Cephalometric Study on the Influence of Vertical Traction of Teeth on Maxillofacial Bones in Young Dogs

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Nakano, H. Cephalometric Study on the Influence of Vertical Traction of Teeth on Maxillofacial Bones in Young Dogs. Tohoku J. Exp. Med., 1993, 169 (4), 289-297 — The influence of one-sided vertical traction of teeth on maxillofacial bones was investigated using cephalometric radiographs and tetracycline-labeling in young dogs. On the frontal view of the dry skull, traction resulted in a downward distortional deformity of the maxilla including the nasal floor. Cephalometry of radiographs revealed a downward displacement of the upper premolar and incisor teeth, medial maxillary region, and alveolar process of molar, canine and incisor on the right side, where traction was applied. Displacement was from 2.2 ± 0.4 (mean ± S.D.) mm at P3 to 0.8 ± 0.2 mm at I1. In the control group without traction, it was 0.0 ± 0.0 at P3 and 0.2 ± 0.1 at I1. Tetracycline-labeling disclosed, in the frontal cut surface of maxillofacial bones at P3, that traction affected not only the periodontal tissue and alveolar processes, but also the neighboring bones and midpalatal suture. The ratio of the labeled area in the bone, measured using an image analyzer in 6 sectors of the cut surface, was 1.2 ± 0.3% in the left upper sector to 13.0 ± 4.3% in the right lower sector. In the control group, it was 1.2 ± 0.4% in the left upper and 4.8 ± 1.1% in the right lower sector. In conclusion, vertical traction of teeth induces a vertical deformation of the maxilla. ——— vertical traction of teeth; maxillofacial deformity; cephalometric radiography; tetracycline-labeling

The roots of teeth are located in the sockets or alveoli of the maxilla or mandible, and supported by the periodontal ligament. From these anatomical characteristics, it appears that in orthodontic practice, vertical traction is more effective than anterior-posterior or buccal-lingual traction in moving teeth, and the sites responding to the tractions are different from each other (Niikura 1979). There are various clinical and experimental studies describing morphologic changes of maxillofacial bones induced by mechanical forces in the anterior or posterior direction through the teeth or skin (Alexander 1966; Cutler et al. 1972; Kambara 1977; Millard 1977; Nakano et al. 1980; Baumrind et al. 1983). How-
ever, morphological studies reported hitherto on the vertical traction have been limited on the influence of the periodontal tissues caused by single-tooth traction (Reitan 1975; Niikura 1979), although the vertical traction of multiple teeth is the main method of treatment for open bite and its influence has been presumed to be more broad. Bilateral and one-sided vertical tractions of teeth are performed for bilateral and one-sided open bites, respectively.

This paper reports the influence of one-sided vertical traction of premolar and incisor teeth to the maxillofacial bones, which was investigated using cephalometric radiography and tetracycline-labeling.

**Materials and Methods**

*Animals, materials and vertical traction of teeth*

The material comprised 10 male crossbred dogs weighing 9-12 kg and ranging in age from 1-1.5 years. The right teeth underwent traction. In the experimental group (n = 6), occlusal surfaces of the M1 and P4 of both left and right sides were filled with dental composite resin, and bite-raising (opening) of approximately 7 mm was performed in the incisor region prior to applying traction. A steel wire with rectangular cross section of 0.018 inches × 0.025 inches, and hooks, 0.014 inches in diameter, were rigidly bonded to the buccal surface of premolars P3-P1 with a resin (Super-Bond; Sun Medical, Tokyo). Hooks were rigidly bonded to incisors I3-I1. The same wire and hooks were bonded to the lower teeth corresponding to the upper teeth treated, and 4 elastic rings (Type 404-226, Unitek/3M, Monrovia, CA, USA), 3/16 inches in diameter, were set on the hooks (Fig. 1). The magnitude of traction of each elastic ring was measured using a dial push-pull gauge (YS-31D; Yamamura, Tokyo). Under static conditions, the total magnitude of traction on these 6 teeth was approximately 280 g. Elastic rings were set on the teeth for 20 hr each day, for 60 days. In the control group (n = 4), the occlusal surface was treated as in the experimental group, but no traction was applied. Dogs were caged individually without restraint and fed commercial dog food.

![Fig. 1. The procedures for vertical traction of dog teeth. The occlusal surfaces of M1 and P4 of both left and right sides were filled with dental composite resin to achieve a 7-mm raise in the bite of the incisor. An orthodontic brace was rigidly bonded to the surfaces of the upper and lower P3-P1, and I3-I1 on the right side, and then elastic rings, 3/16 inches in diameter, were set for traction.](image-url)
Implantation as an x-ray marker

Tantalum implants were placed in the upper teeth and maxillofacial bones to determine their positional shift using cephalometric radiographs (Fig. 2). The implants, 1.5 mm long and 0.2 mm in diameter, were placed on the right side only, according to the technique described by Björk (1968). Implants, under general anesthesia, were placed at the following sites: the cusps of M1 and P4-P1, the edges of I1-I4, the zygoma, frontal bone, maxillary corpus, and the alveolar process in molar, canine, and incisor areas.

Cephalometric radiography

Lateral radiographs were taken twice, before and 60 days after traction, for cephalometry. During radiographic procedure, dogs were under general anesthesia. The x-ray films were exposed at a 100 cm object-to-tube distance, and a 10 cm object-to-film distance. Exposures were made at 90 kV and 200 mA, for 1.5 sec. The outlines of maxillofacial bones and the implants were traced to transparent films from the radiographs. Then, the tracings were superimposed on the anterior cranial base which was used as the line of reference for measurement, and the shift of each implant was measured.

Vital staining

After traction was initiated, each dog received a subcutaneous injection of 1 ml of 2% tetracycline hydrochloride solution (TC, Neocycline; Meiji Seika, Tokyo) per kg body weight every 7th day. Fluorescent microscopy of undecalcified sections disclosed areas of TC uptake at remodeling, shown as a golden yellow color.

Preparation of ground sections

Dogs were killed under general anesthesia. They were perfused with 10% buffered formalin by intravenous injection into the right jugular vein, and their skulls were cut frontally through the bilateral P4. Dehydration was accomplished by graded ethanol series, which was then replaced by acetone. The skulls were embedded in polyester resin, then cut into 500 μm-thick slices using a cutter (Crystal Cutter MC-411 D; Maruto, Tokyo) with a diamond blade. The slices were then ground to 100 μm-thick slices.

Measurement of labeled area

The sections were examined by a fluorescent epimicroscope (Nikon UPX-2A; halogen;

Fig. 2. Tracing from a radiograph of the lateral view of a dog skull showing location of implants (dots) as an x-ray marker. Implants of tantalum are placed on the occlusal surfaces of M1, P4-P1, I1-I4, and maxillofacial bones on the right traction side. F, frontal bone; Z, zygoma; M, maxilla; AM, alveolar process in a molar; AC, alveolar process in a canine; AI, alveolar process in an incisor.
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12 V, 100 W) at a UV of 330–380 nm. In addition, TC-labeled fluorescence was inputted into a color image processor (TAS-300; Kyoei-Olympus, Tokyo) using a triple-tube television camera (400 DPI; Ikegami, Tokyo), and converted into binary data, then the labeled areas were measured. The fluorescent color, golden-yellow, showing TC-labeling was identified as a mixed color of 47.1% red, 42.4% green and 10.5% blue by an image analyzer. Measurement was made in 6 maxillofacial bone sectors, excluding nasal conchae and teeth. Sectors were divided as follows. The region between the upper margin of the nasal bone and the crest of the alveolar process was divided into superior and inferior sectors by the horizontal midline. The superior and inferior sectors were further divided into the left, medial and right sectors by 2 vertical lines, which were set at the median of the left and right maxillofacial bones (Fig. 4). Then, TC-labeled area/cm² was calculated in each sector.

RESULTS

Macroscopic changes in dry skulls

In the experimental group, significant extrusion of teeth was seen in the right premolar and incisor segments where vertical traction had been loaded (Fig. 3). Maxillary occlusal plane was inclined towards the right side. Furthermore, a downward distortional deformation was observed on the nasal floor of the maxilla. Overbite, the distance between I¹ upper and I¹ lower incisor edges at occlusion, narrowed to 1.1 mm on the right traction side and to 3.9 mm on the left non-traction side. In the control group, overbite was 6.8 mm, indicating that occlusal position remained unchanged after bite was raised at the start of experiment.

Positional shifts of the implants

The mean shifts of the upper teeth before and after traction were M¹, −1.2 mm; P¹, −0.5 mm; P³, +2.2 mm; P², +2.5 mm; P¹, +3.0 mm; and I¹, +0.8 mm (Table 1). In the control group, the values were M¹, −0.3 mm; P¹, −0.2 mm; P³, +0.0 mm; P², +0.0 mm; P¹, +0.0 mm; and I¹ +0.2 mm (Table 1). The “+” means downward shift of implants, and the “−”, upward shift. These values show significant downward shift of premolars and incisors due to traction. In the control group, no positional shifts were found other than for M¹, P¹ and I¹. A slight downward shift at I¹ could be accounted for by the absence of occlusal contact with lower incisors, and regarded as natural extrusion.

In the experimental group, shifts of implants of maxillofacial bones by traction had the following mean values: zygoma, 0.0 mm; frontal bone, 0.0 mm; maxillary corpus, +0.3 mm; molar alveolar process, +0.3 mm; canine alveolar process, +0.4 mm; and incisor alveolar process, +0.6 mm. In the control group, no positional shifts were seen on any implants (Table 2).

Remodeling sites of bone

In the experimental group, TC fluorescence was observed in and around the alveolar process and midpalatal suture on the traction side (Fig. 4). The areas showing TC fluorescence were measured. Results revealed a statistically significant difference in TC-labeled areas of the maxillary alveolar process (p <
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Fig. 3. Frontal view of a dry skull. Upper: Control dog subjected to bite-raising without traction. Lower: Experimental dog subjected to vertical traction of right premolar and incisor teeth. On the right traction side, extrusion of teeth and downward distortional deformation of maxilla are seen.

<table>
<thead>
<tr>
<th>Table 1. Shift of implants placed in teeth caused by traction</th>
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<tr>
<td></td>
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<tr>
<td>Control group</td>
</tr>
<tr>
<td>Experimental group</td>
</tr>
</tbody>
</table>

Data are the mean $\pm$ s.d. in mm.
+$, \text{downward shift}; -$,$ \text{upward shift}.$
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0.01, t-test) and corpus (p < 0.05) between the experimental and control groups, where traction was performed in the experimental group. Also, TC-labeled areas adjacent to the midpalatal suture and in the vomer were significantly larger in the experimental group than in the control group (p<0.01). No significant difference was seen between the experimental and control groups at the alveolar process on the left, non-traction, side (Table 3).

Fig. 4. Fluorescent photomicrographs of unstained ground sections. The frontal section of the maxilla was divided into 6 sectors to facilitate evaluation of TC-labeled areas. RU, right upper; RL, right lower; MU, medial upper; ML, medial lower; LU, left upper; LL, left lower; m, maxilla; n, nasal bone; v, vomer. Upper: In a control dog, fluorescence is seen, although weak. Lower: In an experimental dog, prominent golden-yellow fluorescence at remodeling is seen in the alveolar processes (AP) as well as in the midpalatal suture (MS).
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Discussion

As a preliminary treatment to facilitate primary lip surgery in cases of bilateral labial cleft with protruding premaxilla, the premaxilla is placed in a normal position by applying traction of the projecting prolabium in a posterior direction. Response occurs also on the suture of the premaxilla and vomer, and on the vomer itself (Millard 1977). However, no morphometrical data were described. In the present study, the implant in the right \( P^3 \), on which vertical traction was loaded, shifted downward 2.2 mm and the implant in the maxillary corpus also shifted downward 0.3 mm, i.e., the shift of the implant in the maxillary corpus decreased to approximately one-seventh of the shift of that in the right \( P^3 \). The TC-labeled area in the right upper sector including the maxillary corpus also decreased to approximately one-seventh of that in the right lower sector including the alveolar process.

By analysis of cranial radiographs, Alexander (1966) reported changes in maxillofacial growth due to the former Milwaukee brace therapy for scoliosis. These changes were a decrease in the upper anterior, and lower anterior and posterior face heights, and an elevation of the palatal plane with a tendency to flatten the palatal vault. In an experiment using a Milwaukee brace on monkeys, displacement of maxilla and zygoma was caused by sutural resorptive remodeling,

**Table 2. Shift of implants placed in maxillofacial bones caused by traction**

<table>
<thead>
<tr>
<th></th>
<th>Zygoma</th>
<th>Frontal bone</th>
<th>Maxillary corpus</th>
<th>Alveolar process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
</tr>
<tr>
<td>Experimental group</td>
<td>0.0±0.0</td>
<td>0.0±0.0</td>
<td>+0.3±0.1</td>
<td>+0.3±0.1</td>
</tr>
</tbody>
</table>

Data are the mean±s.d. in mm.
+ , downward shift.

**Table 3. The total TC-labeled area in each sector in the frontal section of the maxilla at \( P^3 \)**

<table>
<thead>
<tr>
<th></th>
<th>Right side</th>
<th>Median</th>
<th>Left side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control group</td>
<td>1.0±0.4</td>
<td>-</td>
<td>0.9±0.0</td>
</tr>
<tr>
<td>Experimental group</td>
<td>1.8±0.5</td>
<td>-*</td>
<td>3.3±1.1</td>
</tr>
<tr>
<td>Lower side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control group</td>
<td>4.8±1.1</td>
<td>-**</td>
<td>1.5±1.0</td>
</tr>
<tr>
<td>Experimental group</td>
<td>13.0±4.3</td>
<td>-**</td>
<td>4.2±1.0</td>
</tr>
</tbody>
</table>

Data are the mean±s.d. in %
* \( p < 0.05 \); ** \( p < 0.01 \); t-test.
particularly at frontomaxillary, frontozygomatic and zygomaticomaxillary sutures (Cutler et al. 1972). The influence by traction of teeth is not so considerable compared to that by the Milwaukee brace. In the present study, the TC-labeled areas in the right lower sector including the alveolar process, the medial lower sector including the midpalatal suture, the medial upper sector including the nasomaxillary suture, and the right upper sector without any suture in the experimental group were 2.7, 2.8, 3.6 and 1.8 times as wide as those in controls, respectively. These results indicate that remodeling occurred not only on the sutures, but also in the bone itself.

In monkeys, a positional change of maxillofacial bones with a slight counterclockwise rotation in the right-left roentgenograph is caused by extraoral, anteriorly directed force (Kambara 1977). From that study, it was concluded that anteriorly directed loading of a magnitude ranging from 300 g to several kg, via upper teeth over several months, changes bone growth direction, and causes bone deformation and displacement. According to Niikura (1979), a magnitude of 30 g in the vertical traction of a single tooth is enough to cause histologic changes in the periodontal tissue. In this study, vertical traction was performed with a magnitude of 280 g on 6 right upper teeth, i.e., approximately 50 g per tooth. Consequently, deformity was induced in maxillofacial bones in addition to remarkable extrusion of teeth.

Facial and cranial bones are mostly membranous in origin. Bones develop and grow by osseous apposition at the periosteum and resorption at the endosteum. The growth of the membranous bones are more readily influenced by muscle forces than by genetic factors (van Limborgh 1970). Nanda (1978) and Jackson et al. (1979) reported that, in monkeys, extraoral, anteriorly directed force on maxillofacial bones was transmitted through the maxilla to midfacial bones, resulting in remodeling of even such deep cranial structures as sphenoidal synchondrosis. The intensity of remodeling was proportional to the distance from the active site of the force to the suture, and was related to the directions of the suture and force. In the present study, the TC-labeled area in the experimental group was 4.2% in the area of the medial lower sector and 3.3% in the medial upper sector. In controls, the labeled area was 1.5% in the medial lower and 0.9% in the medial upper sectors. The labeled area was larger in the medial lower than in the medial upper in both groups. However, no influence of vertical traction of teeth was observed on the opposite side. The above observations suggest that the sutures intercept transmissions of the vertical traction to the opposite side. Recently, Tanne and Sakuda (1991) have investigated deformity of maxillofacial bones resulting from extraoral anteriorly directed traction on maxilla using the finite element analysis, and demonstrated that compression was loaded on the frontonasal suture because of the presence of a counterclockwise rotation, contrary to traction of the maxilla. Also in this study, the presence of TC-labeling adjacent to the midpalatal suture showed, that the main sites responding to
traction of teeth were not merely the periodontal tissues and alveolar processes, but also the suture. This indicates that the suture responds remarkably to traction of the teeth, with remodeling of the bone.

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References