European Journal of Orthodontics 24 (2002) 319–326

Biomechanical influences of head posture on occlusion: an experimental study using finite element analysis

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SUMMARY The biomechanical influences of head posture on the cervical column and craniofacial complex during masticatory simulation were quantified using three-dimensional (3D) finite element analysis (FEA).

Three types of finite element model (FEM) were designed to examine relationships between the position of the head and malocclusion. Model A was constructed to have a standardized cervical column curve, model B a forward inclined posture, and model C a backward inclined posture.

The results of the spinal displacements revealed that model B moved in a forward direction and model C in a backward direction during masticatory simulation. The stress distributions on the cervical column (C1–C7) for models A, B, and C showed differences; stress converged at the atlas in model A, high-level stresses were observed at the spinous processes of C6 and C7 in model C, and the stress converged at the anterior edge in the vertebral body of C4 of model B. Stress distribution on the occlusal plane and maxillofacial structure did not show absolute differences among the three models. Alteration of head posture was directly related to stress distribution on the cervical column, but may not always directly influence the occlusal state.

Introduction

The relationship between facial shape and head posture has been examined using radiological measurements (Huggare, 1991; Solow and Sonnesen, 1998). Patients with dolicocephalic faces often have a tendency for the cervical column to be straight and long, whereas that of brachycephalic patients appears to be curved (Bench, 1963). Some other researchers (Solow and Tallgren, 1976, 1977; Özbek and Köklü, 1993) described positive associations between vertical jaw relationship and the position of the head in relation to the cervical column. This relationship can be explained by the differential growth of the muscles and fascia that are attached to the mandible, and pass to the cranium above and to the hyoid bone and shoulder girdle below (Houston, 1988). Alteration of the position of the head would influence the neck and the stomatognathic system, bringing changes in occlusal stress distributions, and would also be likely to affect craniofacial morphology.

The purpose of this study was to examine the biomechanical influences of head posture on the cervical column and occlusal stresses using three types of finite element model (FEM) with various head positions in an attempt to elucidate the relationship between head posture and occlusion. To simulate masticatory movement in the terminal occlusal phase of the FEM, contractions of the masticatory muscle elements were produced using a computer. Stresses and strains on the cervical column and craniofacial complex during masticatory simulation were then calculated, and the biomechanical effects of postural alterations in head and cervical position on occlusion were considered.

Materials and methods

Preparation of the FEMs

Three types of FEM were constructed by transforming the standard FEM used in a previous study (Motoyoshi *et al*., 2000).

Model A was formed to have a standardized cervical column curve (Figure 1a), model B to have a forward inclined posture by transforming the cervical column elements in model A (Figure 1b), and model C reproduced a backward inclined posture in the same way (Figure 1c). These transformations were performed using a three-dimensional (3D) computer-aided design program (Motoyoshi *et al*., 2000).

The structures of temporomandibular joint, food elements and pulpiform nucleus elements were also defined following the previous model (Motoyoshi *et al*., 2000). A unilateral side of the body was adopted assuming symmetry (Figure 2). The material properties of the elements composed in this FEM were defined using data from Yamada (1970), Sundaram and Feng (1988), Motoyoshi *et al*. (1992), and Müller and Rüegsegger (1996; Tables 1 and 2). The intervertebral discs were defined as non-linear materials. The model consisted of a total of 5795 nodal points and 3024 3D elements (Figure 2).

Boundary conditions and solution

The ANSYS rev. 5.5 program (Cybernet system Co., Tokyo, Japan) was used to calculate the stresses and strains at each nodal point. In order to carry out geometric non-linear processing, a large deflection arithmetic was used. The convergent tolerance of the non-linear analysis was fixed at 0.1 per cent.

Contractions of the masticatory muscle elements, temporal, masseter, medial pterygoid, lateral pterygoid, sternocleidomastoid, and trapezius were simulated, assuming masticatory movement in the terminal occlusal phase of the FEM. The initial strains for these muscle elements were fixed at a constant value of 0.3. To determine the area of the cross-section for each part, the difference in strength for each muscle during mastication was reproduced. Nodes consisting of sole elements were restricted to 3 degrees of freedom to hold the restricted position separate from the cervical columns,

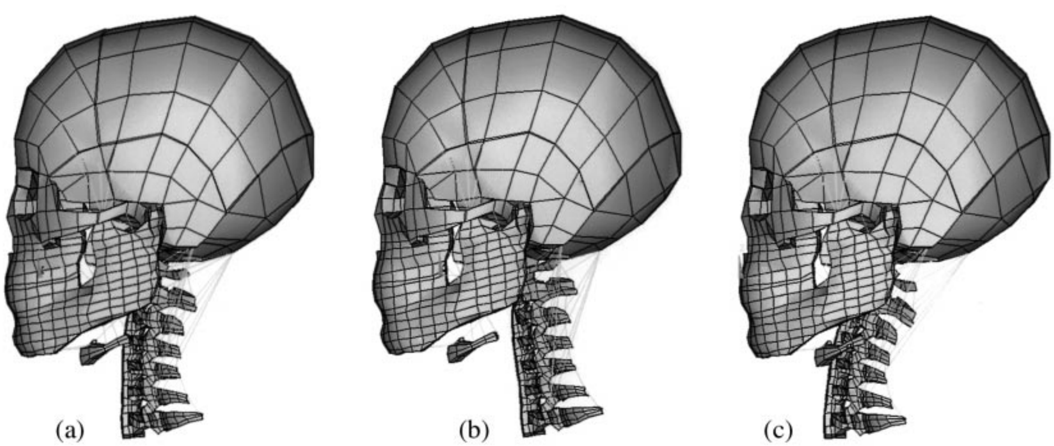

Figure 1 Finite element models used in this study. Model A has a standardized cervical column curve (a). The head and neck position of model A were determined following a previous study (Motoyoshi *et al*., 2000); the central axis of the body passes C1 and C7 when a healthy adult has an upright posture. Model B has a forward inclined posture (b, 5 degrees forward) and model C a backward head posture (c, 5 degrees backward). These inclinations were experimentally defined to reveal morphological differences in the cervical column.

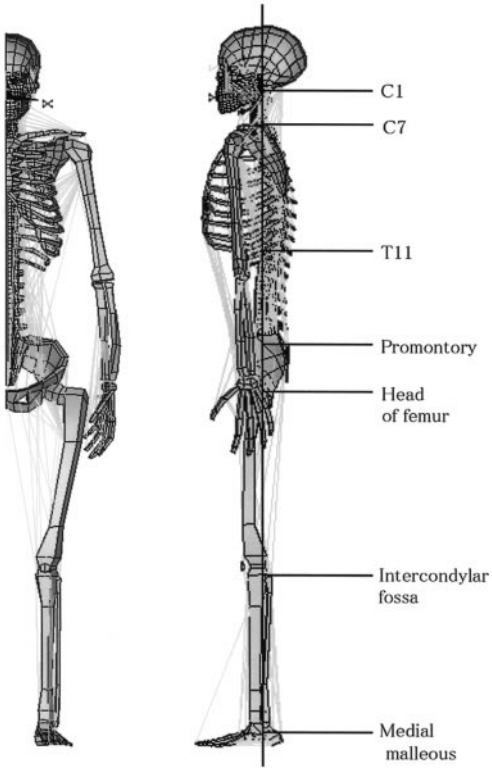

Figure 2 The unilateral side of the whole body was used in order to calculate biomechanical effects during masticatory simulation. The model consisted of a total of 5795 nodal points and 3024 3D elements.

which were observed in detail. A symmetric restrictive condition was given to nodes on the median line of the whole FEM.

The following computer system was used to the calculate stresses, strains and displacements at each node: CPU, Pentium II 450 MHz; Hard disk, 23.2 Gb; and RAM, 256 Mb.

Assessments of the stresses and strains on the occlusal plane and cervical column were performed using 'Von Mises' equivalent stress', defined by the following equation, which is useful for analysing stress distribution.

$$\text{Equivalent stress} = 1/\sqrt{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]^{1/2}$$

where σ_1, σ_2, σ_3 is the principal stress and $\sigma_1 > \sigma_2 > \sigma_3$.

Results

Figure 3 shows the maxillofacial displacements for models A, B, and C. No remarkable differences were observed. The displacements calculated after masticatory simulation for the spines of the three models are shown in Figure 4. The displacement of the spine of model A was small. Model B moved in a forward direction and model C in a backward direction during mastication. Equivalent stresses at the occlusal plane and maxillofacial skeleton are shown in Figures 5 and 6, respectively. No differences concerning stress distribution were observed among the three models. The stress distributions on the cervical (C1–C7) column for models A, B, and C are shown in Figure 7. Differences were found among the three models. The stress distribution for model A ranged from C1 to C7, with the converged stress observed at the atlas (Figure 7a). For models B and C, the stresses did

Table 1 Material properties of constituent materials (Motoyoshi *et al*., 2000).

Material	Young's modulus kgf/mm² (MPa)	Poisson's ratio	Viscosity kg/s/mm² (N/s/mm²)	Mass density kg/mm³
Bone	2000 (19,613.3)	0.15		2.59e–07
Suture	0.7 (6.9)	0.49		
Teeth	8000 (78,453.2)	0.15		
Cartilage	150 (1471.0)	0.4		
Intervertebral disc	Non-linear	0.35		
Skeletal muscles	0.1 (1.0)	0.3		
Food	0.1 (1.0)	0.3		
Pulpiform nucleus	211 (2069.2)		1.15e–10 (1.13e–9)	

Table 2 The material properties of intervertebral disc elements (Motoyoshi *et al*., 2000).

	Stress kgf/mm² (MPa)	Strain
Intervertebral disc	0.020 (0.196)	0.2
	0.021 (0.206)	0.5
	0.022 (0.216)	1.0
	0.023 (0.226)	1.5
	0.024 (0.235)	2.8
	0.040 (0.392)	7.5
	0.060 (0.588)	10.5
	0.080 (0.785)	13.0
	0.100 (0.981)	14.5
	0.200 (1.961)	19.5
	0.300 (2.942)	22.1
	0.400 (3.923)	23.6
	0.500 (4.903)	24.7
	0.600 (5.884)	25.8
	0.700 (6.865)	27.0
	0.800 (7.845)	28.2
	0.900 (8.826)	29.3

not converge at the atlas and were scattered. In model C, high-level stresses were observed at the spinous processes of C6 and C7 (Figure 7c). For model B, the stress converged at the anterior edge in the vertebral body of C5 (Figure 7b).

Discussion

Some researchers have morphologically studied the relationship between posture and malocclusion (Rocabado *et al*., 1982; Huggare, 1998; Solow and Sonnesen, 1998). Huggare (1998) reported plausible evidence for an increased prevalence of Angle Class II malocclusions associated with hyperlordosis of the cervical spine and an increased risk of lateral crossbite in children affected by scoliosis and torticollis. In addition, documentation of associations between anterior crowding and head posture seems convincing. Rocabado *et al*. (1982) found an association between Class II occlusion and forward head posture. Solow and Sonnesen (1998) advocated the soft tissue stretching hypothesis, according to which the sagittal development of the dentoalveolar arches is impeded by the increased dorsally-directed soft tissue pressure in subjects with extended cranio-cervical posture. They also found associations between vertical jaw relationship and the position of the head, and considered that the activities of the masticatory muscles are related to those of the neck muscles. Alterations of the body muscular equilibrium may influence the mandibular position and facial morphology (Mohl, 1976).

The results for spinal displacement revealed clear differences among the three models (Figure 4). Against immovability of model A, model B moved in a forward direction and model C in a backward direction during the terminal occlusal phase. These phenomena mean that alteration of head posture directly influences head pitching during mastication; forward head posture being related to forward swaying and

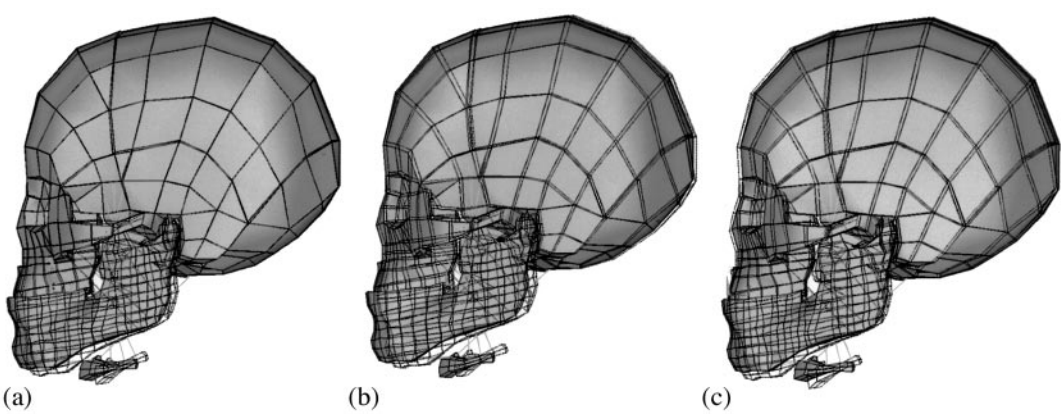

Figure 3 Displacements of the maxillofacial bones of the three models. No differences were found for the three models.

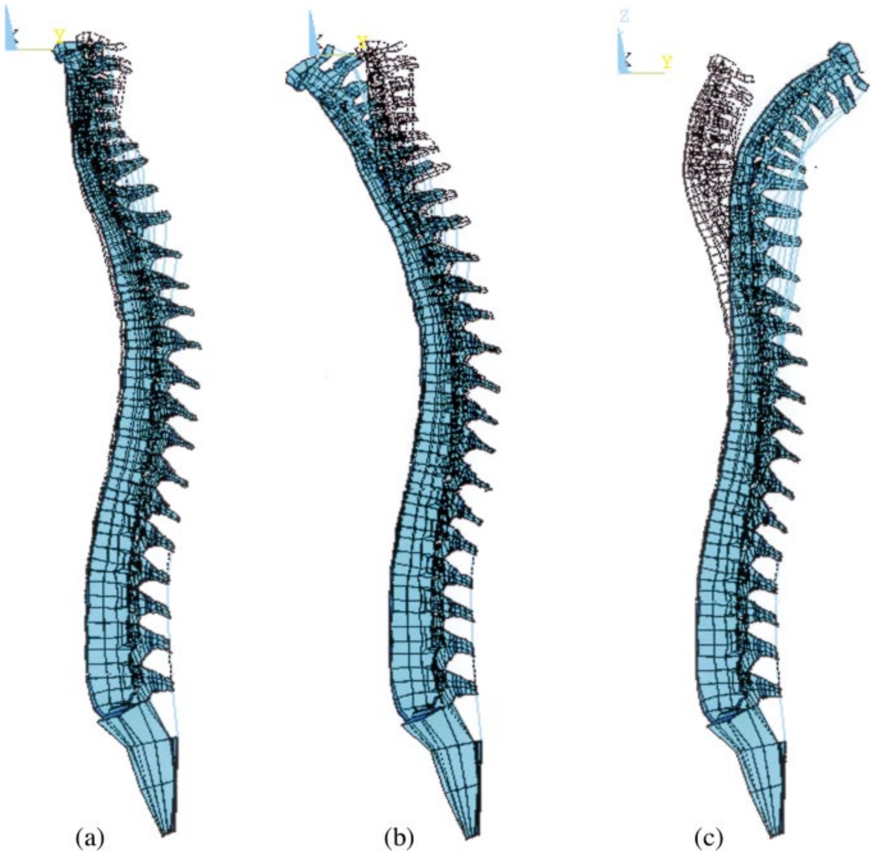

Figure 4 Displacements of the spines of the three models. The spinal displacement of model A was small (a). Model B moved in a forward direction (b) and model C backwards (c). These phenomena mean that alteration of head posture directly influences head pitching during mastication; forward head posture being related to forward swaying and backward posture prompting backward swaying.

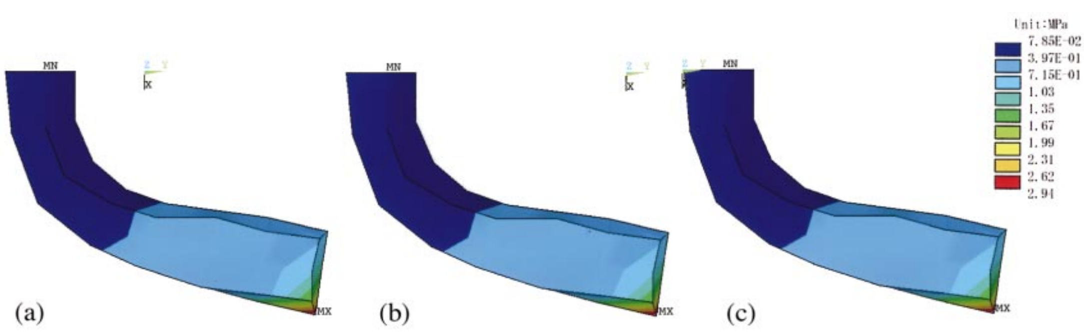

Figure 5 Equivalent stresses at the occlusal plane for models A (a), B (b), and C (c). No differences were found.

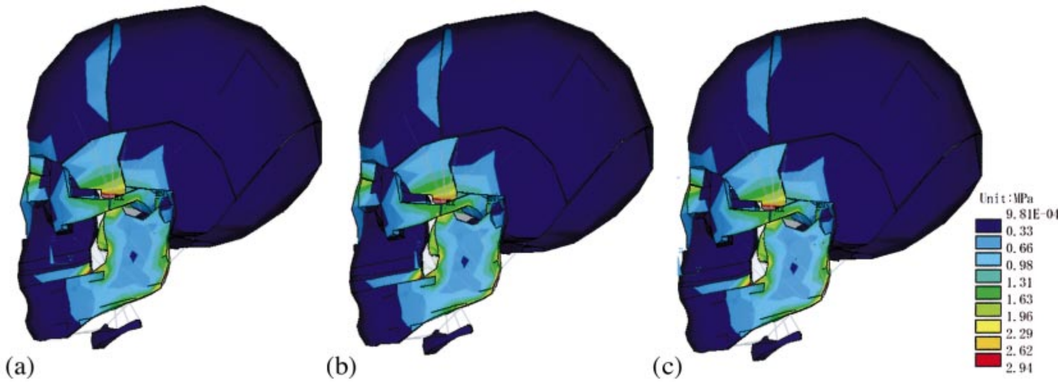

Figure 6 Stress distribution of the maxillofacial skeleton for the three models. No differences were observed among the three models.

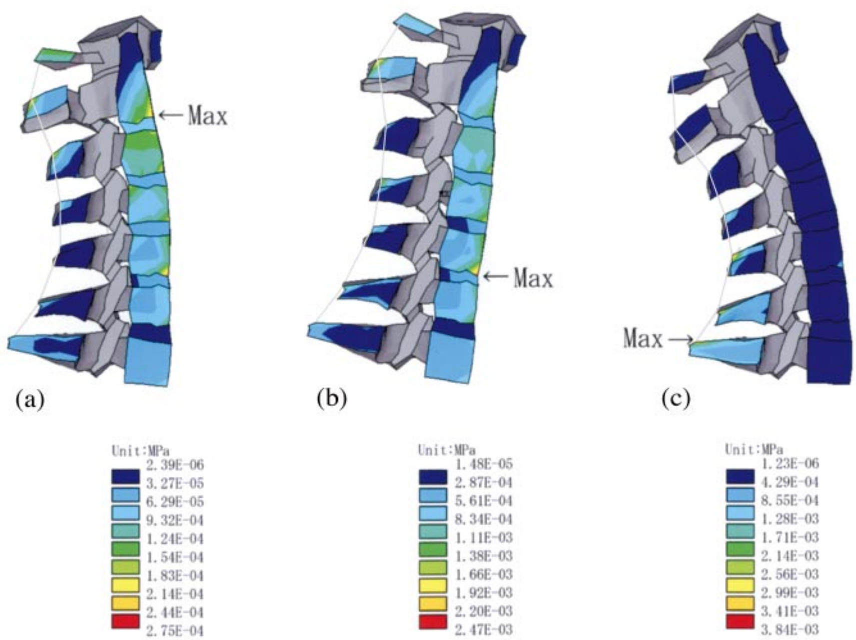

Figure 7 Stress distributions on the cervical (C1–C7) column. The converged stress was observed at the atlas in model A (a). For models B (b) and C (c), the stresses did not converge at the atlas and were scattered. Arrows indicate positions showing maximum stresses.

backward posture prompting backward swaying. This could also explain the differences in stress distribution at the cervical spine among the three models (Figure 7). In humans, head posture may be related primarily to resisting the force of gravity (Solow and Tallgren, 1976; Daly *et al.*, 1982). Furthermore, the physiological requirements permitting respiration, deglutition, sight, balance, and hearing must also influence deportment (Vig *et al.*, 1980). Nevertheless, head posture is maintained by the neuromuscular system with several afferent pathways from proprioceptors in muscles, tendons and joints, vestibular and visual receptors, and information from the cortical and subcortical motor areas (Ferrario *et al.*, 1996). Head pitching during mastication is also controlled by the above-mentioned system; when the head and neck sway forward, the occipital cervical muscles become tense; this tension would put pressure on the cervical column and possibly modify the spine position and eventually also the shape.

In the stress distribution of model A having a standardized cervical column curve, the converged stress was observed at the atlas. Panjabi *et al.* (1988) studied 3D movements of the upper cervical spine using human cadavers, and concluded that there was more motion at C1–C2 articulation than at occiput C1 in flexion movement and most motion took place at C1–C2 of axial rotation. Their report and the results in the present study would suggest that C1–C2 articulation plays a pivotal role in cervical movement, including jaw movement.

The results of maxillofacial displacements and stress distributions on the occlusal plane and maxillofacial skeleton revealed no difference among the three FEMs, and could not provide evidence of an influence of alteration of the head posture on occlusion. One could ask which came first: malocclusion or head posture? Some researchers have described associations between some types of malocclusion and head posture (Rocabado *et al.*, 1982; Solow and Sonnesen, 1998). A previous study (Motoyoshi *et al.*, 2000) also provided evidence that supported their reports, and the hypothesis that occlusal alterations have an effect on muscular balance and posture. If this hypothesis is true, malocclusion might come first. Daly *et al.* (1982) studied postural response of the head associated with experimental bite opening and found that forced separation of the jaws of 8 mm from full closure is associated with a statistically significant alteration in head posture. McLean *et al.* (1973) also reported results that support the hypothesis that graded changes in body position produce no noticeable changes in dental contact patterns resulting from voluntary jaw closure. On the contrary, McLean *et al.* (1973) showed a tendency that the occlusal contact pattern resulting from electrically stimulated jaw closure resulted in occlusal alteration when the body position was changed. FEM could not reproduce the involuntary movement induced by the neuromuscular system. This may explain the results of displacements and stress distributions on the occlusal plane and maxillofacial skeleton for the three FEMs. Furthermore, other factors must be considered. Ricketts (1968) described the relationship between head posture and respiratory functional demands. Respiratory obstruction exerts functional influences that result in structural adaptations. There are many Angle Class II patients who demonstrate mouth breathing. Maxillary stenosis associated with protrusion results in narrowness of the nasal cavity, prompting oral respiration. Simultaneously, one would encounter the event cascade of rhinostenosis, i.e. lack of oxygen, forward head posture, and a widened airway. It may safely be said that alteration of the occlusion influences head posture, while a change of head posture may not always directly influence occlusion.

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Acknowledgements

We wish to thank the Department of Anatomy, Nihon University School of Dentistry for the use of their specimens and Professor Minoru Takagi for his assistance.

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