The purpose of this study is to evaluate the masticatory muscle activity and mandibular movement during function in marginal mandibulectomy patients. Three marginal mandibulectomy patients and three healthy subjects participated in this study. The activities of the temporalis (TA) and masseter muscles (MM) on the normal and resected sides during maximum voluntary clenching (MVC) and gum chewing (Gch), and mandibular movement during Gch were analyzed. Paired t-test, Student’s t-test and one-way ANOVA were performed at $P < 0.05$. For MVC, integrated EMG (iEMG) in patients was lower than in healthy subjects. When iEMG of each muscle activity in patients was compared, TA activity on the resected side was greater than that of MM. There were no differences between the normal and resected sides in TA or MM. For Gch, no differences in iEMG, burst or chewing time were found between patients and healthy subjects. MVC was greater than Gch in healthy subjects, but no difference was found in patients. The range of mandibular movement along the X axis in patients was greater than in healthy subjects. Within the limitations of this study, EMG activity in patients during MVC was remarkably lower than that in healthy subjects, and altered mandibular movement was observed.

Key words: electromyographic activity, masticatory muscles, mandibular movement, marginal mandibulectomy, rehabilitation

Introduction

Mandibulectomy is performed to treat a tumor of the mandible, soft palate, floor of mouth, or tongue. If discontinuity results, facial deformity and functional deficits may occur. These include rotation and deviation of the mandibular segment, facial asymmetry, impaired speech articulation, difficulty swallowing and masticating, and compromised control of saliva. Mandibular movements, occlusal contacts and proprioception, and masticatory efficiency are compromised. Resections involving the tongue and mandible, with loss of mandibular continuity, demonstrate the most significant impairments in mastication.\(^1\)

As quality of life (QOL) has been highly emphasized recently, the reconstruction of the mandible and the soft tissues after mandibulectomy has been required, not only for the restoration of mandibular continuity, but also for better functional rehabilitation. Therefore, mandibulectomy and the following reconstruction should be always considered from the viewpoint of the reduction of stomatognathic functional disabilities and recovery in such patients. Although numerous papers have been published outlining reconstructive techniques for establishing continuity of the mandible, there is little knowledge of jaw function, especially mas-
ticatory activity, after mandibulectomy.

Endo\(^2\) reported that the EMG activities of masticatory muscles in mandibulectomy patients with reconstruction were almost the same as in normal subjects; and in patients without bone transplantation, remarkably low muscle activities were observed. Curtis et al.\(^3\), Saito\(^4\) and Takahashi\(^5\) demonstrated that deviation of the mandible toward the operated side always occurred when the mouth was fully open, and obstructions to forward movement and lateral movement toward the normal side occurred. Takeuchi et al.\(^6\) stated that the ranges of border movements in mandibulectomy patients showed a tendency to be smaller than those in healthy subjects. Marunick et al.\(^7,8\) reported that occlusal force and masticatory efficiency decreased after hemimandibulectomy and that prosthetic treatment could not restore patients to their pre-treatment occlusal force and masticatory efficiency levels. The most comprehensive study evaluating masticatory function and mandibular reconstruction in cancer patients was reported by Urken et al.\(^9\) Their results indicated that patients with reconstructed mandibles had significantly improved bite force levels, improved masticatory performance levels, and a more vertical masticatory cycle.

As stated above, some studies mention jaw function after hemimandibulectomy and segmental mandibulectomy, but few studies report on the jaw function of marginal mandibulectomy patients; perhaps because this is not regarded as causing practically any functional deficit. But when the patients are asked about their ability to eat, they are not always satisfied with their mastication skills. The purpose of this study is to evaluate the masticatory muscle activity and mandibular movement simultaneously during function in marginal mandibulectomy patients.

**Material and Methods**

**Subjects**

Three marginal mandibulectomy patients (1 female, 20 years and 2 males, 55 and 64 years) participated in this study (Table 1). The integrity of the anterior temporalis (TA) and masseter muscles (MM) was preserved. Each patient had a complete natural maxillary dentition (Fig. 1, A, B, C) and occlusal contacts with some natural mandibular teeth in the habitual occlusion (Fig. 2, A, B). A removable partial denture with wire (Co-Cr) and cast (Au-Pd) clasps, artificial teeth

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Resected side</th>
<th>Resected part</th>
<th>Remaining teeth</th>
<th>Post-surgical period</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>20</td>
<td>Ameloblastoma</td>
<td>Right</td>
<td>Posterior from first molar</td>
<td>26</td>
<td>2Y 2M</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>55</td>
<td>Ameloblastoma</td>
<td>Right</td>
<td>Posterior from lateral incisor</td>
<td>22</td>
<td>9M</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>64</td>
<td>Myxoma</td>
<td>Right</td>
<td>Posterior from canine</td>
<td>23</td>
<td>1Y 10M</td>
</tr>
</tbody>
</table>
(Duradent™, GC Co., Tokyo, Japan) and heat-processed base (Acron™ GC Co., Tokyo, Japan) was made for each patient (Fig. 2, C, D). Measurements were carried out after several adjustments of the partial denture over a period of 2 months in all patients. At the end of the process, they all had clinically satisfactory dentures with acceptable occlusion, retention and stability. Three volunteers (2 males, 27 and 50 years and 1 female, 54 years) with complete natural dentitions, normal occlusion, and no signs or symptoms of cranio-mandibular disorders participated as healthy control subjects.

Informed consent was obtained from all subjects prior to testing.

**EMG technique**

The activities of TA and MM on the normal and resected sides during maximum voluntary clenching (MVC) and gum (Free Zone™, Lotte, Tokyo, Japan) chewing (Gch) were recorded using a Gnatho-hexagraph™ (JM-1000 version 1.25, Ono Sokki, Yokohama, Japan) combined with surface electromyography (Multichannel Amplifier MEG-6116™, Thermal Array Recorder RTA-3200™, Input Box JB-640J™, Nihon Kohden, Tokyo, Japan). Bipolar surface electrodes of Ag-AgCl, 10 mm in diameter, with an inter-electrode distance of 20 mm, were used. The electrodes were placed by palpation of the muscles in accordance with the main direction of the muscle fibers and as far as possible in the same position with respect to the muscles in all subjects. The 4 EMG signals were amplified 1000 times and filtered (bandwidth frequency 5-1000 Hz), and then were digitized (sampling rate 2560 Hz, 12-bit resolution) in the Gnatho-hexagraph.

**Measurement system of mandibular movement**

The Gnatho-hexagraph system was also used to measure mandibular movement using conventional methods. This system is a non-contact measuring device, and has the ability to conduct three-dimensional measurements of the movement of arbitrary points on the mandible with 6 degrees of freedom. In the 30X30 cm space 1.1 m in front of 2 CCD cameras, the error of measurement is less than ±150 μm in the anterior-posterior direction, ±100 μm in the vertical direction and ±50 μm in the lateral direction. Data were recorded during Gch at a sampling rate of 89.4 Hz.

**Experimental protocol**

Each subject was seated in a dental chair in an upright and relaxed position, with the head in natural balance. Test condition is shown in Table 2. Every subject was asked to perform MVC in the inter-cuspal position for 11 seconds (s). EMGs during MVC were recorded 2 times at a 3-min interval. For Gch, EMGs and the mandibular movements were recorded for 30 s simultaneously under each test condition. All measurements were carried out in an exclusive laboratory where the temperature was maintained at approximately 23 °C. All testing was performed on the same day for each subject.

**Data analysis**

Integrated EMGs (iEMGs) for 4 muscle activities during MVC were calculated using JM-0154 analysis software (Ono Sokki, Yokohama, Japan). The value of iEMG for 3 s during 2 MVC tasks in each subject was

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**Table 2.** One set of test conditions

<table>
<thead>
<tr>
<th>Marginal mandibulectomy patients</th>
<th>B. MVC with denture = MVC+</th>
<th>(11 s) x 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Gum chewing on the normal side without denture = NS(-)</td>
<td>(30 s) x 2</td>
<td></td>
</tr>
<tr>
<td>D. Gum chewing on the normal side with denture = NS(+)</td>
<td>(30 s) x 2</td>
<td></td>
</tr>
<tr>
<td>E. Gum chewing on the resected side with denture = RS(+)</td>
<td>(30 s) x 2</td>
<td></td>
</tr>
</tbody>
</table>

**Healthy control subjects**

| A. MVC | (11 s) x 2 |
| B. Gum chewing on the left side | (30 s) x 2 |
averaged from 6 data items by every 3 s value of the middle 9 s in 11 s MVC task (Fig. 3). Finally, iEMG for 3 s was converted into iEMG / 1 s and analyzed.

The most stable 10 consecutive cycles were detected from the mandibular movements during 30 s Gch, and burst iEMG summed from 4 muscle activities / 1 cycle was calculated (Fig. 4). Burst periods were decided from EMG activity of TA on the chewing side. iEMGs / 1 cycle were also converted into iEMGs / 1 s and averaged. The average burst time and chewing time / 1 cycle were also obtained.

Further iEMGs / 1 s of MVC and Gch were compared.

Statistical analysis
To compare the difference between MVC in the patients without and with dentures, between the left and right, between TA and MM activities and between MVC and Gch, the paired t-test was used. To compare the difference between the patients and healthy subjects, Student’s t-test was used. One-way analysis of variance (ANOVA) was performed to compare among each test condition in the patients. All statistical tests were conducted at a significance level of $P < 0.05$.

Results
For MVC, there was no significant difference between iEMGs summed muscle activities in the patients without and with dentures (MVC−, MVC+) (Fig. 6). MVC− was significantly lower than that in the healthy subjects (Fig. 7, $P < 0.05$). When the iEMG of each muscle activity in the patients during MVC− was

The mandibular incisor point was used as the measurement point for the mandibular movement and the Frankfurt plane was used as the reference plane. The mid-point of the line connecting right and left porions was designated as the origin of the coordinates. Three coordinate axes, anterior-posterior (X), lateral (Y), and vertical (Z) were thus defined (Fig. 5). The most stable 10 consecutive cycles during 30 s Gch were detected by using the value on the Z axis (Fig. 4). The ranges of incisor point movement were calculated on the X, Y and Z axes for each cycle. The data analyses were carried out using mean values for the 10 cycles.
compared, TA activity on the resected side was signif-
ically greater than that in the MM (Fig. 8, P < 0.05),
but on the normal side there was no significant differ-
ence (Fig. 8). There were also no significant differences
between the normal and resected sides in the TA and
MM (Fig. 8). The results during MVC were also the
same as those during MVC (Fig. 8).

For Gch, no significant differences in iEMG
summed muscle activities were found among the
patients during Gch on NS (−) (the normal side without
dentures), NS (+) (the normal side with dentures) and
RS (+) (the resected side with dentures) (Fig. 6). There
was also no significant difference between NS (−) and
the healthy subjects (Fig. 7). No significant dif-
fferences in burst or chewing time/ cycle were found
respectively among NS (−), NS (+) and RS (+) (Table 3), and also between NS (−) and the healthy
subjects (Table 3).

Comparison of MVC with Gch, in the patients,
showed no significant differences between MVC—
and NS (−) (Fig. 9). In the healthy subjects, MVC was
significantly larger than Gch (Fig. 9, P < 0.05). iEMGs
of NS (−), NS (+) and RS (+)/ MVC during MVC (Gch/ MVC × 100%) were 71.1, 73.8 and 57.6% respectively. Gch / MVC of the healthy subjects was
Each range of mandibular movement on the X axis of NS (ʵ), NS (ʴ) and RS (ʴ) showed no significant differences (Fig. 10). But that of NS (ʵ) was significantly greater than that of the healthy subjects (Fig. 11, \(P < 0.05\)) and increased in the posterior direction. As for the Y and Z axes, no significant differences were found in any of the pairs (Fig. 10, 11).

**Discussion**

Reports suggest that clenching force and gum chewing may relate to masticatory function. In the current study, these parameters were evaluated in patients with marginal mandibulectomy and results were compared to normal subjects. Muscle activity in the marginal mandibulectomy patients was shown to be different from that of the healthy subjects. The EMG activity in the patients during MVC was significantly lower than that in the healthy subjects, and dominant TA activities on the resected side were observed.

It has been reported that changes in muscle forces produced during function are the result of alterations following surgery, including loss of mandibular continuity, loss of masticatory muscles, changes in tongue status, pain in the supporting tissues, and uncoordinated mandibular movements. It is also reported that MM EMG activities are lower than those of TA in patients with attrition, uncoordinated occlusion and temporo-mandibular disorder. However, the marginal mandibulectomy patients who participated in this study did not show any of the symptoms stated above.

Marunick et al. reported that for hemimandibulectomy patients EMG activity and occlusal force values showed a similar difference and also that evaluations of postoperative prosthodontic treatment showed significant decreases in occlusal force, regardless of prosthodontic treatment. Naeije et al. demonstrated that, at low clenching levels in healthy male subjects, temporal muscle activity tended to dominate, but at high levels the masseter muscle activity was stronger. Therefore, decreased iEMG level in patients during MVC and observed dominant TA activities on the resected side may indicate a lower maximum bite force. Mandibular defects, damage to the surrounding muscles and nerves, and losses of the periodontium,

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**Table 3.** Burst and chewing time / 1 cycle during gum chewing

<table>
<thead>
<tr>
<th>Gum chewing</th>
<th>Burst time (s) / cycle</th>
<th>Chewing time (s) / cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS(+)</td>
<td>3 0.368 ± 0.078</td>
<td>0.691 ± 0.133</td>
</tr>
<tr>
<td>NS(+)</td>
<td>3 0.393 ± 0.107</td>
<td>0.727 ± 0.112</td>
</tr>
<tr>
<td>RS(+)</td>
<td>3 0.409 ± 0.080</td>
<td>0.689 ± 0.086</td>
</tr>
<tr>
<td>Healthy Subject</td>
<td>3 0.362 ± 0.028</td>
<td>0.689 ± 0.043</td>
</tr>
</tbody>
</table>

NS(−) = gum chewing on the normal side without dentures in patients; NS(+) = gum chewing on the normal side with dentures in patients; RS(+) = gum chewing on the resected side with dentures in patients. One-way ANOVA was performed among NS(−), NS(+) and RS(+) Then Student's t-test was performed between NS(−) and healthy subjects: significant at \(P < 0.05\). No significant differences were found.

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**Fig. 10.** The range of mandibular movement / 1 cycle during Gch in patients (*: \(P < 0.05\)).

X axis: the anterior-posterior direction, Y axis: the lateral direction and Z axis: the vertical direction. One-way ANOVA was performed: significant at \(P < 0.05\). Data indicate mean ±SD.

**Fig. 11.** The range of mandibular movement / 1 cycle during Gch (*: \(P < 0.05\)).

Student's t-test was performed: significant at \(P < 0.05\). Data indicate mean ±SD.
periodontal receptors and teeth were thought to be the reason. Further study is needed to confirm this phenomenon.

Since the patients in the current study had undergone marginal resection of the mandible, it is plausible that the decrease in the muscle activity during MVC was observed only in the MM on the resected side. Practically MM activity on the resected side decreased, but at the same time 3 other muscles also decreased to the same level. More specifically, as the equilibrium between TA and MM tended to compensate each other on one side and to balance between the left and right sides, the result was no difference between the normal and resected sides. However, the patients may not perform MVC aggressively due to psychological damage resulting from surgery.

The lack of significant difference in muscle activity between patients with and without dentures in this study, as Marunick et al.\textsuperscript{7} stated, indicates the impact of mandibulectomy on the integrity of the structures essential for maximum occlusal force. They found surgery resulted in a measurable impairment in mastication that could not be always reversed by prosthetic rehabilitation. But since the patients can masticate on the resected side using their dentures and avoid the accumulation of foods in the resected area, it appears that prosthodontic treatment contributes to functional rehabilitation.

Marunick et al.\textsuperscript{8,21} also reported that the extent of mandibular resection and loss of continuity tended to decrease masticatory function, and the time required to perform the mastication test (15 and 30 strokes) and the number of strokes required to achieve the swallowing threshold in the patients increased when using Frito\textsuperscript{79} corn chip as a test food. Conventional prosthetic rehabilitation can improve masticatory function to some extent in some patients, but few, or none, are able to achieve pretreatment levels of masticatory function. Neill et al.\textsuperscript{22} have reported that the reduced muscle force per chew used by edentulous subjects was compensated for by an increase in the burst duration of the applied force. However, in the current study, burst and chewing time / 1 cycle and iEMG of 1 cycle / 1 s during Gch in the patients with mandibular continuity were not significantly different from those of the healthy subjects despite having the mandibular defect. For these reasons, the EMG activities of the patients with mandibular continuity were stable, and chewing gum might be soft enough not to affect the chewing time. Further study is needed for other texture of foods.

There was no significant difference between iEMG in patients during MVC and Gch. On the contrary, the healthy subjects showed significantly larger iEMG during MVC than that during Gch. Gch / MVC of the healthy subjects was 28.6%. However, since 57.6-73.8% of the muscle activity during MVC was used for 1 masticatory performance in the patients, Gch tasks needed more than 50% of the maximum muscle activity and were over 2 times greater than that seen in healthy subjects. In the case of foods that need time to acquire consecutive masticatory performance, they may cause fatigue or stress in the masticatory muscles over the limit of their chewing abilities. As stated by Marunick et al.\textsuperscript{7}, our results for higher Gch / MVC values in patients should be compensated for by diet selection or by taking more time to eat a meal.

Every range of mandibular movement in the anterior-posterior direction / 1 cycle during Gch in the patients showed significantly larger movements than that in healthy subjects, and in vertical direction also tended to increase. This result shows that patients may produce muscle activities for grinding foods by moving their mandibles to a larger extent in the posterior-down direction. Additional testing is needed in this area.

Although it is generally accepted that marginal mandibulectomy patients are not practically different from healthy subjects, EMG activity in the patients during MVC was remarkably lower than that in the healthy subjects, and altered mandibular movement was observed. Therefore, the results of this study suggest that not only prosthetic rehabilitation, but also surgical reconstruction, meal and psychological counseling for the improvement of QOL should be considered for every mandibulectomy patient. Further investigation is recommended to further evaluate the masticatory function and efficiency of mandibulectomy patients and methods for prosthetic rehabilitation, identify problems regarding mastication and direct future rehabilitation efforts.

Acknowledgments

We give our heartfelt thanks to Dr. Yamanaka and all subjects cooperated in this study.

References