ORIGINAL ARTICLE

Force distribution of the temporomandibular joint and temporal bone surface subjected to the head-chincup force

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The present study is an in vitro study of chincup therapy. The purpose of the study was to investigate the localization and distribution of stress induced by the head-chincup appliance. Thin single and three-dimensional strain gauges were affixed on a young dry human skull capped by the head-chincup appliance. Three kilograms of force was then applied in the direction of the condyle. In a slight opening (5 mm at the incisor position), compressive force was observed to be constant at the anterior part of mandibular neck and tensile force at the posterior part. The joint cavity showed both tensile and compressive forces, whereas its posterior site showed only compressive force. Stress distribution at the lateral surface of the temporal bone indicated that long-term use of the chincup appliance affects the craniofacial structures. The longitudinal laminagraph records of a clinical case were also presented to support the current biomechanical findings. (Am J Orthod Dentofacial Orthop 1998;114:277-82.)

Chin cup therapy may improve the following variables of dental and skeletal Class III morphology: (1) retrusive maxilla,[1-4] (2) moderate to severe protrusive mandible, (3) anterior crossbite, and (4) concave profile.[5-8]

Early treatment of Class III malocclusion with chincup appliance only,[6-8] or a combination of maxillary protraction and chincup,[9-11] face mask,[12,13] and functional appliances[14,15] produce improvement of skeletal Class III pattern. The disadvantage of early treatment, however, is prolonged treatment time and instability of the changes obtained. Recognizing the limitation of skeletal Class III treatment by chincup appliance, acceptable treatment results were obtained even at the late mixed dentition of pubertal period and the changes were stable during the retention phase.[4]

Our previous study of temporomandibular joint (TMJ) laminagraphs indicated that chincup-treated subjects showed significant forward bending of condyle, deepened-widened glenoid fossa, and decreased space between the condyle and fossa in comparison with those of non-chincup subjects.[16] This study concluded that chin-cup therapy may improve not only Class III jaw relationship but also change TMJ morphologic characteristics.

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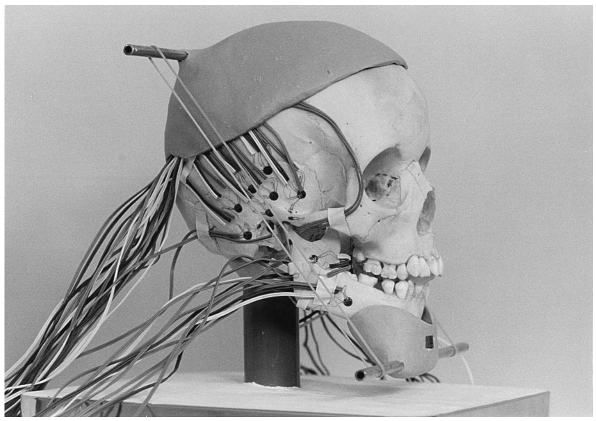

Fig. 1. Head-chincup appliance on the young dry skull.

In the literature, there are several biomechanical studies reporting the strain and stress distribution on the ramus and body of the mandible induced by chin-cup mechanics.[17-21] However, few strain gauge studies use dry human skull[17] focused to TMJ structures, exclusively. The current thinner three-dimensional strain gauges are more accurate than those used in the past.[17]

In the present study, a thin three-dimensional strain gauge was applied to visualize the stress distribution coincident to the morphologic changes of the condyle examined by laminagraphs.[16] In addition, a case treated with a chincup with longitudinal laminagraph records is presented under a long

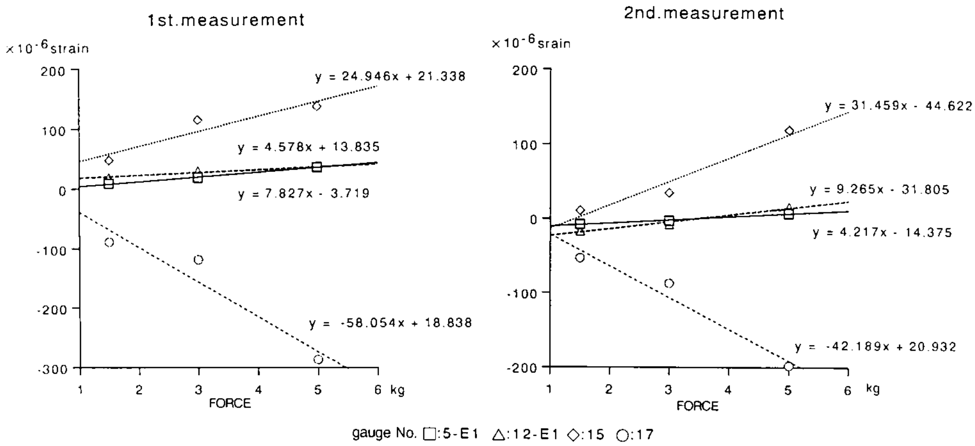

Fig. 2. Four times trial measurements. Proportional relationship of strain and stress for strain gauge no. 5, 12, 15, and 17 in three force levels.

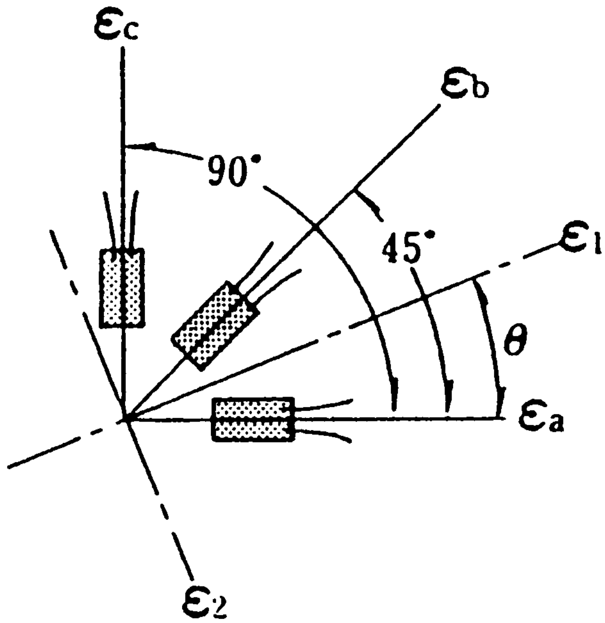

Fig. 3. Thinner three-dimensional strain gauges.

period of retention to add clinical treatment support of the dry skull findings.

MATERIAL AND METHODS

To visualize the direction of chincup force, nine (No. 0-6, 12, 13) thin three-dimensional and ten (No. 7-11, 14-18) single strain gauges (KFG-1-120-D17-11L1M2S, KFG-02-120-C1-11L1M2R, Kyowa Electronic Manufacturing Co., Tokyo, Japan) were affixed to a young dry human skull that was capped by the head-chincup appliance (Fig. 1). Silicone rubber was placed between the head of the condyle and cavity as a cushion. Each bone surface site was smoothened and flattened by sandpaper, and the strain gauges were glued with Strain Gauge Cement (CC-33A, Kyowa, Tokyo, Japan). Triaxial strain gauges showed constant gauge factor of 0.9434 and 2.12, and 0.8889, 2.25 for single gauges.

To obtain a head-chincup force, heavy elastic bands (No. 641-07, gum band, Tomy Co., Tokyo, Japan) were used, and five different forces ranging about 1.5 to 10 kg were applied to the chin areas in the direction of the condyle (Fig. 1). Traction forces were measured by the Miniature Load Cell (LM-20KA, Kyowa, Tokyo, Japan), which was incorporated at the inner surface of the chincup.

Traction forces of 1.5 kg, 3 kg and 5 kg showed the proportional relationship of strain and stress, and so three force levels were applied in the present study (Fig. 2). As a force distribution in the pilot trial, tooth-contact condition was mostly observed at the sites of maxillary and mandibular posterior dentition but not in TMJ areas. The data for only slight opening (5 mm) was obtained and analyzed as four measurements for each of three force levels at intervals of 30 minutes. The third trial measurements at three force levels were represented as a sample (Table I).

A unit is × 10-6 strain and a unit of stress distribution was obtained by the formula: × 10-6 strain × Young's modulus = Newton/square meter. Each strain was recorded by a Data Logger Analyser (UCAM-10B) and a Universal Scanning Box (USB-50A, Kyowa, Tokyo, Japan). The direction and value of the recorded principal strain was calibrated with the roset analysis (Fig. 3).

The formula of which is as follows:

$$\varepsilon_1 = \frac{1}{2}[\varepsilon_a + \varepsilon_c + \sqrt{2\{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2\}}]$$

$$\varepsilon_2 = \frac{1}{2}[\varepsilon_a - \varepsilon_c - \sqrt{2\{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_b - \varepsilon_c)^2\}}]$$

$$\theta = \frac{1}{2}\tan^{-1}\left[\frac{2\varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c}\right]$$

ε_1 (The recorded principal strain, maximum)

Table I. Third trial measurements represented in three force levels

Gage no.	1.5 kg		3.0 kg		5.0 kg	
	ϵ1	ϵ2	ϵ1	ϵ2	ϵ1	ϵ2
0	8	−13	1	−16	9	−23
1	0	−6	−8	−16	−13	−24
2	14	−29	17	−45	29	−76
3	2	−12	6	−26	9	−43
4	3	−3	15	−8	31	−10
5	3	−10	16	−6	33	−6
6	2	−10	17	−14	38	−24
7	3		8		14	
8	−22		−33		−84	
9	−1		−14		−23	
10	5		−4		−7	
11	−8		−21		−40	
12	17	−7	32	−37	47	−71
13	1	−12	7	−19	15	−33
14	33		53		60	
15	119		186		250	
16	84		97		107	
17	−174		−263		−364	
18	58		56		43	

UNIT; $\times 10^{-6}$ STRAIN

ε_2 (The recorded principal strain, minimum)

θ (The direction of the recorded principal strain)

Patient IH (Fig. 4*A* to *I*)

A male patient, aged 9 years 4 months, presented with a skeletal Class III pattern associated with a slight retrusive maxilla and protrusive mandible. The initial ANB angle was −0.5°. Chincup treatment associated with the modified Mershon lingual arch appliance was started at 9 years 6 months. The patient's anterior crossbite was corrected 6 months after starting chincup treatment, which was continued for 7 more months to obtain proper posterior occlusion. When the patient was 13 years old, phase 2 nonextraction treatment with edgewise appliance was initiated; treatment was completed at 15 years 2 months. The last retention records were taken at 17 years 3 months.

RESULTS

All strain gauge data characteristically showed the direction and the amount of force distribution for a slight opening, although measurements of the four-time trial showed some variation (Fig. 2). Table I shows the third trial measurements with the 1.5 kg, 3 kg, and 5 kg forces. Fig. 5 indicates the location and the direction of strain gauges glued on the lateral surface of the dry skull. Fig. 6 schematically represents the amount and the direction of force of the third-trial measurements in the 3 kg force group.

In a slight opening (5 mm) data, a larger amount of compressive force was consistently observed at the anterior part of mandibular neck and tensile force at the posterior part. The middle site of condylar neck indicated tensile force.

No. 14 and 18 strain gauges at each site of angle of the mandible indicated the same amount of tensile forces. No. 12 strain gauge at the middle of the ramus and 1 cm under the mandibular notch showed the same amount of tensile and compressive forces.

No. 7 strain gauge, which was glued at the inner surface of distal wall of the outer ear, showed tensile force; and no. 8 strain gauge glued to the most inner surface of the joint cavity showed compressive force. No. 4 strain gauge at the posterior site of the zygoma indicated compressive force that may have some effect on the maxilla.

Strain gauges no. 3, 4, and 5 at the lateral surface of the temporal bone showed a greater tensile force than compression, while on the other hand, strain gauges no. 0, 1, and 2 showed a greater compressive force than tension.

Patient IH

Cephalometric analysis showed 1.5° of ANB at the time of the chincup stopped but rebounded to –1.0° at posttreatment and postretention. The initial 33° FMA decreased to 30°, 130° of the initial angle of the mandible to 125° and 84° of the initial IMPA increased to 89° at postretention. Initial laminagraphic records showed a slight forward bending of the condylar neck. After 13 months of chincup use,

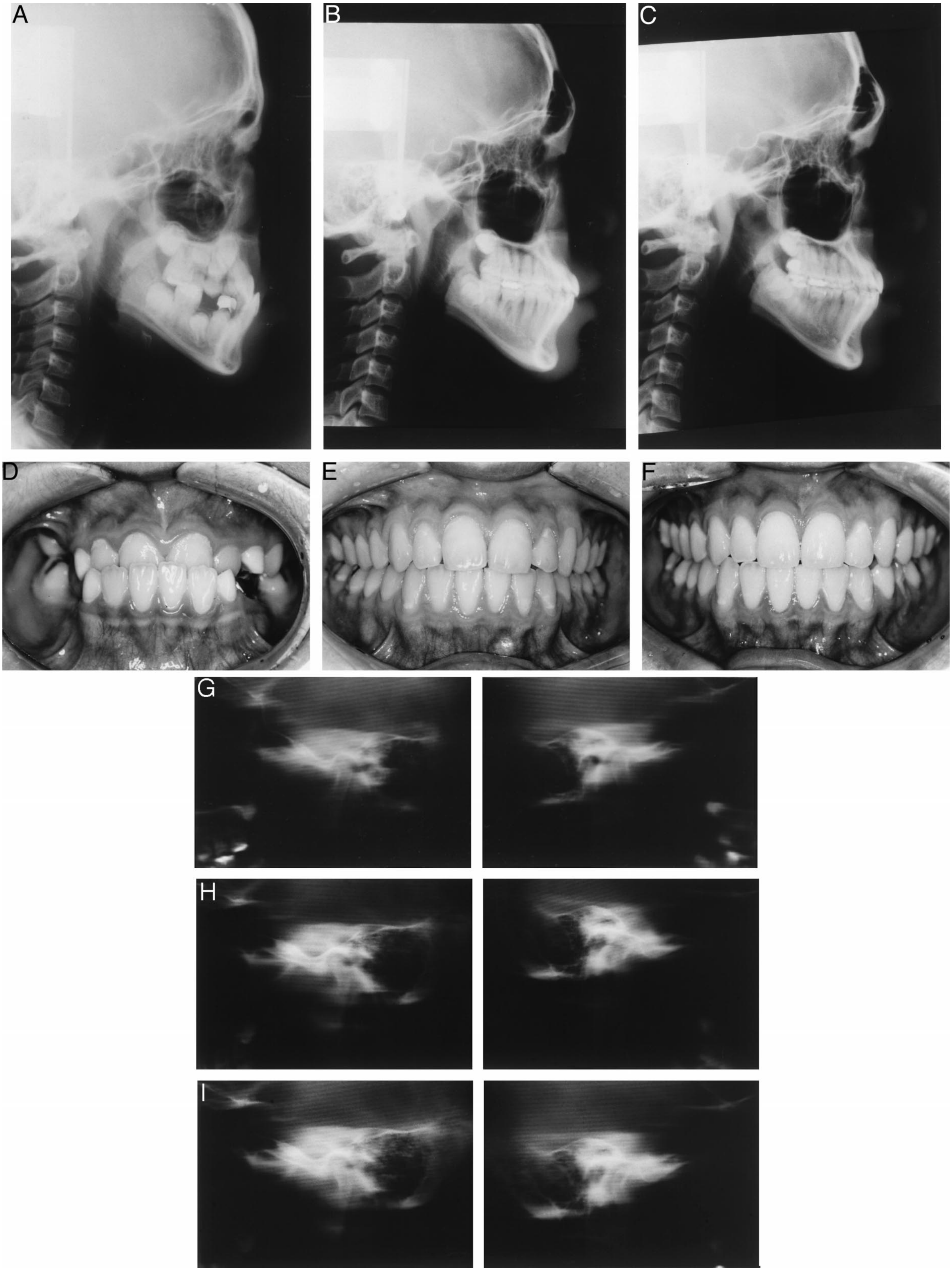

Fig. 4. Lateral head films (A-C; pretreatment, postactive treatment, retention), Frontal oral photographs (D-F in the same order) and laminagraphs (G-I in the same order).

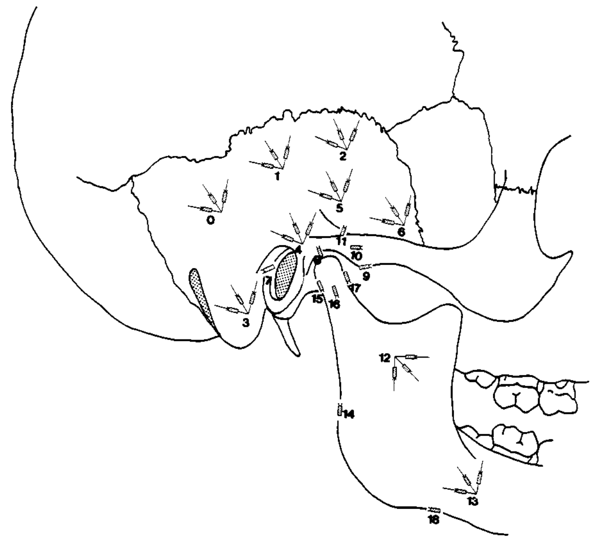

Fig. 5. Schema of the location of glued strain gauges on dry skull.

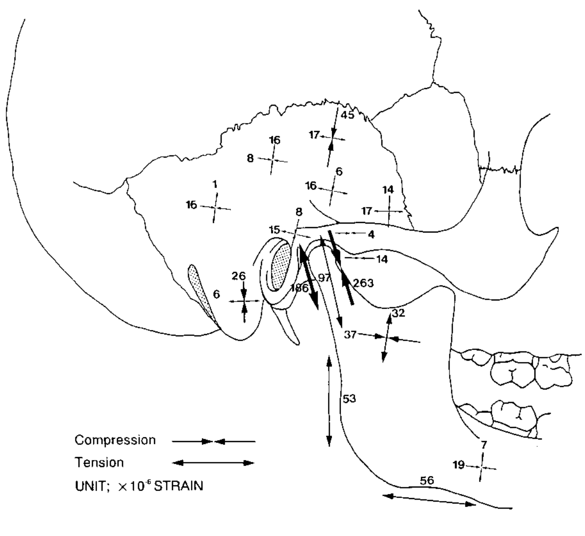

Fig. 6. Schema of the third trial measurements at 3 kg force.

condylar head and neck became more forwardly bent than initially. The laminagraph of postretention records showed a prominent forward bending of condylar neck with an enlarged joint cavity (Fig. 4*I*). The soft tissue profile at postretention showed a well-balanced lip relationship with upper lip (–2 mm) and lower lip (2 mm) to the Esthetic line.

DISCUSSION

Several biomechanical studies have been done on the orthopedic effect of the chin retractor on the mandible with three-dimensional strain gauges attached to dry human skull[17] and monkey,[18] photoelastic model,[19] and finite element model.[20,21]

They found that a force direction to the condyle induced a higher compressive strain at the medial surface of the condylar head and tensile strain on the distal surface, and also supported a possibility of decreased angle of the mandible.

In the current study of a slight opening, there was the same pattern of force distribution on the head and neck of condyle, and a bending stress at the angle of the mandible.

Iguchi et al.[20] studied a relationship between a force direction and the shape of mandible by a two-dimensional finite element model. They concluded that stress distribution at rest position showed the most effective results of chincup use. A slight opening in the current study is a quite similar condition to their results at rest position.

Seren et al.[22] suggested that relative condylar protrusion with a relative mesiolateral elongation of the condyle within a relatively small joint cavity are correlated with the anterior mandibular displacement in skeletal Class III malocclusions. In the previous chincup study, its biologic reaction showed an increased enlargement of joint cavity that may induce a favorable posterior displacement of the mandible in skeletal Class III morphology.

Agronin and Kokich[23] reported that the temporal bone and joint cavity are displaced posteriorly during facial development with conventional orthodontic treatment and that the amount of displacement can affect mandibular position. Kerr and Tenhave[15] reported that the FR-3 appliance showed a small but significant increase in cranial base flexure. Ritucci and Nanda,[24] although their sample size was small, found that chincup therapy caused a closing of the cranial flexure angle N-S-Ba and inhibited posterior growth of the point basion. In the current study, force distribution was observed at the lateral surface of temporal bone, which may affect the position and the size of cranial structures, and also at the TMJ regions, which may be related to the displacement of the joint cavity by chincup therapy.

Bjork and Skiller[25] describe two types of forward rotation of mandible during growth and concluded that forward rotating patterns with forward inclination of condyle are favorable for Class II but not for Class III. However, recently Tollaro et al.[26] evaluated possible significant changes in the mandibular rotation and the direction of condylar growth in children with Class III malocclusion who were treated with a functional appliance. They found no statistically significant difference between the untreated and the treated groups for positional (total) rotation of the mandible, but a significant (1%) upward-forward direction of condylar growth was assessed in the treated group. This therapeutically induced change in growth direction of the mandibular condyle was considered a skeletal sign of anterior morphologenetic rotation of the mandible: for example, a mechanism compensating for excessive mandibular growth.[27,28] The forward bending of the condyle in the present chincup study may also be a biologic response to compensate for an excessive growth of mandible.

As clinical observation in case IH, the chincup appliance was used for only 13 months and stopped, but forward bending of the condyle neck continued over the following 7 years.

CONCLUSION

The current mechanical investigation of TMJ showed quite similar changes to our previous laminagraphic TMJ study subjected to chincup therapy. The present study found significantly more forward bending of the condylar neck, a closing of the angle of mandible, and an enlargement of the joint cavity greater than that observed in the non-chincup treated skeletal Class III subjects. The current findings also showed force distribution at the lateral surface of temporal bone, which may affect the size and the position of the cranial structures.

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