An analysis of static occlusion including occlusal force and occlusal contact area in intercuspal position may be helpful but a dynamic analysis of occlusion should be regarded as more important for analyzing the stomatognathic system. Anthropological research has shown that the Japanese and the Mongolian populations share morphological and genetic similarities, although their dietary lives are not the same. The purpose of this study was to evaluate the relationship between environmental factors such as dietary life and stomatognathic function with a dynamic analysis of physiological tooth displacement. Ten clinically healthy subjects were recruited (mean age 24.8 ±1.0 years). The subjects were divided into two groups 1) Mongolian group: five Mongolians grown with a more or less natural texture diet and 2) Japanese group: five Japanese grown with a relatively soft diet. The displacement of the upper left first molar was measured during function using a three-dimensional tooth displacement transducer Type M-3. The tooth displacement in the Japanese group occurred mostly in an apicopalatal direction, but intruded basically parallel to the tooth axis in the Mongolian group. The stress-strain curve revealed that elastic socket deformation and viscous elements were more pronounced in the Japanese group. It was concluded that environmental factors such as dietary life could influence tooth displacement during function.

Key words: tooth displacement, dietary life, tooth displacement transducer M-3, environmental factor, first molar.

Introduction

Intercuspal position (IP) is thought to be an essential jaw position because it is the intermaxillary tooth relationship most often referred as a basis of occlusal analysis. Therefore, there have been large number of studies on IP\(^1,2\), however, the majority of them were static analyses. The parameters of static occlusion such as occlusal force and occlusal contact area in IP may be helpful but a dynamic analysis of occlusion should be one of the main parameters for evaluating the stomatognathic system. When the tooth is not in function, it seems that it does not make contact with the proximal teeth, but pulsates in the dental alveoli because of the circulation of blood in the periodontium\(^3-6\) in a range of 0.25 to 0.70 μm. During mastication, the tooth displaces into the dental alveoli and the periodontal ligament plays a role of a natural cushion with up to 60 μm of axial shock-absorbing margin\(^7,8\). The biting force generated during mastication would tend to cause distortion of the periodontal membrane, alveolar processes and even both maxillary and mandibular bones. Also it could influence the morphological...
development and stability of alveolar process, dental arch and occlusion, because bone tissue responds to mechanical stress\textsuperscript{7,9,10}. Tooth displacement is influenced by a number of factors, which include occlusal contacts and supporting structures, bite force and dietary life, but it is not clear which of these factors is the most crucial\textsuperscript{11}.

Anthropological research has shown that the Japanese and Mongolian races share morphological\textsuperscript{12} and genetic\textsuperscript{13} similarities. On the other hand, their dietary lives are not the same. Modern Japanese food is refined and soft, and contains relatively few hard particles. Also it requires little chewing with rather fewer chewing strokes. Mongolia’s nutritional structures remain untouched, compared with the other countries such as Japan, although its customs and lifestyles have changed through the onset of industrialisation and information technology. The Mongolian basic diet consists of animal husbandry products such as meat and its derivatives, and milk products including very hard dried curd.

The purpose of this study was to evaluate the relationship between environmental factors such as dietary life and stomatognathic function using a dynamic analysis of physiological tooth displacement.

**Materials and methods**

Ten clinically healthy subjects aged 21-30 years were recruited for this study (mean age 24.8 ± 1.0 years). The following criteria were used in the procedure:

1. Complete natural dentition (except for missing third molars)
2. Absence of any temporomandibular joint disorder
3. Absence of any neuromuscular disturbances
4. Absence of any periodontal pockets or increased tooth mobility
5. No previous orthodontic treatment

The subjects were divided into two groups 1) Mongolian group: three men and two women grown with a more or less natural texture diet (living in Ulan Bator, Mongolia) and 2) Japanese group: four men and one woman grown with a relatively soft and refined diet (living in Tokyo, Japan).

Mongolian common dried milk curd, named “aaruul” was chosen as a representative hard food of Mongolian dietary life and used for a confirmation test of the subjects’ oral function for hard food. Its initial breakage force was around 287 N tested as previously described\textsuperscript{14} and 6 times larger than that of a peanut (49 N) categorized as same fractural food. The initial breakage force is equal to the definition of fracturability\textsuperscript{14}. The subjects were offered a piece of “aaruul” and asked to chew it in a normal manner. Then they selected the food as easy to chew, difficult to chew or impossible to chew. All Japanese subjects responded that the food was impossible to chew whereas for Mongolians it was easy to chew. All the participants were given an explanation and accepted the objectives of this study. The displacement of the upper left first molar was measured during function with the three-dimensional tooth displacement transducer Type M-3 developed by Miura\textsuperscript{8}. As a transducer, three Magnesensors (Sony Magnescale Inc., Tokyo, Japan) were used to record the displacement path of the tooth. The Magnesensor is a compact and light weight non-con-
The displacement transducer Type M-3 consists of three pick-up heads, three magnets, universal joints, a measuring probe, and a plate for setting up the transducer. Three dimensional movements of the end of the measuring probe are accurately transmitted to the magnets by the universal joints.

All the parts of the measuring device except for the measuring probe are set-up extraorally. Therefore, the apparatus does not disturb the chewing movement.

The transducers are not affected by the intraoral environment (temperature and humidity). The transducer was calibrated before and after each measurement trial. The linearity error of this transducer in each direction was less than 2% for a range of 200 mm. The amount of the tooth displacement in function was considered to be between about 50 and 150 mm. The accuracy of this Type M-3 tooth displacement transducer was satisfactory for measuring the physiological tooth displacement in function. The output signals from the three transducers were amplified (Biotop 6R12 NEC-Sanei Co., Tokyo, Japan) at the rate of 10 mV/mm. The signals were monitored and recorded on a Digital Data Recorder (PC 208 Ax, Sony Inc., Tokyo, Japan). The data were processed by personal computer at 2.5 msec intervals and then the tooth displacement was displayed in the bucco-palatally, mesio-distally and corono-apically directions (Fig. 1).

The present study was concerned with the frontal plane to minimise the factor of adjacent teeth, since it is easier to visualise distortion of the periodontal tissues in relation to displacement. Axial displacement was defined as 90 degree to the occlusal plane. An angle greater than 90 degrees represented an inclination in a palatal direction (Fig. 2). Tooth displacement was measured under various clenching conditions, intercuspal position (IP) with habitual occlusal force, clenching on four or eight sheets (AP4 and AP8) of articulating paper of 30 μm thickness (GC Co., Tokyo, Japan) and biting a custom table fitted with an occlusal force measuring device (MPM 3000, Nihon Kohden Co., Tokyo, Japan). Electromyogram recordings were made simultaneously from the masseter muscles using bipolar surface electrodes for confirmation of the intensity of muscle contraction during clenching. Each clenching trial was maintained for 2 sec with along enough interval to allow the tooth to...
return to its original position between the trials. To standardise the procedure, the same operator recorded data for all the measurements. The measurements were performed three times for each condition. The intra-individual variation of displacement degree was to be less than $\pm 5$ degrees among the clenching trials. The Student’s t-test was applied for statistical analysis. A significance level of $p<0.05$ was considered to be statistically significant.

**Results**

Tooth displacement varied in relation to the clenching intensity at the intercuspal position (Table 1, Figs. 3 & 4). When the clenching intensity was light (mean 2-12% of the maximum voluntary contraction (MVC) of masseter muscles), in both groups, the displacement was mostly apical with some slight inclination to the palatal side in the Japanese group. When the clenching intensity increased to heavy (mean 33-61% of MVC), the amount of displacement increased and the measured point of subject tooth in the Japanese group displaced slightly apically at the IP in the early phase, and then in a palatal direction, or directly in the palatal direction in the frontal plane. However, in the Mongolian group, the tooth mostly intruded parallel to the tooth axis. One Mongolian subject showed partly similar displacement paths to the Japanese group but with a lesser degree toward the palatal direction. The degree of direction of tooth displacement in the frontal plane was in a range of 111-145 degrees (average 124.6 degree) for the Japanese group, and in a range of 89-137 degrees (average 107.6 degree) for the Mongolian group during heavy clenching.

When clenching on four sheets of articulating paper (AP4) at the subject tooth, the direction of displacements in the frontal plane were in a range of 109-164 degrees (average 144.0 degree) in the Japanese group. The direction of tooth displacement was toward the apicopalatal direction, which was similar to clenching at the intercuspal position with habitual occlusal force. In the Mongolian group, the direction of displacement in the frontal plane ranged from 76 to 136 degrees (average 106.4 degree). These were basically toward the apical direction and in one case with a slight displacement toward the palatal direction.

When clenching on eight sheets of articulating paper (AP8), the displacement of the subject tooth of the Japanese group was first in an apical direction and then toward the palatal direction. The range was 127-160 degrees (average 146.4 degree). For the Mongolian group, the displacement of the subject tooth was mostly in an apical direction with one case, which inclined slightly toward the palatal direction. The direction of the displacement in the frontal plane ranged from 76 to 118 degrees (average 91.8 degree).

The mean degrees of displacement between Mongolian and Japanese groups at the IP were not significantly different ($p>0.05$), but were significantly different in the AP4 ($p<0.05$) and different with a higher significance level in the AP8 conditions ($p<0.01$).

The stress-strain curve (SSC) that represents the relation between the amount of tooth displacement and occlusal force revealed differences of tooth supporting tissue (Figs. 5 & 6). The stress-strain curve was composed of the two phases. The first phase represented distortion of the periodontium and the second phase, distortion of the alveolar bone. In the Japanese group, the first phase showed gradual distortion until the occlusal force reached a certain level. In the second phase, the distortion increased gradually and evenly as long as the force was applied. In the Mongolian group, during the first phase, the amount of tooth displacement increased rapidly along with the distortion of the periodontium despite a small amount of force. After the occlusal force reached a certain level, the amount of tooth displacement did not change very much in the second phase. The relationship between the displacement and the occlusal force indicated that elastic socket deformation was more pronounced in the Japanese group.

**Discussion**

The occlusal characteristics at the intercuspal position measured by static means alone seem to be of limited validity. On the other hand, the dynamics of the teeth at the IP during different clenching intensities may provide more information of clinical significance. Previous studies\cite{3,4,7,11,15-18} on tooth displacement were carried out on mostly anterior teeth and premolars and measured with different methods both in static situation and in function. However, the results of the precise directions and amounts of tooth displacement contradicted each other in these studies. In this study, the upper first molar was chosen because of timing and sequence of tooth eruption, tooth shape and position and its role in masticatory function.

The tooth displacement data of the Japanese group
Fig. 3. Tooth displacement paths in the frontal plane of a Japanese subject. IP, intercuspal position; AP4, biting four sheets of articulating paper; AP8, biting eight sheets of articulating paper.

Fig. 4. Tooth displacement paths in the frontal plane of a Mongolian subject. IP, intercuspal position; AP4, biting four sheets of articulating paper; AP8, biting eight sheets of articulating paper.
Fig. 5. Stress-strain curves (SSC) of a Japanese subject.

Fig. 6. Stress-strain curves (SSC) of a Mongolian subject.
obtained in the present study were similar to the
direction of the tooth displacement reported by Kato\textsuperscript{18},
Miura\textsuperscript{5,8} and Okada\textsuperscript{19}. These demonstrated that tooth
displacement occurred in an apical and palatal direc-
tion. However, the results of the Mongolian group
were different in that the teeth displaced mostly along
the tooth axis and clenching intensity was related to the
amount rather than the direction of tooth displacement.

When clenching on four or eight sheets of articulating
paper, the direction of displacement in the Japanese
group became more palatal when the paper thickness
increased. On the other hand, in the Mongolian
group, thickness was related to the amount rather than
the direction of tooth displacement, which remained
less affected even when articulating paper intervened.
These findings indicate that the occlusal contact factor
was probably more dominant in the Japanese group
because its displacement direction was influenced.
However, in the Mongolian group, the occlusal contact
factor was less dominant.

Regarding the supporting tissue, the tendency of
palatal inclination of displacement of the Japanese
group may suggest elastic deformation of the tooth
socket. Also, in the Japanese group, slow recovery in
different path, after unloading of occlusal force
reflects pronounced periodontal viscous element
described as “dash pot” in the Voigt model\textsuperscript{20}. This was
supported by Masuda\textsuperscript{10}, who reported the periodontal
distortion without occlusal influence.

On the other hand, because of the tooth displace-
ment along the tooth axis and of the immediate and
complete recovery of stress-strain curve, the
Mongolian group might be expected to have rather
more dense and rigid alveolar bone and dominant elas-
tic periodontium.

It was reported that the mean occlusal forces of the
total dentition in Mongolian and Japanese races were
not significantly different\textsuperscript{21}. The force was around
1000 N and was measured by Dental Prescale.
However, peak stress on the periodontal tissues of a
single tooth in the Mongolian group should be far high-
er than that of the Japanese group because hard milk
curd “aaruul” used in the subject confirmation test
showed 6 times larger initial breaking force (287 N)
that than of peanut which was also categorized as frac-
tural food.

The remodelling of tissue according to functional
demands such as the hardness of food is closely
related to the biomechanical properties of the alveolar
bone and periodontal ligament\textsuperscript{8}. Such biomechanical
changes could affect tooth displacement behaviour.

Since food with a more or less natural consistency
should require more force for mechanical breakdown,
then biomechanically advantageous or optimised
tooth displacement, in other words, axially oriented
 intrusion with pronounced shock absorbing behaviour
could possibly be induced under more critical condi-
tions.

In the present study, for the subject groups raised on
different dietary lives, the displacement patterns differed
from each other. This may suggest possible environ-
mental influences on tooth displacement as a result of
the different physical properties of periodontal tissues.
From this point of view, it is suggested that the
occlusal surface of any restoration should be created
and adjusted according to individual characteristics of
tooth displacement and then must be in harmony with
the periodontal tissues.

In conclusion, the teeth of the Japanese group dis-
placed mostly in an apicopalatal direction, but the
teeth of the Mongolian group intruded basically parallel
to the tooth axis. The stress-strain curve revealed that
elastic socket deformation and viscous elements were
more pronounced in the Japanese group. This study
indicated that environmental factors such as dietary life
could influence tooth displacement during function. The
individuality of periodontal tissues should be considered
when we place any restorations.

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