not possible. This study evaluated the impact of the presence of erupted third molars on the mandibular angle of resistance when submitted to trauma. A three-dimensional (3D) mandibular model was obtained through finite element methodology using computed tomography (CT) with the geometry and mechanical properties to reproduce a normal mandibular structure. Human mandibles with no, one or two erupted third molars were evaluated. Whenever the third molar was present there was a greater concentration of tensions around the cervical part of its alveolus. Approximated Von Mises equivalent stress of the third molar region was 107.035 MPa in the mandible with teeth and 64.6948 MPa in the mandible without teeth. In the condylar region it was 151.65 MPa when the third molar was present and 184.496 MPa when it was absent. The digital models created proved that the mandibular angle becomes more fragile in the presence of third molars. When they are absent the energy concentrates on the lateral e posterior aspect of the condylar neck.

Key words: finite element analysis; molar, third; mandible.

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The mandible is one of the bones most susceptible to trauma in the facial region due to its more projected position in the facial skeleton.[1–3] This prevalence is influenced by factors such as sex, age, socioeconomic condition and the type of trauma.[4] An experimental study with monkeys has shown that mandibles containing unerupted third molars fractured at approximately 60% of the force required to fracture mandibles with erupted third molars.[5] Bezerra et al.[6] reported a 1.94-fold higher risk of mandibular angle fractures when the third molar is present.

Force applied directly in the symphysis region in axial plane is distributed along the arch of the mandible. The condylar heads are free to rotate within the glenoid fossa, to a certain degree, thus tension develops along the lateral aspect of the condylar neck and mandibular body regions, as well as along the lingual aspect of the symphysis. This leads to a bilateral condylar fracture and a symphysis fracture, unless a fragility factor exists.[7]

The reason for the increased prevalence of mandibular angle fractures is not well established.[1] The presence of third molars has been suggested to contribute to an increased mandibular fragility because the mandible loses part of its bone structure to harbour tissues that do not contribute to its strength.[4,8,9] Some authors suggest that completely unerupted teeth are more associated with mandibular fragility because they compromise the bone structure to a great extent. The effect of partially erupted teeth on the support structures of the mandibular framework (external oblique line) should also be taken into account.[3–5,10] A review of retrospective data files indicated that the prevalence and relative risk of mandibular angle fracture are both significantly higher in subjects with fully erupted third molars than in individual lacking those teeth.[11]

For ethical reasons, no human study design would permit the elucidation of this interference, since it would be impossible to submit experimental and control groups to injuries likely to fracture the mandible, in order to evaluate the resistance of this bone and the effect of the third molar on mandibular fractures.

Aeronautical engineering studies have allowed the development of a computational method for mechanical tests by creating virtual elements with finite dimensions and physical properties. This may be adapted to real structures, to recreate load applications and present the distribution of stresses and deformation.[12] This methodology, called finite element analysis (FEA), is a powerful tool for computational modelling that is being widely used to predict the mechanical behaviour of complex biological structures such as bone.[13] The accuracy of FEA to describe the biomechanical behaviour of bone specimens has been shown by different authors.[13–16]

In the present study, a three-dimensional (3D) computed tomographic-based finite element reconstruction of three human mandibles with or without third molars was performed to evaluate these mechanical properties. The aim was to evaluate the impact of the presence of erupted third molars on mandibular angle stiffness when submitted to a trauma to the chin region.

Materials and methods

The ethics committee of the local institution approved the protocol for this study. Informed written consent was obtained from a 30 year old, male patient selected for the study who underwent computed tomography (CT), based on the fact that he had all the mandibular teeth, and no structural mandibular changes (osseous callus/fracture, pathologic entities, previous orthodontic treatment maxilla-mandibular discrepancy or periodontal illness).

The images were obtained by a cone beam CT, and were imported by the ScanIP software (Simpleware® Ltd., Exeter, UK) in which the tomographic density window applicable to the object in study (2240×550 UH) and pixel size to be used (0.55 mm) were defined.

In order to produce the virtual structure, the 3D mesh and all the steps to perform the FEA were adapted from the procedure described by Silva et al.[17] The mesh production began by separating the masks of the mandibular structures in order to include them in the model (discretization). These masks were obtained by digitalization of each CT slice, and a pixel-by-pixel individualization of the tissues evaluated in the study (cortical bone, marrow bone, enamel, dentin, cement, pulp, periodontal ligament), based on the tomographic density. During segmentation only bone- and teeth-related structures were kept and soft tissues were disregarded.

After the production of the final model in all slices, the software generated a 3D structure maintaining each discretized mask in position. For greater smoothness on the surface of the structure, a software tool was used to fill in small gaps and round angles. The result was a very detailed 3D mesh.

To create the three meshes to be included in this study, the initial mandibular structure (mandible 01) was submitted to a digital mask substitution. On the software interface the pixels of the third molar were changed from the initial tooth structure masks to those from cortical and medullar bone in each CT slice in accordance with an anatomic aspect. Therefore, it was possible to create a second structure without the left third molar (mandible 02), and a third one without third molars (mandible 03) (Fig. 1). The remainder of the structure remained the same.

In the ScanFE® software (Simpleware Ltd., Exeter, UK), each of the three mandibles was exported to a finite element mesh that consisted of triangular and tetrahedral elements to interconnect the nodes. The meshes were exported to the software ANSYS® (SIMULIA, Providence, RI, USA), version 13.0, for structural analysis of the mechanical tests. The homogeneity of the structures, linear elastic deformation pattern, and the standardization of the isotropic mechanical properties were ensured for each discretized mask (Table 1). The values of Young modulus and Poisson ratio were based on Lotti et al.[18]

To simulate an anatomically normal mandibular function, the external nodes of the most posterior and superior part of the mandibular condyle were fixated in all degrees of freedom bilaterally (Fig. 2). The actions of the masticatory muscles were reproduced by the creation of spring

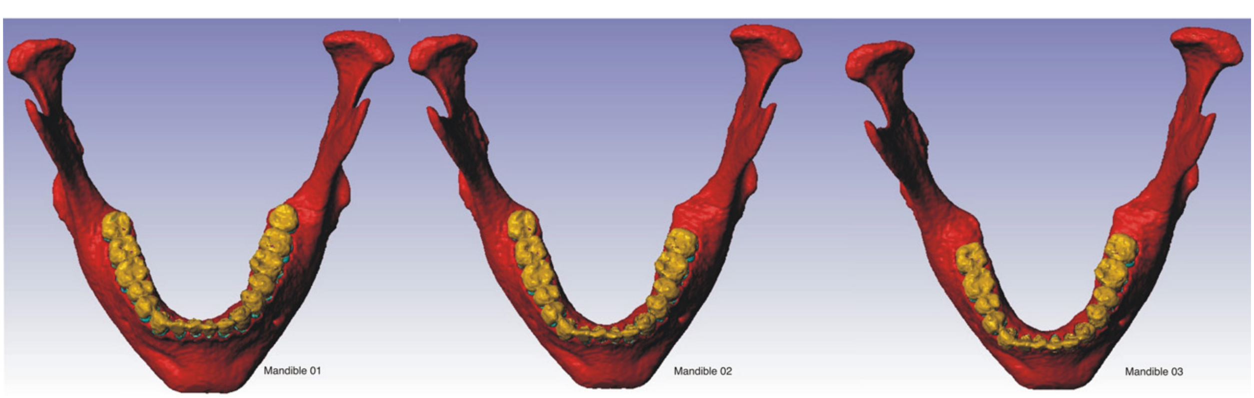

Fig. 1. The three structures developed in the study. Mandible 01 with both third molars; mandible 02 without the left third molar; mandible 03 without both third molars.

Table 1. Mechanical properties, references of number of nodes and elements in each mask reconstructed.

Anatomic structure	Young modulus	Poisson ratio	Mandible 1		Mandible 2		Mandible 3	
			Nodes	Elements	Nodes	Elements	Nodes	Elements
Pulp	0.02	0.45	–	17.914	–	16.250	–	14.764
Dentin	18.60	0.31	–	174.940	–	149.896	–	141.569
Cement	18.60	0.31	–	114.618	–	104.475	–	96.478
Enamel	41.00	0.30	–	54.887	–	50.659	–	47.247
Medullar bone	1.37	0.30	–	193.168	–	192.120	–	189.685
Cortical bone	13.70	0.30	–	331.759	–	327.615	–	317.851
Periodontal ligament	0.0689	0.45	–	23.359	–	21.356	–	19.337
Muscle	–	–	–	4.307	–	4.812	–	4.966
Total	–	–	178.041	914.952	169.929	867.183	163.507	831.897

resistance elements with vectors as described by Bujtár et al.,[19] and the rigidity was based on an estimation of deformation of the muscles.

A blunt trauma with a magnitude of 250 kgf was applied perpendicularly to the frontal plane, on a circular area 1 cm in diameter (centre on the pogonium), in the midline of the symphysis, perpendicularly to the coronal plane. This was a simulation representative of a punch (frontal aggression). The results were evaluated by a descriptive analysis of the chromatic Von Misses stress distribution after the impact.

Results

A highly detailed, patient-specific, custom-made, high-resolution yet simplified model of the mandible could be generated with a very dense volume mesh of 914.952 finite elements for mandible 01; 867.183 for 02, and 831.897 for 03. Based on this method the details of the mandible could be emphasized and successfully included in an analysis of the dynamics of a response to an impact.

The maximum stresses were located at the symphysis (point of impact), in the retromolar area and both condyles on the three experimental models.

The presence of the third molars resulted in a difference in the stress distribution on the three meshes studied. Whenever the third molar was present there was a greater concentration of stress around the cervical part of the alveolus (Fig. 3). It was noticeable that the impact resulted in a concentration of stress on the external oblique ridge, and when the third molar was present this concentration extended to the alveolar process (Fig. 4). On mandibles 2 and 3, the structural reinforcement provided by the bone in the retromolar area without third molars made the stress concentrate more on the condylar region on the side without a third molar (Fig. 5).

Approximated Von Mises equivalent stress in the third molar region was 107.035 MPa in the mandible with a third molar and 64.6948 MPa in the mandible without a third molar. In the condylar region the Von Misses equivalent stress was 151.65 MPa when the third molar was present and 184.496 MPa when it was absent.

Discussion

FEA has been developed into a branch of applied mathematics for numeric modelling of physical systems, which is used in many engineering disciplines. In its simplest mathematical terms, this numerical

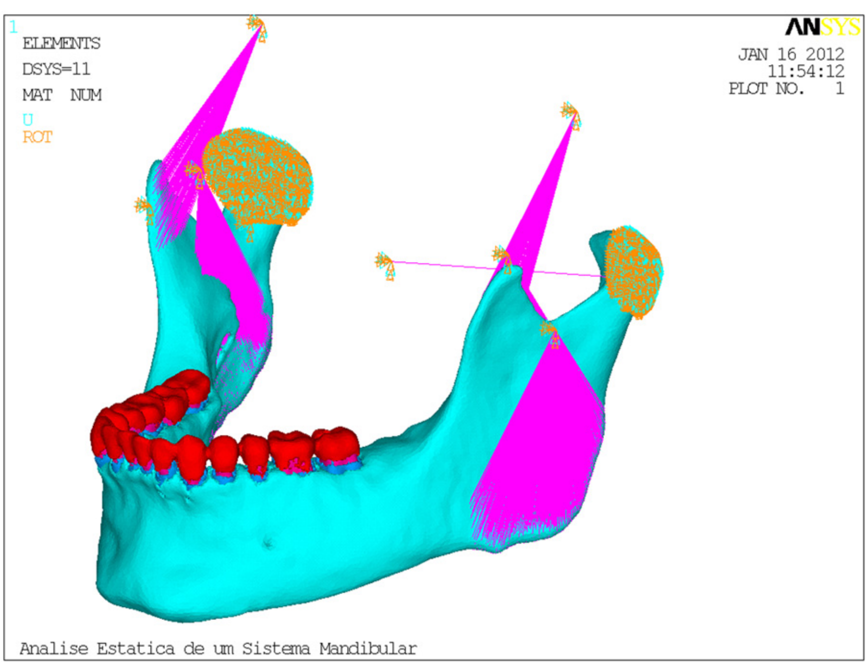

Fig. 2. Boundary conditions of the nodes with restrict movement on both condyles and the elements representing the masticatory muscles.

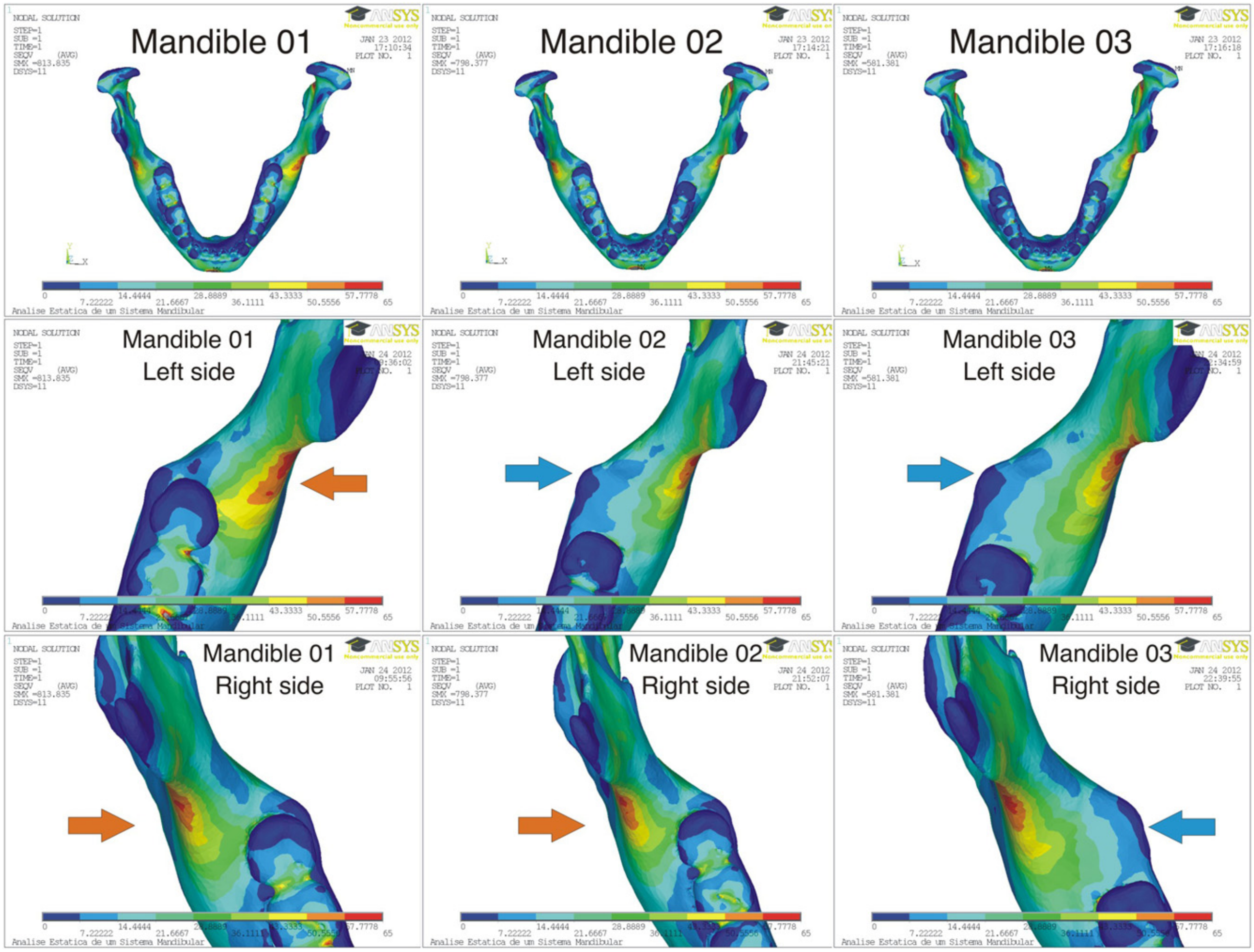

Fig. 3. The Von Misses chromatic stress distribution showing the concentration of stress on the alveolar area when the third molar is present on mandible 01 and on the right side of mandible 02. The orange arrows indicate the increased stress concentration around the third molar. The blue arrows indicate the lowered stress concentration without third molar.

technique is used to find approximate solutions for partial differential and integral equations through the generation of meshes of a continuous domain for a set of discrete subdomains or elements. Numerical methods are then used to predict the behaviour of the object in question in various situations, for example, under conditions of loading.[20] The external forces and the mechanical properties/geometry are used to calculate the nodal displacements; the differentiation of the displacement field yields the strain distribution; and the stress distribution is determined mathematically.[21]

FEA is being developed to overcome the experimental models in biomechanical studies. It is difficult to create an experimental model of the mandible; the geometry, internal structures and the function cannot be grossly simplified. The muscular action cannot be reproduced as a unique vector of force attached to a single point.[22] Muscle tension is needed to cause an angle fracture.[23] This reduction in detail leads to a simplified model of the item's behaviour that may often lead to incomplete or incorrect mechanics of the structure models.[22] By avoiding these significant variables, the experimental computational model developed in this study approached the real mandibular behaviour. Its geometric shape was reconstructed based on a real mandibular structure, the masticatory muscles were attached to the mandible as in an anatomic body, and the physical and mechanical properties were reproduced similarly to the normal body.

In addition, to allow the comparison between the structures in order to evaluate the influence of the third molar presence, the only difference was in the mechanical properties of the third molar pixels. The rest of the structures remained exactly the same to reduce structural bias.

It is important to study this subject because full understanding of the facial bone fracture mechanisms is necessary to enable appropriate treatment to be provided and this modelling provides more information than clinical experience alone. It has previously been reported that bone fails and fractures more readily under tension than compression.[24] In undertaking any therapy that affects the skeleton, it is important to understand the potential problem of excessive loading of bone.[25]

Huelke and Harger[24] described that once a force is applied to an anterior mandibular region the energy dispersion will occur along the body toward the condyles, causing stress on the lateral aspect of the angle and condyle. The force seeks out the weakest point in the arch and causes extreme bending and tensile failure at that point. These aspects could be verified in the present study, characterized by stress concentration on the external

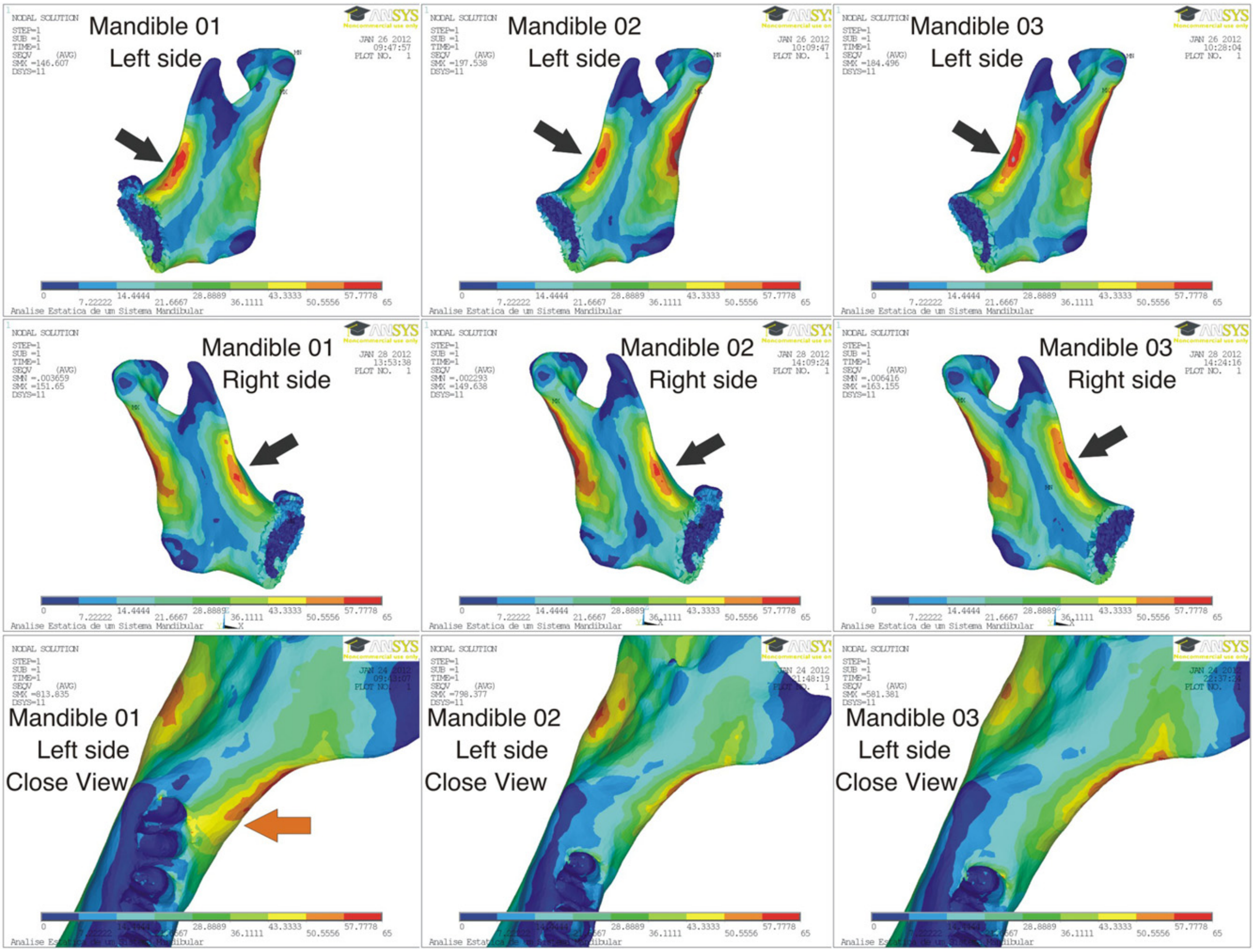

Fig. 4. The Von Misses chromatic stress distribution showing the concentration of stress on the external oblique ridge in all models (black arrows). On mandible 01 it can be seen that the concentration goes to the cervical alveolar area (orange arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

oblique ridge near the third molar, and in the neck region of the condyle on its buccal and posterior sides.

Third molars can be related to the fragility of the angle, since their presence significantly alters its biomechanics. Retrospective studies, case series and literature reviews have shown that the presence of third molars is linked to the increased prevalence of mandibular angle fracture.[6] There are not enough studies from the perspective of biomechanics, which show the true impact of third molar presence and the occurrence of fractures, because reproducing a real model of the mandible is difficult.

FEA is a valid and non-invasive method that provides useful results to predict different parameters of the complex biomechanical behaviour of human mandibles.[14] In the present study, the digital models proved that the mandibular angle becomes more fragile when the third molar is present. The study by Gallas-Torreira and Fernandez[15] is the only published article with a similar methodology and results. They highlighted that clinical extrapolations from mathematical models may not give absolute values. The reason for this is inadequate recreation of the computational model, considering that they did not apply differential mechanical properties to the teeth, allowing them to function as a part of the mandibular structure. Vollmer et al.[14] added the necessity of attributing the boundary conditions of the condyles and the distribution of the masticatory muscles to obtain an adequate computational model, as was done in the present computational method.

The study of Szücs et al.[25] showed that the mandibular external oblique ridge on each side was the location where stress was concentrated. The models developed in the present study had similar stress distribution. Mandibular third molars are usually situated close to this ridge. They can diminish the structural reinforcement of the mandible. Szücs et al.[25] showed that the removal of these teeth with bone osteotomy could increase the fragility of the mandibular angle. It is important to know this when deciding on third molar removal.

In a retrospective study, Inaoka et al.[1] reported that the percentage of impacted third molars was greater in angle fractures than in condylar fractures. Duan and Zang[23] stated that when the mandible is submitted to a low force trauma, the presence of a third molar predisposes the bone to fracture in the mandibular angle. In an overall evaluation of the sample reviewed, the data revealed that patients without third molars had a significantly higher risk of sustaining condylar fractures than those with third molars. This information can be confirmed by the results of this study based on the increased equivalent Von Misses stress in the third molar region when the tooth was present and in the condylar region and when it was

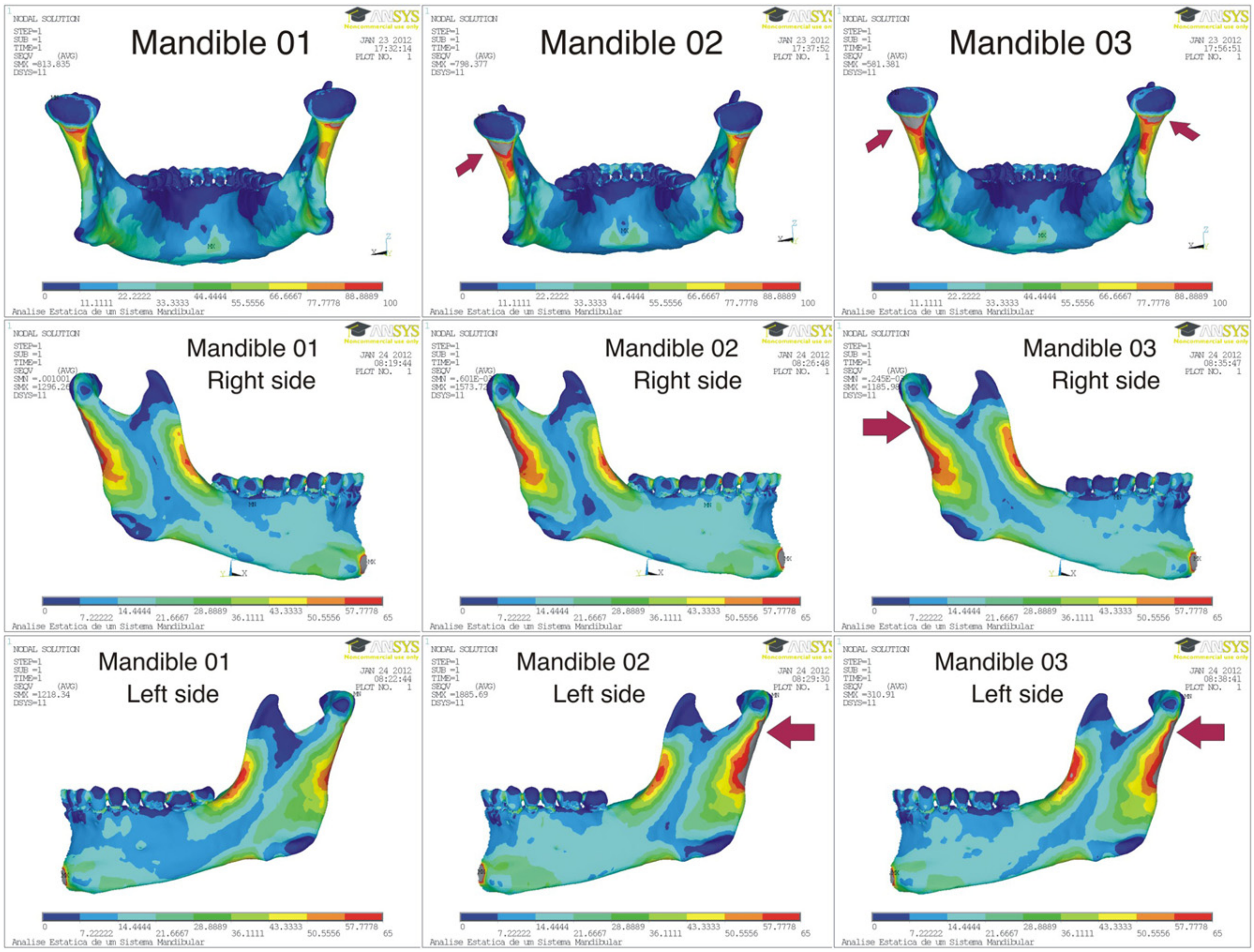

Fig. 5. The Von Misses chromatic stress distribution showing that when the third molar is absent the stress is greater on the posterior part of the condylar neck (red arrows).

absent. When comparing the subcondylar region among the three mandibles it can be seen that when the third molar was substituted by normal bone, the energy was concentrated more on the subcondylar region. That is why a mandible with third molars tends to fail in the angle region, while one without these teeth tends to fail at the condylar neck.

Duan and Zang[23] considered that low force trauma was able to fracture the mandible in one site, moderate trauma in two, and high trauma in three or more. With respect to prophylactic third molar extraction, it appears that impacted teeth in patients with a high risk of suffering low trauma forces, such as in contact sports, should be extracted, whereas patients more often subjected to moderate or high trauma forces might not benefit from prophylactic third molar extraction. After analyzing the relationship between multiple mandibular fractures and the presence of lower third molars, Choi et al.[11] found that, in mandibles with embedded lower third molars, the mandibular symphysis is the most common site of comorbid fracture in individuals with a mandibular angle fracture. The studies indicated that the presence of third molars predisposes the mandible to fracture in the third molar region when the trauma is of moderate intensity and can cause two fractures, one at the place of the impact (symphysis) and the other in the angle. The images obtained in the present study support this information as far as the energy concentrates on the impact point and on the retromolar area of the third molar.

Bujtár et al.[19] evaluated reconstructed models of three subjects of different ages and stated that physiologic load stress and strain distributional changes in the mandible vary according to age, with higher elasticity in younger models. This is a limitation of a study with a real body simulation *in vivo* and can be extrapolated to computational models. To overcome this limitation a larger sample would be needed, but in a real situation it would be impossible to submit a large number of subjects to mandibular impacts, and to perform computational simulation would be a laborious and time-consuming task.

The aim of the present study was to evaluate the influence of the presence of third molars on mandibular angle weakness through a finite element model methodology. Under the conditions of this study this experimental model reproduced a reliable situation found in '*in vivo*' facial traumas. The comparative analysis showed a stress concentration on the vestibular aspect of the mandibular angle when the third molar was present, and on the condylar neck when it was absent. These findings must be considered in the decision making about prophylactic removal of third molars in subjects prone to receiving facial trauma. Future simplifications of this method and its evolution into a more user-friendly modality for dentistry may facilitate the use of FEA in the preoperative analysis of specific surgical sites.[25]

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Competing interests

None declared.

Ethical approval

This study was submitted and approved by the local committee on human research of Walter Cantídio University Hospital, registered under protocol 0.43.04.11.

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