Characteristics of sensing lower-jaw-position in patients with cerebral palsy during laughing gas-induced sedation

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Abstract To clarify the effects of the applied during sedation with nitrous oxide (hereafter referred to as laughing gas) on the ability of muscles attached to the lower jaw to sense lower-jaw-position and on the sensation of muscle spindles attached to the lower jaw in patients with cerebral palsy (CP) using healthy adult subjects without functional abnormalities of the jaws and oral cavities as control subjects (hereafter referred to as healthy subjects). Experiments were performed under the following conditions: for each subject, before the inhalation of laughing gas (LG) and oxygen (air-inhalation condition: referred to as without LG inhalation) and during the inhalation of LG and oxygen (inhalation condition of LG and oxygen under LG-induced sedation: referred to as during LG inhalation). Subjects in the experiments were eight CP patients and eight healthy people as controls. The ability to discriminate lower-jaw-position was estimated by asking the subjects to determine whether the diameter of a test stick was larger or smaller than that of a reference stick after performing the following tasks: a) holding a reference stick between the central teeth of their upper and lower jaws for 5 s, and b) replacing the reference stick with a test stick and holding it at the same position for 5 s, and the test stick was then removed. The following findings were obtained.

1) In comparing discrimination ability in the absence of LG-induced sedation and that during LG-induced sedation of healthy control subjects, the rate of mis-estimation (RME) was significantly larger during LG-induced sedation than in the absence of LG-induced sedation for a test stick diameter (10.5 mm or 11.0 mm) larger than the reference stick diameter (10.0 mm) \( (P<0.05) \). No significant differences were observed for any other test sticks \( (P>0.05) \).

2) In comparing discrimination ability in the absence of LG-induced sedation and that during LG-induced sedation of CP patients, RME was significantly smaller during LG-induced sedation than in the absence of LG-induced sedation, when the test stick diameter (9.5 mm) was smaller than the reference stick diameter \( (P<0.05) \). No significant differences were observed for any other test sticks \( (P>0.05) \).

These results indicate that neural functions are inhibited at the upper level of the central nervous system in CP patients, leading to the attenuation of sustained increase in muscle tonus that is characteristic of CP patients. In summary, it seems that the LG has some inhibitory effect on the activity of \( \gamma \)-motor neurons innervating muscle spindles attached to the lower jaw via the upper level of the central nervous system and that this inhibitory effect contributes to an improvement in the discrimination ability.

Key words Cerebral palsy, Laughing gas-induced sedation, Lower-jaw-position sensation, Muscle spindle, Muscle tonus
Introduction

Cerebral palsy (CP) is a motor disorder involving the central nervous system caused by nonprogressive pathological changes in the brain that may occur at any stage from the embryonic to early postnatal stages. As symptoms of motor disorders, increased muscle tonus and reflection of voluntary muscles during motions or maintaining postures, as well as the development of involuntary motions, are observed. These symptoms are observed not only in the four limbs but also in various muscles in the jaw-facial and head-neck regions. Hence, abnormalities in muscle activities in CP patients become obstacles in daily life activities, preventing social independence. In addition, it is difficult to evaluate occlusion relationships in CP patients with the aim of recovering occlusion functions. Therefore it cannot be claimed on the basis of scientific data that occlusion functions are recovered in CP patients in dental clinical practice.

Yamaguchi et al. observed an abnormal sensation of the masticatory muscle in CP patients, for example the overvaluation of interincisal distance, compared with healthy adult subjects (hereafter referred to as healthy subjects), on the basis of their investigation using a test of ability to discriminate lower-jaw-position (LJP). They reported that the reason for this sensation is excessive stress due to the increased muscular tonus and overactivation of \(\gamma\)-motor neurons. However, many factors as causes of motor dysfunctions in the oral region of CP patients are still unclarified.

Based on these findings, we assumed that an increased muscle tonus of the muscles attached to the lower jaw in CP patients affects the LJP sensation. Regarding the inhibition of increased muscle tonus, a method using laughing gas (LG) in an LG-induced sedation method are known. Therefore, in this study, we investigated the effects of the inhibition of increased muscle tonus by LG on the LJP sensation. Furthermore, Yoshida et al. reported that the involuntary muscle tonus of the jaw-facial plane in CP patients is inhibited by the inhalation of nitrous oxide gas (hereafter referred to as laughing gas (LG)) during dental practice, on the basis of the frequency analyses of electromyographies.

The LG-induced sedation is a simple and fairly safe method for humans; hence it is used to alleviate anxiety and fear. However, in addition to the sedative effect, the method was reported to increase the threshold value of sensation in the oral cavity of patients; for example, alleviating aches and decreasing the vomiting reflex. Yoshida et al. investigated the effects of LG-induced sedation on muscle sensation accompanied by the extension of the muscles attached to the lower jaw in healthy subjects, and confirmed that the ability to discriminate LJP is decreased by LG. To the best of our knowledge, there is no report of the characteristics of oral sensations of patients with CP in terms of the LG effects on occlusion and the sensation of LJP.

The activity of \(\gamma\)-motor neurons is involved in the occlusion and LJP sensation of humans. As a physiological evaluation index of the activity of \(\gamma\)-motor neurons, discrimination ability for LJP is known and its test was developed by Morimoto. This test is applied to evaluate not only healthy subjects, but also CP patients and patients with dysfunctions in the jaw and oral cavity.

We assumed that LG used in the induced sedation method inhibited the activity of \(\gamma\)-motor neurons in CP patients. To investigate the effects of LG-induced sedation on the sensation of muscles attached to the lower jaw, we compared differences between the sensation of LJP of CP patients before the inhalation of LG and oxygen (air-inhalation condition: referred to as without LG inhalation) and during the inhalation of LG and oxygen (inhalation condition of LG and oxygen under LG-induced sedation: referred to as during LG inhalation), with healthy adults as the control group using a test of the ability to discriminate LJP.

Subjects and methods

Subjects

The subjects in this study were eight patients with CP who visited the Department of Dentistry, Saitama Prefecture Colony Ranzango (four males and four females; average age, 32.0 ± 6.0 years old, hereafter referred to as the CP group), and eight healthy adults as control subjects (four males and four females; average age, 29.0 ± 4.6 years old; hereafter, referred to as the control group). While the subjects of the current study are adult patients with CP, a similar tendency may be observed in infant patients with CP. Therefore, we consider that the findings obtained in this study could also be effective in pediatric dentistry.

Prior to the study, the details of this study were fully explained to the subjects themselves, guardians (parents) and caretakers, and their consent was
obtained. Approval for the study was given by the President of Colony Ranzango, the Director of Ranzango Hospital and the Manager of the Dental Department.

The subjects were selected on the basis of the following criteria.

1) They understood and approved of the objectives of the study. (They could communicate well without dysarthria.)
2) The patients showed no significant difference in the severity of CP. (This was evaluated by a specialist at the medical department of Colony Ranzango.)
3) They could breath through the nose and showed no involuntary muscle tonus on the jaw-facial region due to the use of a nasal mask.
4) They had no functional abnormalities of the jaw or oral cavity, and they could eat and swallow solid food normally.
5) During experiments in this study, they could maintain a posture appropriate for a dental chair and could hold their head and jaw positions stably.
6) They had slight systemic involuntary motions, particularly facial motions due to CP, but these symptoms did not pose any problems in this study.
7) They had neither dental prostheses nor defects in the front teeth of the upper and lower jaw.
8) They had no systemic complications.
9) They were not using drugs such as muscle relaxants.
10) They have normal occlusion without functional abnormalities of the jaw or oral cavity.

Methods

In a test of the ability to discriminate LJP, a subject was seated on a dental chair in a treatment room of the dental division. The backrest of the dental chair was set at an angle of about 100 degrees from the lower limb side, and the extension of its headrest was set at the same angle as the backboard. A subject’s Frankfurt plane was maintained parallel to the floor, and the subject wore an eye mask to eliminate visual information. The trunk of the subject was fixed with a strap attached to the dental chair. The hips and legs were fixed with sandbags (NAVIS). No particular measures were taken to alleviate the tension of the subject. The test of the ability to discriminate LJP was performed in accordance with the method of Morimoto\textsuperscript{15–18).} The reference and test ticks used in the experiments are made of stainless steel (Tokyo Shizai). The reference stick has a diameter of 10.0 mm (124 g). Eight test sticks of different diameters at intervals of 0.5 mm were used; these were categorized into two groups on the basis of their diameters with respect to the reference stick; one group included test sticks whose diameters were smaller than that of the reference stick, and the other included those whose diameters were larger than that of the reference stick. The group of smaller-diameter sticks consisted of those with diameters of 8.0 mm (79 g), 8.5 mm (89 g), 9.0 mm (100 g) and 9.5 mm (110 g). The group of larger-diameter sticks consisted of those with diameters of 10.5 mm (136 g), 11.0 mm (150 g), 11.5 mm (162 g) and 12.0 mm (178 g). The measurement procedure was as follows. First, a subject was instructed to hold the reference stick between the central teeth of his/her upper and lower jaws for 5 s. The reference stick was replaced with a test stick, and the subject was instructed to hold the test stick at the same position for 5 s. Then, after removing the test stick, the subject was asked to determine whether the diameter of the test stick was larger or smaller than that of the reference stick. This procedure was repeated using test sticks of different diameters. Eight test sticks were presented randomly using a table of random

Table 1 Conditions of optimal sedation for LG-induced sedation

<table>
<thead>
<tr>
<th>Objective symptoms (items evaluated by the operator)</th>
</tr>
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<tbody>
<tr>
<td>1. The patient is conscious and able to talk.</td>
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<tr>
<td>2. The patient responds to the operator’s questions and instructions.</td>
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<tr>
<td>3. The patient has a non-nervous relaxed look on his/her face.</td>
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<tr>
<td>4. The patient shows a marked reduction in the frequency of blinking his/her eyes.</td>
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<table>
<thead>
<tr>
<th>Subjective symptoms (items evaluated by the subject)</th>
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<tr>
<td>1. The patient has a sense of exhaustion or a sense of slight intoxication.</td>
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<td>2. The patient feels warm with his/her palms sweating.</td>
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Table 1 Conditions of optimal sedation for LG-induced sedation

Objective symptoms (items evaluated by the operator)

1. The patient is conscious and able to talk.
2. The patient responds to the operator’s questions and instructions.
3. The patient has a non-nervous relaxed look on his/her face.
4. The patient shows a marked reduction in the frequency of blinking his/her eyes.

Subjective symptoms (items evaluated by the subject)

1. The patient has a sense of exhaustion or a sense of slight intoxication.
2. The patient feels warm with his/her palms sweating.
numbers. Eight test sticks were presented in each session, and a total of ten sessions were performed for each subject. The rate of mis-estimation (RME), which was used to evaluate the discrimination ability of each patient, was obtained by dividing the total number of incorrect answers by the total number of answers, then multiplying the quotient by 100 to calculate the percentage. The higher the RME, the lower the ability to discriminate LJP, and vice versa.

These measurements were also performed before the inhalation of LG and oxygen (air-inhalation condition: hereafter referred to as without LG inhalation) and during the inhalation of LG and oxygen (condition of LG and oxygen inhalation under LG-induced sedation: referred to as during LG inhalation). In a test of the ability to discriminate LJP during LG inhalation, measurements were begun when a subject exhibited the optimal sedation as described in Table 1. Table 1 lists optimal sedation conditions. For the inhalation of a mixture of LG and oxygen, a continuous-flow inhalation sedation system, Psychorich T-70 (SEKIMURA), was used. The subjects were instructed to inhale a mixture of 40% LG and 60% oxygen through a nose mask fixed on their face. The flow rate in the sedation system was set at approximately 6 to 8 l/min by taking into account the breathing capacity of healthy adults. A test of ability to discriminate LJP during LG inhalation was performed one week after the test and without LG inhalation.

Table 2 Comparison of RME between the first time and the second time for the absence of LG inhalation in each CP patient (A) and healthy adult (a) for different test sticks, and results of the significance tests

<table>
<thead>
<tr>
<th>The patients with CP (A)</th>
<th>(Unit: %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The interincisal distance (mm)</td>
<td>8.0 8.5 9.0 9.5 10.0 (The reference stick) 10.5 11.0 11.5 12.0</td>
</tr>
<tr>
<td>The first measurement</td>
<td>0.0 1.3 6.3 8.8 1.3 6.3 3.8 0.0</td>
</tr>
<tr>
<td>The second measurement</td>
<td>0.0 1.3 6.3 7.5 1.3 6.3 5.0 3.8 0.0</td>
</tr>
</tbody>
</table>

A healthy adult (a) (Unit: %)

| The interincisal distance (mm) | 8.0 8.5 9.0 9.5 10.0 (The reference stick) 10.5 11.0 11.5 12.0 |
| The first measurement | 0.0 0.0 0.0 1.3 1.3 0.0 0.0 0.0 0.0 |
| The second measurement | 0.0 0.0 0.0 1.3 3.8 0.0 0.0 0.0 0.0 |

Table 3 Comparison of mean RME in the control group between the absence and presence of LG inhalation for different test sticks, and results of the significance tests

(Unit: %, N: 8)

| The interincisal distance (mm) | 8.0 8.5 9.0 9.5 10.0 (The reference stick) 10.5 11.0 11.5 12.0 |
| In the absence of LG-induced sedation | 0.0 0.0 0.0 1.3 ± 1.2 4.4 ± 2.1 0.5 ± 0.5 0.0 0.0 |
| During LG-induced sedation | 0.0 0.0 0.0 0.8 ± 2.2 9.4 ± 3.5 5.5 ± 2.2 2.3 ± 2.1 0.0 |

*: P<0.05 mean ± S.D.

Table 4 Comparison of mean RME in the CP group between the absence and presence of LG inhalation for different test sticks, and results of the significance tests

(Unit: %, N: 8)

| The interincisal distance (mm) | 8.0 8.5 9.0 9.5 10.0 (The reference stick) 10.5 11.0 11.5 12.0 |
| In the absence of LG-induced sedation | 0.0 0.8 ± 2.2 5.5 ± 2.2 8.6 ± 3.2 5.5 ± 2.2 5.5 ± 2.2 3.9 ± 3.2 0.0 |
| During LG-induced sedation | 0.0 0.8 ± 2.2 3.1 ± 2.4 3.1 ± 2.4 3.9 ± 3.3 3.9 ± 3.3 2.3 ± 2.1 0.0 |

*: P<0.05 mean ± S.D.
In this study, the measurements of the ability to discriminate LJP were performed for CP patients and healthy adults for the absence of LG inhalation (the first time) and during LG inhalation. Measurements were also performed on the same subjects on a day one week after the first measurement for the absence of LG inhalation (the second time). This confirmed that there was no learning effect in the subjects.

Table 2 shows the comparison of RME for the absence of LG inhalation between the first and second times for one subject each from the CP group and the control group (the CP patient (A) and healthy subject (a)).

**Statistical analysis**

As statistical methods, a significance test using the paired t-test was performed to compare the RME between the first and second times for the absence of LG inhalation in each of the CP patients (A) and the healthy subjects (a).

For the comparison between the absence of LG inhalation and during LG inhalation both in the control group and CP group, the paired t-test was used; to compare the control group and the CP group in the absence of LG inhalation and during LG inhalation, the unpaired t-test was used in the significance tests.

**Results**

Table 2 shows results of comparison and significance tests of RME in CP patient (A) and in the healthy adult (a) for the absence of LG inhalation (the first and second times) using different test sticks. No significant differences in RME were observed for any test sticks in either the CP patient (A) or the healthy adult (a).

Table 3 shows results of comparison and significance tests of mean RME between the absence of LG inhalation and during LG inhalation in the control group using different test sticks. In the case of test stick diameters of 10.5 mm and 11.0 mm, which are larger than the reference stick diameter, the mean RME during LG inhalation was significantly higher than that during the absence of LG inhalation ($P<0.05$). No significant differences were observed for any other test sticks.

Table 4 shows results of comparison and significance tests of mean RME between the absence of LG inhalation and during LG inhalation in the CP group for different test sticks. In the case of test stick diameters of and 9.5 mm, which are smaller than the reference stick diameter, the mean RME during LG inhalation was significantly lower than that during the absence of LG inhalation ($P<0.05$). No significant differences were observed for any other test sticks.

Table 5 shows results of comparison and significance tests of the mean RME between the control group and the CP group for the absence of LG inhalation using different test sticks. In the cases of test stick diameters of 9.0 mm and 9.5 mm, which are smaller than the reference stick diameter, and those of 11.0 mm and 11.5 mm, which are larger than

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the reference stick diameter, the mean RME of the 
CP group was significantly higher than that of the 
control group ($P<0.01$, and $P<0.05$, respectively).
No significant differences were observed for any 
other test sticks.

Table 6 shows results of comparison and 
significance tests of mean RME between the control 
group and the CP group during LG inhalation using 
different test sticks. In the case of a test stick 
diameter of 10.5 mm, which is larger than the 
reference stick diameter, the mean RME of the CP 
group was significantly lower than that of the control 
group ($P<0.05$). No significant differences were 
observed for any other test sticks.

Discussion

Subjects

In addition to dysfunctions in the four limbs, CP 
patients have dysfunctions in their oral cavity region, 
for example disturbances in eating, swallowing and 
chewing due to the discoordination of motions, 
primarily of the muscles of mastication\(^1,2\). In 
particular, it was reported that the causes of the 
discoordination of motions of the muscles of 
mastication in CP patients are disturbances in the 
information-output system linked to the peripheral 
effector organs due to dysfunctions in the central 
nervous system\(^20–22\), or the influence of the feedback 
control for sensing information from the muscles 
of mastication not working properly\(^14\). Generally, 
patients are categorized as either having spastic 
CP or athetosic CP. However, many patients are 
classified as having the intermediate type of CP, in 
which the characteristics of both types are present\(^1,2\), 
therefore, accurate classification is difficult. In addition, 
some reports state that no differences in the 
functions such as occlusal pressure or mastication 
ability are observed between different diseases\(^23–25\).

Therefore, we did not carry out investigations in 
terms of different diseases.

Methods of study

Conventionally, studies using LG-induced sedation 
methods focused mainly on its sedative and analgesic 
effects\(^26–28\). On the other hand, attention was directed 
to a decrease in the muscle tonus by an LG-induced 
sedation method\(^27,29,30\).

In a study using electromyographic frequency 
analyses, Yoshida \(et al.\)^5 observed that the activity of 
maxillofacial muscles in CP patients was suppressed 
by LG inhalation in dental practice. Nagao \(et al.\)^29 
applied an LG-induced sedation method to CP 
patients whose jaws were difficult to position so that 
they corresponded to interdigitation, and to patients 
for whom it was difficult to determine the occlusion 
relationship for other reasons. They reported that 
this sedation method facilitated the monitoring of 
jaw position and of the ability to direct the jaws. 
If LG-induced sedation decreases the tonus of 
muscles attached to the lower jaw, the activity of 
spindle muscles is also considered to be inhibited 
simultaneously, and it is possible that the sensations 
of occlusion and LJP are affected. Yoshida \(et al.\)^14 
investigated the effect of LG-induced sedation on 
muscle sensations associated with the extension 
of the muscles attached to the lower jaw in 
healthy subjects and identified a reduced ability 
to discriminate LJP as a result of exposure to 
LG. These findings suggest that LG increases 
the threshold of muscle sensation by inhibiting the 
central nervous system. Yoshida \(et al.\)^5 reported 
that involuntary maxillofacial muscle tonus was 
decreased by inhalation of LG in dental practice 
based on electromyographic frequency analyses.

In this report, therefore, to investigate the 
influence of LG inhalation on the activity of the 
muscle spindle of the muscle attached to the lower 
jaw, differences in the ability to discriminate the LJP 
in the absence of LG-induced sedation and during 
LG-induced sedation were evaluated.

Sensory receptors controlling the sensation of 
LJP are considered to be associated with the 
periodontal membrane\(^31\), jaw joint\(^32\), tendon\(^33\), 
and muscle spindles of the occlusal muscle\(^31–34\). 
Broekhuijzen \(et al.\)^19 applied a local anesthetic to 
each sensory receptor of the oral cavity, such as 
the jaw joint and periodontal membrane, to clarify 
mechanisms by which LJP is sensed by humans. 
They found that the sensation of LJP does not change 
significantly after the application of the anesthetic. 
Morimoto \(et al.\)^18 investigated the sensation of LJP 
in subjects in whom the jaw joint was injured by 
wounds or abnormal calcification. They found no 
differences from that in healthy subjects. In another 
study, Morimoto \(et al.\)^17 investigated the sensation of 
LJP in patients with Duchenne muscular dystrophy, 
whose muscle tissues were severely damaged, and in 
patients whose muscles attached to the lower jaw on 
one side were removed; they observed a significant 
deterioration in the ability to sense LJP as compared 
with healthy subjects. On the basis of these results,
we suggest that the sensation of LJP is affected by muscle spindles rather than by other sensory receptors.

Morimoto’s test\textsuperscript{15–18}, reflects the activity of \(\gamma\)-motor neurons controlling the muscle sensation detected by the receptor of the extended muscle spindle of the muscle attached to the lower jaw; that is, the activity of \(\gamma\)-motor neurons can be evaluated. Therefore, the ability to sense LJP during LG-induced sedation and that in the no LG-induced sedation were compared using the test of the ability to sense LJP. The ability to discriminate LJP was measured in accordance with the method developed by Morimoto et al.\textsuperscript{15–18} Subjects were instructed to determine the intercincisal distances of test sticks of different diameters, and the LJP sensation discrimination ability for each intercincisal distance was quantitatively measured using RME for each test stick.

Yoshida et al.\textsuperscript{14} also reported that the appropriate LG concentration in an LG-induced sedation method was 40\% based on clinical experience. Ógata\textsuperscript{35} treated 107 CP patients who required dental treatment by applying LG inhalation at a concentration of 36–50\%, and reported that, from the patients’ responses to a postoperative questionnaire, the most effective LG concentration was approximately 40\%. On the basis of these reports, a mixed gas of 40\% LG and 60\% oxygen was used in this study. The test of the ability to discriminate LJP during LG inhalation was begun after achieving optimal sedation with LG. As a result, regarding the starting time of the test, all subjects were determined to be in the optimal sedation state less than 5 min after LG inhalation. In general, the solubility of LG in blood and tissue is low (blood/gas dissolution coefficient is 0.47). It was reported that the degree of saturation in blood and tissue reached approximately 90\% of the inhalation concentration less than 5 min after the inhalation of the gas, and that the LG-induced sedation state was attained quickly\textsuperscript{36}.

Results

One point should be noted regarding the results before discussing them. As shown in Table 2, in the comparison of RME between the first and second times for the absence of LG inhalation in the same subject, no significant differences in RME were observed for any test sticks in either the CP patient (A) or the healthy adult (a). Thus, the RME for during LG inhalation in both the CP group and control group are considered temporary values. As already mentioned in the section on Subjects and methods, the CP patients as the subjects of this study have only cerebral palsy without mental retardation and are capable of responding similarly to healthy adults; we confirmed that the RME are reproducible, and they are not due to learning effects.

As shown in Table 3, when the RME of the control group was compared between during the absence of LG inhalation and during LG inhalation, in the cases of test stick diameters of 10.5 mm and 11.0 mm (larger than the reference stick diameter), the RME during LG inhalation was significantly higher than that during the absence of LG inhalation \((P<0.05)\). No significant differences were observed for any other test sticks. In the above cases of test stick diameters of 10.5 mm and 11.0 mm, the discrimination ability during LG inhalation was lower than that during the absence LG inhalation; thus, the effect of LG inhalation was observed for test stick diameters larger than the reference stick diameter.

As shown in Table 4, when the RME of the CP group was compared between during the absence of LG inhalation and during LG inhalation, in the cases of test stick diameters of 9.5 mm (smaller than the reference stick), the RME during LG inhalation was significantly lower than that during the absence of LG inhalation \((P<0.05)\). No significant differences were observed for any other test sticks. In the above cases of test stick diameters of 9.5 mm, the discrimination ability during LG inhalation was higher than that during the absence of LG inhalation; thus, the effect of the LG inhalation was observed for test stick diameters smaller than the reference stick diameter.

In this study, we investigated the effects of LG on LJP sensation. Yamaguchi et al.\textsuperscript{3} investigated the effects of air-inhalation on LJP sensation. In our stud using LG, we selected subjects with particular importance placed on the following two points: (1) They could breath through the nose and showed no involuntary muscle tonus in the jaw-facial region due to the use of a nasal mask during experiments. (2) They could maintain a posture appropriate for a dental chair. Yamaguchi et al. do not provide such a detailed explanation for the selection of subjects under the condition of air inhalation. Accordingly, because the subjects in our study satisfy these conditions, the severity of CP dysfunctions of the patients in our study is milder than that in
Yamaguchi’s study. (In our study, the ADL survey of the subjects was not carried out; however, a specialist in Ranzango diagnosed the subjects and evaluated the severity of their CP to be mild.) This difference in the severity of dysfunctions may have led to the difference in RME by one order of magnitude smaller for CP patients.

Regarding the sensory property of the ability to discriminate muscle sensation in the four limbs, it is known that CP patients overvalue muscle sensations compared with healthy subjects, which this leads to the coordinated motion of the four limbs being more difficult\(^\text{27}\). Regarding oral dysfunctions as well, because CP patients characteristically overvalue the sensation of muscles attached to the lower jaw, similar to the cases of the four limbs, they are thought to have greater difficulty than healthy subjects in performing intended oral motions smoothly.

Next, let us compare the RME obtained between the CP group and control group during LG inhalation, in contrast to those obtained during the absence of LG inhalation. Morimoto et al.\(^\text{38}\) reported that healthy subjects opened their mouths wider momentarily before and after reference stick removal during the absence of LG inhalation. That is, the muscle spindles, which were already extended, were further extended.

Regarding the results of the control group shown in Table 3, the RME increased during LG inhalation in the cases of test stick diameters of 10.5 mm and 11.0 mm (larger than the reference stick diameter), compared with that during the absence of LG inhalation, thus indicating a decreased discrimination ability. In general, when the LG-induced sedation method is applied to healthy subjects, the functions of the central nervous system deteriorate and a change in the consciousness accompanying a feeling of euphoria develops, and the healthy subjects are in a state of stable sedation with a decreased tension in the sympathetic nervous system. Therefore, the range of the spontaneous tapping motions of the jaw reportedly increases\(^\text{27}\). On the basis of these findings, we consider that, in healthy subjects, a decrease in the function of the central nervous system occurred due to the inhalation of LG, and the LG affected the spindles of the peripheral muscles attached to the lower jaw, which yielded results different from those during the absence of LG inhalation (in the cases of test stick diameters of 10.5 mm and 11.0 mm). Yoshida et al.\(^\text{14}\) investigated the effect of LG-induced sedation on muscle sensations associated with the extension of the muscles attached to the lower jaw in healthy subjects and identified a reduced discrimination ability for test stick diameters larger than the reference stick diameter during LG inhalation, compared with that during the absence of LG inhalation, similar to our results shown in Table 3. Thus, their results agree with the results of this study.

Regarding the results of the CP group shown in Table 4, the muscle tonus of the jaw and facial muscles characteristic of CP patients was suppressed during the inhalation of LG in the CP patients, which is different from the results of healthy subjects\(^\text{5}\). In particular, the muscle sensation from the spindles of the muscles attached to the lower jaw approaches the normal state. Accordingly, the discrimination ability increased as shown by the decrease in the RME for test stick diameters of 9.5 mm (smaller than the reference stick diameter) during LG inhalation, in comparison to that during the absence of LG inhalation. In addition, an LG-induced sedation method has been widely used for prosthetic treatments and others against involuntary muscle tonus to facilitate the induction of lower jaw position and recording jaw motions by alleviating mental stress in CP patients\(^\text{29}\). Thus, we speculate that because the LJP sensation of the CP patients approaches that of the healthy subjects due to inhalation of LG, the results of RME during LG inhalation differ from those during the absence of LG inhalation (for test stick diameters of 9.5 mm).

As shown in Table 5, in the comparison of RME between the control group and the CP group for the absence of LG inhalation, in the case of test stick diameters of 9.0 mm and 9.5 mm, which are smaller than the reference stick diameter, and of 11.0 mm and 11.5 mm, larger than the reference stick diameter, the RME of the CP group was significantly higher than that of the control group \((P<0.01, \text{ and } P<0.05, \text{ respectively})\). In contrast, no significant differences were observed for any other test sticks. The RME for test stick diameters other than 8.0 mm or 12.0 mm in the CP group were higher than those of the control group. Yamaguchi et al.\(^\text{3}\) investigated the ability to discriminate LJP in CP patients using RME and found that CP patients showed more difficulty in discriminating LJP when test stick diameters were smaller than the reference stick diameter than did healthy subjects. In our study, CP patients also had difficulty discriminating LJP when test stick diameters were larger than the reference stick
diameter. Yamaguchi et al.\textsuperscript{3,4} observed an abnormal sensation of masticatory muscles in CP patients, such as the overvaluation of interincisal distance, compared with healthy subjects in their investigation using a test of ability to discriminate LJP. They reported that the reason for this is excessive tonus due to the overactivity of \(\gamma\)-motor neurons. Suzuki et al.\textsuperscript{37} reported that CP patients overvalue small changes in the muscle tonus compared with healthy subjects. They speculated that the reason for this in CP patients is the overactivation of \(\gamma\)-motor neurons, which control the muscle spindles, leading to an increase in the frequency of discharge of afferent impulses. Because the sensory property of LJP sensation of the muscles attached to the lower jaw is considered to arise from the sensory property of the muscle sensation of the four limbs\textsuperscript{37}, a decrease in the ability to discriminate LJP sensation in CP patients is considered to reflect the overactivation of \(\gamma\)-motor neurons controlling the spindles in the muscles attached to the lower jaw.

The effects of LG, in the comparison of RME during LG inhalation between the control group and CP group are shown in Table 6. In the case of the test stick diameter of 10.5 mm, which is larger than the reference stick diameter, the RME of the CP group was significantly lower than that of the control group \((P<0.05)\). No significant differences were observed for any other test sticks. This indicates that the discrimination ability of the CP group increased due to the inhalation of LG, and the CP patients are affected by LG more strongly than the healthy subjects. Yoshida et al.\textsuperscript{5} reported that the activity of the muscles of the jaw-facial plane in CP patients was inhibited during the inhalation of LG in dental practice, on the basis of frequency analyses of electromyography. Kaufman et al.\textsuperscript{30} stated that the amplitude of muscle discharge induced by the Hoffmann (H) reflex of the muscles in the lower limbs in CP patients decreased due to inhalation of LG. They concluded that LG has an inhibitory effect on the activation of motor neurons at the level of the central nervous system.

These results indicate that neural functions are inhibited at the upper level of the central nervous system in CP patients, leading to attenuation of sustained increase in muscle tonus that is characteristic of CP patients.\textsuperscript{1,2} In summary, it seems that LG has some inhibitory effect on the activity of \(\gamma\)-motor neurons innervating muscle spindles attached to the lower jaw via the upper level of the central nervous system and that this inhibitory effect contributes to an improvement in the discrimination ability.

We intend to further investigate the effects of the LG-induced sedation on the ability to discriminate LJP using electromyography.

References


