Bone mineral content of human mandible related to bite force and occlusal contact area

Masanori SHOZUSHIMA, *Hirokazu NAKANO, *Munetsugu KUBOTA, *Tetsuya KAMEGAI, *Fujiro ISHIKAWA, Hiroki SAITO, Kimio SAKAMAKI

Department of Dental Radiology, School of Dentistry, Iwate Medical University

(Chief : Prof. Kimio SAKAMAKI)

*Department of Orthodontics, School of Dentistry, Iwate Medical University

(Chief : Prof. Fujiro ISHIKAWA)

[Received : October 9, 1996 ; Accepted : November 13, 1996]

Summery : There are some reports that activity in the masticatory system affected the growing craniofacial skeleton. We speculated that biting efficiency affects not only cephalometric data but also mandibular bone mineral content (BMC). In this study, we evaluated the relationship between mandibular BMC and maximum bite force or occlusal contact area as a parameter of biting efficiency.

The subjects consisted of 46 adults, with a mean age of 23 years and 7 months. Mandibular BMC was measured by photodensitometry using dental X-ray films. The subject contrast of mandible was used as a parameter of BMC. Bite force and occlusal contact area were measured using pressure sensitive sheets.

A negative correlation was observed between subject contrast and bite force and between subject contrast and occlusal contact area, with a correlation coefficients of -0.378 ($p<0.01$) and -0.401 ($p<0.01$) respectively. Thus, BMC increased with maximum bite force and occlusal contact area. It was indicated that masticatory activity appears to affect not only cephalometric data, as previously reported, but also bone strength.

Key words : bone mineral content, bite force, occlusal contact area, masticatory activity

Introduction

Physical activity in Japanese school children has been suggested to be decreasing in recent years despite an increase in the mean height. This is often discussed as a social problem concerning the maintenance and promotion of health. Clinical and experimental studies on the association between bone growth and muscle function have shown increases in bone weight and bone mineral content (BMC) with increased physical activity[1,2] or a decrease in BMC after inhibition of

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(Department of Dental Radiology, *Department of Orthodontics, School of Dentistry, Iwate Medical University, 1-3-27 Chuodori, Morioka, 020 Japan)

岩手県盛岡市中央通1丁目3－27（〒020）

activity by immobilization of a unilateral upper or lower limb of animals using a cast[3,4]. These findings suggest marked effects of gross body movement on bone development.

There have been similar reports on the association between the jaw bone and chewing function. Inoue[5] evaluated the diet and chewing system in present-day Japanese and suggested that decreases in the chewing time and bite force brought about diminution of jaw bone, to result in a disharmonious relation between the size of the teeth and that of the jaw bone, which is a major cause of tooth-to-denture-base discrepancy. Furthermore, the thickness of the masseter muscle, a masticatory muscle, has been reported to markedly affect bite force and measurements of facial morphology determined from lateral cephalograms[6,7]. Thus, activity in the masticatory system appears to also affect the morphology of bones constituting the face. We speculated that a decrease in craniomandibular function affects not only cephalometric data but also the strength of the jaw bone. In this study, the association between BMC, a parameter of the strength of the jaw, and maximum bite force and occlusal contact area as a parameter of biting efficiency was evaluated in 46 adults aged 22−24 years.

Subjects and methods

Subjects

The subjects consisted of 46 dental students (30 males and 16 females) with a mean age of 23 years and 7 months (SD : ± 1 y1m). Subjects with the following findings were excluded : history of orthodontic treatment, defects in the anterior teeth, defects in 2 or more molars, morphological right and left differences in the mandibular bone on panoramic radiographs, pain in the temporomandibular joint during mouth opening, or osteoscrelosis in the area for observation of BMC on radiographs, i.e., the region of interest (ROI).

Bone mineral content (BMC)

Mandibular BMC was measured by photodensitometry using dental X-ray films (Ektaspeed plus, Eastman Kodak Co., Rochester, NY, USA). The lead foil (0.065 mm) contained in this film pack was cut, placed in layers like steps and used as a reference. These foils were attached to the exposure surface of the film, and intraoral projection was performed. The site of radiography was mainly the mesial root apex of the mandibular first molar on the primary chewing side. The dental X-ray apparatus was a Lumix 70 (70 kVp, Tokyo Emix Co., Tokyo, Japan). The films were developed at 32℃ in an automated processor using developer of RD-1B (Fuji Photo Film Co., Ltd., Tokyo, Japan). After radiography, ROIs (2mm in diameter) were established on the image of one lead foil and in the center of the line connecting the apex of the first molar and the second premolar in the mandible. Reference photographic density (Dref) and bone transmission photographic density (Dbone) were measured. Densitometric measurements were made with a digital densitometer (PDA-15, Konishiroku Photo Ind., Co., Tokyo, Japan) using the 2 mm ϕ light aperture. Measurement was performed 3 times, and the mean value was used.

A characteristic curve (reference H-D curve) representing the relationship between the X-ray exposure time and the degree of blackening was produced using films of the same lot as that of the above dental films and a Lumix 70. The photographic density was plotted on the longitudinal axis, and the exposure time (sec) was expressed as log of the relative exposure dose and plotted on the horizontal axis. Dref and Dbone in each subject were converted to the relative exposure doses (Iref and Ibone, respectively) using this reference H-D curve. The subject contrast of bone can be defined using the following equation, and this subject contrast was used as a parameter of BMC.

Subject contrast of bone = Ibone / Iref

BMC is often expressed as the $CaCO_3$ content per cm^2 (g/cm^2). Therefore, a step-like $CaCO_3$ phantom was produced using $CaCO_3$ and dental resin (Ortho Crystal, Nissin Dental Products Inc., Kyoto, Japan). Subsequently, the phantom was radiographed together with a small piece of the lead foil. Films of the same lot as the above films and the same X-ray apparatus were used. On developed films, the photographic density was measured by the above method and was converted to the relative exposure dose using the reference H-D curve. The relative exposure dose of the lead foils was expressed as Iref, and that of the $CaCO_3$ phantom step as $ICaCO_3$, and the subject contrast of $CaCO_3$ was obtained using the following equation.

Subject contrast of $CaCO_3$ = $ICaCO_3$ / Iref

Subject contrast of mandible can be converted to the $CaCO_3$ content using the relationship between $CaCO_3$ content and subject contrast.

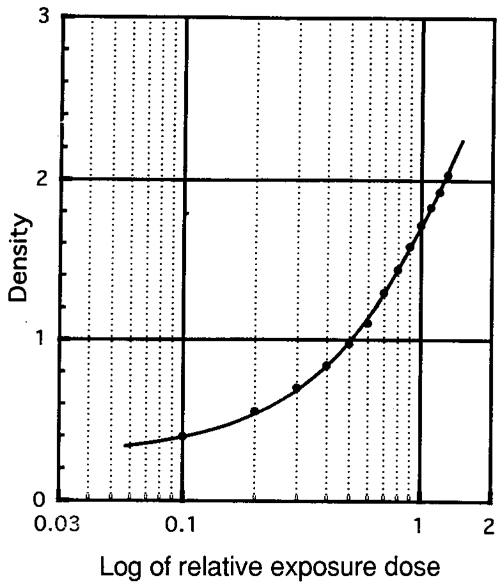

Fig.1. Reference H-D curve
The characteristic curve of reference film used in the present study.

Bite force and occlusal contact area

Bite force and occlusal contact area were measured using pressure-sensitive sheets (Dental Prescale R50H, Fuji Photo Film Co., Ltd., Tokyo, Japan). This sheet develops color depending on the external force ; namely, the color becomes darker with high pressure[8]. The subjects bit a pressure sensitive sheet in centric occlusion, and the maximum bite pressure was measured. The sheet was scanned, and analyzed with a computer (Occluzer, FPD703, Fuji Photo Film Co., Ltd., Tokyo, Japan), and bite force was determined based on the degree of color, and occlusal contact area based on the area of color development.

Results

The reference H-D curve of the dental films is shown in Fig.1. Our preliminary study showed that the density in the mandible near the premolar root apex is

Fig.2. The lead foils were attached to the exposure surface of the dental film package and used as a reference. The ROI was set on the mandible between the apex of second premolar and first molar.

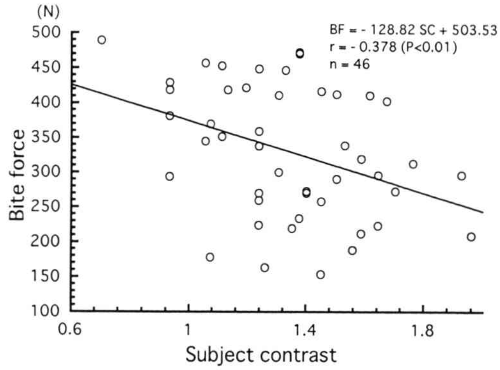

Fig.3a. Plot of the subject contrast (SC) *vs.* bite force (BF) in 46 subjects.
N : newton

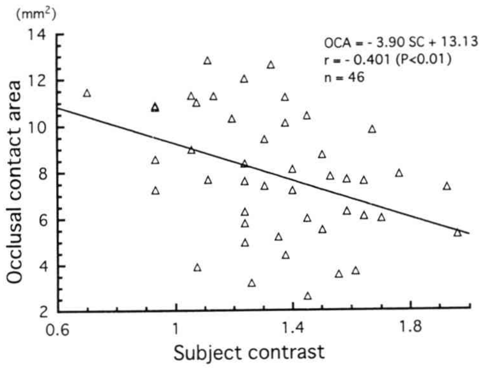

Fig.3b. Plot of the subject contrast (SC) *vs.* occlusal contact area (OCA) in 46 subjects.

about 1. Therefore, the exposure time was set so as to obtain a density of about 0.4-2.0, and an H-D curve was produced. All Dref and Dbone values obtained from the 46 subjects were present on this curve, and the radiographic density could be converted to the relative exposure dose.

Fig.2 show dental radiographic images obtained from one subject. The step wedge in the upper area of the figure indicates the densities of 1, 2, and 4 lead foils from the left. The Dbone near the molar apex was close to the density of one lead foil. Therefore, in all subjects, the density of one lead foil was used as Dref. In Fig.2, the Dref was 0.97, and the Dbone between the first molar and the apex of the second premolar was 1.43. The Iref and Ibone obtained from Fig. 1 were 0.49 and 0.81, respectively. The subject contrast was 1.64. The bite force in this subject was 223 Newton (N), and the occlusal contact area was 6.1 mm^2.

Scatter plots of bite force against subject contrast and against occlusal contact area are presented in Figures 3a and 3b respectively in all subjects. A negative correlation was observed between subject contrast and bite force as well as between subject contrast and occlusal contact area with a correlation coefficient of -0.378 ($p<0.01$) and -0.401 ($p<0.01$), respectively and was statistically significant. Thus, BMC increased with bite force or occlusal contact area. In addition, there was a correlation between bite force and occlusal contact area ($r=0.885$, $p<0.001$). Thus, occlusal contact area was large in subjects with high bite force.

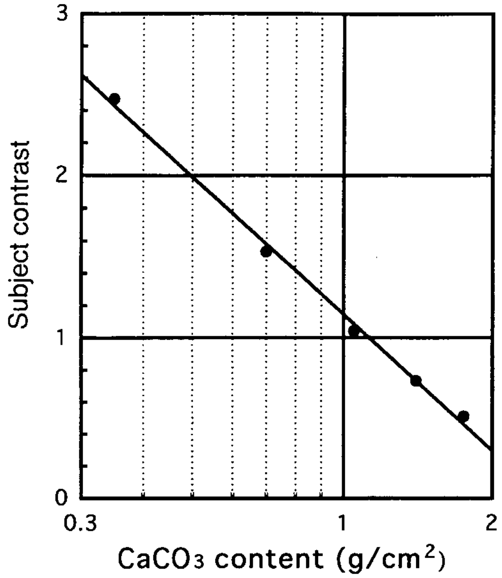

Fig.4. Relationship of subject contrast and $CaCO_3$ content.

The relationship between the $CaCO_3$ content and subject contrast is shown in Fig.4. The maximum, minimum, and mean subject contrast values in the mandibular bone in all subjects were 1.96, 0.70, and 1.34, respectively, and the corresponding $CaCO_3$ contents were estimated from Fig.4 to be 0.52, 1.44, and 0.78 g/㎠.

Discussion

In the diagnosis of bone metabolic diseases, BMC is evaluated by radiographic photodensitometry used in this study, qualitative computed tomography (QTC)[9], or dual energy X-ray absorptiometry (DEXA)[10,11]. QCT and DEXA require special apparatuses, but these apparatuses are difficult to use in the jaw area due to its morphology. In photodensitometry, a reference step wedge is often used to correct changes in X-ray dose, X-ray quality and development conditions, and BMC is measured using the equivalent thickness of this reference material as a scale. Equivalent thickness changes according to the thickness of soft tissue due to the quality hardening phenomenon of X-ray, which is the main cause of decreased accuracy in photodensitometry. However, in photodensitometry by intraoral projection used in this study, since the soft tissue of the mandible is thinner than the lumbar area or femoral bone area, the decrease in accuracy due to soft tissue is slight.

As reference materials, aluminum with an atomic number nearest to bone is generally used. However, aluminum is not appropriate for intraoral projection due to the thickness of aluminum. On the other hand, the method using dental films used in dental practice and lead foils contained in these films is readily performed and optimal especially for field investigation in a large group. After production of a reference H-D curve using the X-ray films and the apparatus used in the subjects, accurate comparison of BMC between groups is possible by comparing subject contrast even when there were slight changes in the X-ray dose.

In this study, the relative value of BMC in the axial direction of the màndibular bone was expressed as subject contrast, and its relationship with bite force or occlusal contact area was statistically evaluated. Subject contrast does not represent the absolute value of BMC. However, after the relationship between subject contrast and the $CaCO_3$ phantom was clarified as shown in Fig. 4, subject contrast can be converted to the $CaCO_3$ content/cm^2. The mean subject contrast in the subjects in this study was 1.34, which corresponded to 0.78 g/cm^2 $CaCO_3$.

The methods of measuring bite force

using pressure sensitive materials include the prescale, photocclusion[12,13], and the T-scan system[14]. We used the dental prescale because the measurement range is wide, and occlusal contact area in the entire dental arch can be measured. Using this system, data on bite force and occlusal contact area can be obtained in many subject for a short time. The prescale may be the most appropriate for evaluating chewing ability in a large group as in this study.

Craniomandibular function is determined by the complex and interrelated components comprising the morphology and biomechanics of the muscles, joints and teeth, and the neuromuscular system. Moss[15] reported that the morphology of the jaw, face, and cranium is affected by functional matrix growth, and the mandible is especially affected by the medial pterygoid muscle and temporal muscle. He suggested that these masticatory muscles are major factors determining the final morphology. Inoue et al.[16] carried out a diet survey and cephalometric analysis in 1981-1982 in 1,355 Japanese who were born between 1924 and 1966 and found an acute increase in malocclusion due to discrepancy factors in younger groups. Based on the diet survey, they also reported a high consumption rate of soft processed foods in younger groups, suggesting an urbanized dietary style as a cause of the increased malocclusion. These findings indicate the marked effects of chewing activities in the growth stage on the subsequent size of the jaw.

Braun et al.[17] investigated the relationship between bite force and cephalometric data in 129 dental students and found a decreased mandibular plane/palatal plane angle and a decreased mandibular plane angle in students with a high bite force. Weijs and Hillen[18] also measured the cross-sectional area of the masticatory muscles by X-ray CT and reported that subjects with large masseter and medial pterygoid muscle areas have a brachycephalic skull, a short face, and a small mandibular angle. Thus, bite force and the cross-sectional area of masticatory muscles also markedly affect the jaw morphology. We speculated that bite force and occlusal contact area affect not only cephalometric data but also mandibular BMC and investigated the relationship between BMC and bite force or occlusal contact area. A statistically correlation was observed between BMC and bite force as well as BMC and occlusal contact area. Therefore, enhancement in biting efficiency such as increases in bite force and occlusal contact area not only affect cephalometric data but also increases the thickness of the mandibular bone, i.e., strength of the jaw.

Ingervall and Bitsanis[19] showed that training of the masticatory muscles by daily chewing on a tough chewing material had a significant positive effect on the maximal molar bite force, and EMG activity of the anterior temporalis and masseter in long-faced children. In this study, dietary style of the subjects was not investigated. However, individual differences in bite force and BMC may be associated not only with congenital factors but also diet, and differences in chewing activities in the growth stage may affect bone growth.

Conclusion

We evaluated the relationship between BMC of the mandible and bite force or occlusal contact area in 46 dental students, and found that BMC increased with bite force and occlusal contact area. Bite force and occlusal contact area appear to affect not only cephalometric data, as previously been reported, but also bone strength.

Acknowledgement : We are most grateful to staff members of our departments for their kind assistance during this experiment.

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ヒト下顎骨骨塩量と咬合力そして咬合接触面積との関連

小豆島正典，*中野　廣一，*久保田宗次，
*亀谷　哲也，*石川富士郎，斉藤　博樹，坂巻　公男
岩手医科大学歯学部歯科放射線学講座
（主任：坂巻　公男　教授）
*岩手医科大学歯学部歯科矯正学講座
（主任：石川　富士郎　教授）

（受付：1996年10月 9 日）
（受理：1996年11月13日）

抄録：咀嚼機能の活動性が，顎顔面の発育に影響しているといういくつかの報告がある。我々は，これらの活動が，顎顔面の形態学的計測値ばかりでなく，下顎骨の骨塩量（BMC）にも影響しているだろうと考えた。本研究では，咀嚼機能のパラメーターとして最大咬合力と咬合接触面積を測定し，これらの値と下顎骨 BMC との関連性を調査した。

本研究に用いた被験者は，46名の成人（平均年齢23歳7カ月）からなる。下顎骨 BMC は，デンタルフィルムを用いたX線写真濃度測定法にて求め，BMC のパラメーターとして被写体コントラストを測定した。咬合力と咬合接触面積は，歯科用圧力感応シートにより求めた。

被写体コントラストと咬合力あるいは咬合接触面積とには負の相関が認められ，その相関係数はそれぞれ－0.378（$p<0.01$）と－0.401（$p<0.01$）であり，BMC の増大は咬合力と咬合接触面積の増大を伴うことがわかった。以上の成績より，咀嚼機能の活動性は，従来より報告されている顎顔面の形態学的計測値への影響の他，骨そのものの丈夫さにも影響していることが示唆された。