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# Stresses on the cervical column associated with vertical occlusal alteration

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SUMMARY The biomechanical effects on cervical vertebral columns (C1–C7) during mastication were calculated using a three-dimensional (3D) finite element method. To verify the biomechanical influences of vertical occlusal alteration to the cervical column, three finite element models (FEM) showing a normal (model A), a steep (model B), and a flat occlusal plane (model C) were constructed. The occlusal stress distribution showed various patterns for the three models; the stress extended to the anterior area as the occlusal plane became steeper. The plots of the stresses on the mid sagittal section of the cervical columns showed different patterns for the three models; the stress converged at the odontoid process in models A and B, whereas the stresses at C7 in model B tended to decrease compared with model A. Concentrated stress was observed at C5 in model C, supporting the hypothesis that vertical occlusal alteration could influence stress distribution in the cervical columns.

## Introduction

Alterations in muscular body equilibrium can influence the mandibular position and facial morphology (Mohl, 1976). Conversely, changes in mandibular posture could influence the neck muscles and posture (Daly *et al*., 1982; Salonen *et al*., 1994).

Huggare *et al.* (1991) concluded that there was a high prevalence of lateral malocclusions among scoliotic patients. In a previous study (Motoyoshi *et al*., 2000), whole body finite element models (FEM) were constructed to simulate mastication, and results supporting the biomechanical influences of lateral occlusal inclination on cervical vertebrae were obtained.

On the other hand, it is important to investigate the relationships between various malocclusions and head posture, involving not only lateral, but also vertical problems. Solow and Tallgren (1976, 1977) found that when the head is extended in relation to the cervical column there is, on average, a significantly increased anterior face height, a reduced sagittal jaw relationship, and a steeper inclination of the mandible. Tanne *et al.* (1995) used a three-dimensional (3D) FEM of the mandible, including the temporomandibular joint (TMJ), and reported that the nature of stress distributions in the TMJ was substantially affected by vertical discrepancies.

The purpose of this study was to verify the relationship between occlusion and the cervical column. To verify the biomechanical influences of the vertical occlusal inclination to the cervical column, masticatory movement was produced by contractions of the masticatory muscle elements of the FEM. Stress distributions on the cervical column and the occlusal plane after muscle contraction were evaluated.

## Materials and methods

### *Preparation of the FEM*

The construction of the FEM was determined using the skull, vertebral column, thorax, and upper and lower limbs of an East Indian skeletal specimen, and the computer tomograms taken in a previous study (Motoyoshi *et al*., 2000). The entire skeleton, sutures, intervertebral discs, and food were constructed using 3D structural solid elements; muscles and the TMJ were 3D spar elements, and cartilages were elastic shell elements (Motoyoshi *et al*., 2000). FEMs for the present investigation were formed using a 3D CAD program. A whole body FEM was metamorphosed into a Japanese male of average size, shape, and proportion following previous studies (Motoyoshi *et al*., 2000, 2002). Craniofacial morphology and the occlusal plane of the standard FEM (model A, Figure 1) were constructed using the cephalometric measurements for normal occlusion in Japanese (Mitani, 1977; Table 1). The FEM was defined to presume the upright posture of a healthy adult; the central axis of the body passed C1, C7, the front of T11, promontory, and the head of the femur (Motoyoshi *et al*., 2000, 2002; Figure 2). Inclining the occlusal plane of model A then produced models B and C. These changes in occlusal inclination were fixed at 10 degrees, assuming a reasonable value for characterizing patients having steep and flat occlusal planes, respectively. To improve the precision in the solution phase, an optimization process was performed; errors regarding aspect ratio, twist, and distortion for all elements were completely eliminated using the 3D-CAD program.

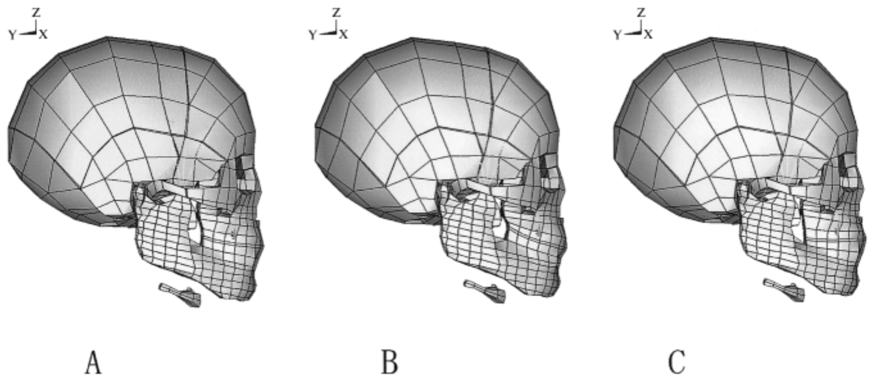


**Figure 1** Three models reconstructed for this study; models A, B, and C represent normal, steep, and flat occlusal planes, respectively.

**Table 1** Standard cephalometric measurements for Japanese.

| | Mean | SD |
|---|---|---|
| N–ANS/N–M | 44.9 | 1.5 |
| ANS–U1/N–M | 23.9 | 1.3 |
| L1–M/N–M | 33.4 | 1.2 |
| ANS–M/N–M | 55.1 | 3.8 |
| Ba–S/Ba–N | 27.8 | 1.6 |
| S–Ptm/Ba–N | 21.3 | 2.6 |
| Ptm–A/Ba–N | 50.5 | 3.9 |
| Ba–A/Ba–N | 100.2 | 4.7 |
| Ba–Ar/Ba–N | 11.5 | 2.3 |
| Ar–Go/Ba–N | 4.8 | 3.0 |
| Go–Po/Ba–N | 76.5 | 5.2 |
| Ar–Po/Ba–N | 80.7 | 6.7 |
| Ba–Po/Ba–N | 92.4 | 6.4 |
| N–M/Ba–N | 133.4 | 7.7 |
| N–S/N–M | 8.3 | 2.2 |
| S–Ar/N–M | 27.3 | 1.9 |
| Ar–Go/N–M | 37.2 | 3.7 |
| S–Go/N–M | 64.4 | 3.9 |

Unit = %.
Coben cephalometric values quoted from Mitani (1977).

The material properties of the elements were composed in these FEM, following previous studies (Motoyoshi *et al*., 2000, 2002; Tables 2 and 3). The model consisted of a total of 5795 nodal points and 3024 3D elements (Figure 2).

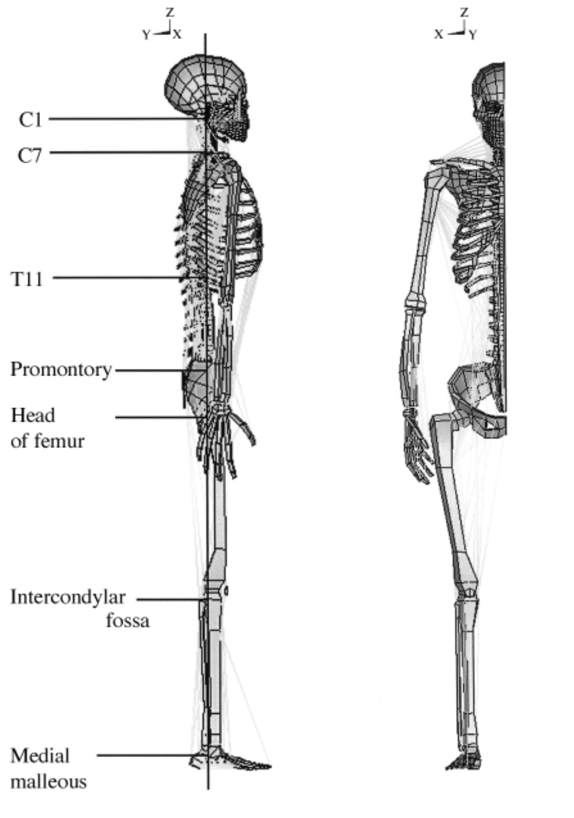


**Figure 2** The whole body 3D FEM (model A). The centre of gravity passes through C1, C7, the front of T11, promontory, and the head of the femur when a healthy adult assumes an upright posture.

*Boundary conditions and Solution*

The ANSYS rev. 5.6 program (Cybernet System Co., Tokyo, Japan) was used to calculate the stresses and strains at each nodal point. A large deflection solution was adopted to carry out geometric non-linear processing. The convergent tolerance of the non-linear analysis was set to 0.1 per cent.

Contractions of temporal, masseter, medial, and lateral pterygoid muscles were simulated, assuming masticatory movement in the terminal occlusal phase of the FEM. The initial strains for these muscle elements were set to 30 per cent. The difference in strength for each muscle during mastication depends on the area of the cross-section for each muscle fixed in this calculation. Nodes consisting of sole elements were restricted to three degrees of freedom. A symmetrical restrictive condition was given to nodes on the median line of the whole FEM to assume geometric symmetry. Acceleration of freefall, $9.8 \times 10^3$ mm/second, was defined in order to take into consideration the influences of gravity.

**Table 2** Material properties of constituents.

| Material | Young's modulus (MPa) | Poisson's ratio | Viscosity N-second/ $mm^2$ | Mass density $N/mm^3$ |
|---|---|---|---|---|
| Bone | 19,613.3 | 0.15 | | 2.54E-06 |
| Suture | 6.9 | 0.49 | | |
| Teeth | 78,453.2 | 0.15 | | |
| Cartilage | 1471 | 0.4 | | |
| Intervertebral disc | Non-linear | 0.35 | | |
| Skeletal muscles | 1 | 0.3 | | |
| Food | 1 | 0.3 | | |
| Pulpiform nucleus | 2069.2 | | 1.13E-09 | |

**Table 3** The material properties of intervertebral disc elements.

| | Stress (MPa) | Strain |
|---|---|---|
| Intervertebral disc | 0.196 | 0.2 |
| | 0.206 | 0.5 |
| | 0.216 | 1.0 |
| | 0.226 | 1.5 |
| | 0.235 | 2.8 |
| | 0.392 | 7.5 |
| | 0.588 | 10.5 |
| | 0.785 | 13.0 |
| | 0.981 | 14.5 |
| | 1.961 | 19.5 |
| | 2.942 | 22.1 |
| | 3.923 | 23.6 |
| | 4.903 | 24.7 |
| | 5.884 | 25.8 |
| | 6.865 | 27.0 |
| | 7.845 | 28.2 |
| | 8.826 | 29.3 |

A computer system (CPU, Pentium III 750 MHz; hard disc, 40Gbytes; RAM, 256 Megabytes) was used to calculate the stresses and strains.

Assessments of the stresses and strains on the cervical column were performed using 'Von Mises' equivalent stress'.

## Results

The stress distributions on the transverse section at the height of the occlusal plane are shown in Figure 3. Compared with the plots of model A, stress distributions in model B extended over a wide range, reaching the anterior parts. In model C, there was a tendency for stresses to be concentrated on the molar area.

Figure 4 shows the stress distributions on the middle sagittal sections of the cervical columns for the three FEMs. The stresses converged at the odontoid process in models A and B. The stresses at C7 in model B tended to decrease compared with model A. In model C, the concentrated stress was observed at C5.

## Discussion

The occlusal stress distribution showed various patterns for the three models, with the stress extending to the anterior area as the occlusal plane became steeper. Soma *et al.* (1991) calculated the occlusal stress distribution on the dental arches in various morphological conditions using FEM, and found that the mesiodistal difference of the stress distribution on the dental arches became more conspicuous as the occlusal plane inclined anti-clockwise. The results concerning the occlusal stress in the present study confirmed their findings. In model B with a steep occlusal plane, the force vector derived from the masticatory muscles was nearly a perpendicular line to the occlusal plane, such that the occlusal force would be received by the entire dental arch (Soma *et al.*, 1991). Inversely, the occlusal stress would converge at the posterior teeth in model C with a flat occlusal plane.

The plots of the stresses on the mid sagittal section of the cervical columns also showed different patterns for the three models, supporting the hypothesis that vertical occlusal alteration could influence stress distribution in the cervical column. The stresses converged at the basal odontoid process, and extended to the inferior columns in model A with a normal occlusal plane. The stresses in model B, with a steep occlusal plane, seem to converge on the upper columns because the areas indicating a lower stress level were widened in the C4–C7 columns. However, the stresses in model C, with a flat occlusal plane, increased in the inferior columns (C5–C7), concentrating at the fifth

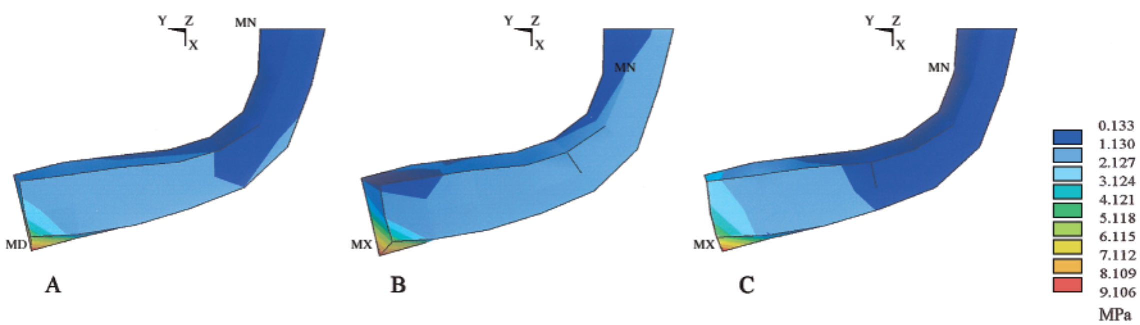


**Figure 3** Stress distributions on the transverse sections at the height of the occlusal plane for models A, B, and C. The plots for the three models present different patterns.

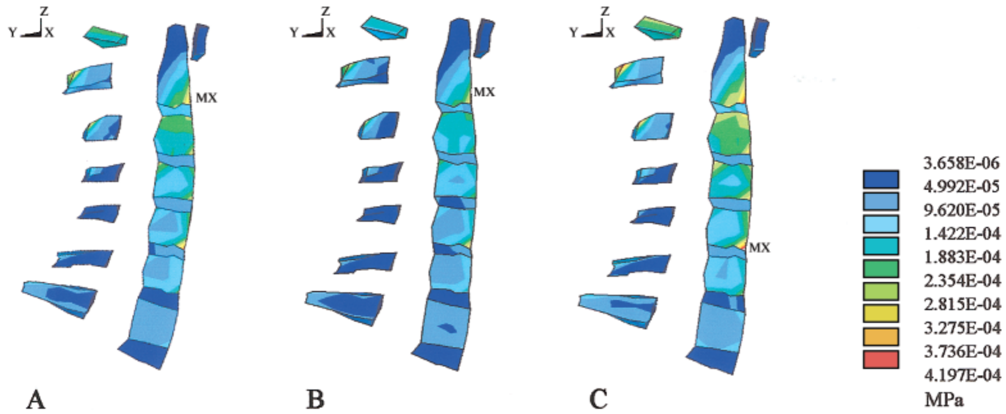


**Figure 4** Stress distributions at the mid sagittal sections for the cervical columns (C1–C7). Various distributions are shown in the three models.

cervical vertebrae. These phenomena would be related to a variety of occlusal stresses on the dental arch distributed in the three models. Solow and Sonnesen (1998) found associations between the vertical jaw relationship and the position of the head. They explained the findings by the soft tissue stretching mechanism that describes the effect of an extension of the craniocervical angle upon the development of the face. They also considered that the activities of the masticatory muscles were related to those of the neck muscles. This relationship can be explained by 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). In a previous study (Motoyoshi *et al.*, 2000), it was also concluded that the head and neck attachment would explain the stress detected in the model. The FEM includes the muscles and fascia elements that are attached to the craniofacial complex and pass to the chest and shoulder below as in a human being. Occlusal alterations could influence head posture (Daly *et al.*, 1982; Salonen *et al.*, 1994). The postural position of the head is a result of muscular interactions and reactions (Daly *et al.*, 1982). The association between occlusion and the cervical column was not only supported for cases showing laterally inclined occlusal planes (Motoyoshi *et al.*, 2000), but also verified in the vertical occlusal relationship. This means that an adequate occlusal inclination would exist in the vertical dimension to maintain neuromuscular body equilibrium.

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