Note

Dietary Patterns Affect Occlusal Force but Not Masticatory Behavior in Children

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Summary

Aim: In this study, we conducted a dietary assessment of the subjects and investigated the relationship of energy, nutrients and food intake to the indices of masticatory ability and masticatory behavior for identifying the differences in their association with dietary patterns. Methods: The subjects were 61 5-y-old children, of whom 45 were included in the final analysis. Occlusal force was measured as an index of masticatory ability. To measure masticatory behavior, the number of chews and time taken for eating the test meal were measured. The subjects’ food intake was determined by a food record completed by their guardians. The food intake was evaluated using a newly produced list of 90 foods thought to affect chewing, in addition to which we made two subsets of its food groups containing an abundance of insoluble dietary fiber. Results: Significant positive correlations were found between occlusal force and intake of dietary fibers, vegetables, set A food group, and set B food group ($r=0.312–0.354$). Significant differences were found in occlusal force by tertile groups for dietary fibers, vegetables, the 90 listed items, set A food group, and set B food group. In contrast, there was no significant correlation between the indices of masticatory behavior (the time-adjusted number of chews and time taken for eating the test meal) and those of dietary intake. Conclusion: Indicators of masticatory ability and masticatory behavior have different implications in their association with dietary patterns in children.

Key Words dietary patterns, food intake, occlusal force, masticatory ability, masticatory behavior

Indicators for masticatory variation are divided into two broad classes: masticatory ability and masticatory behavior. Masticatory ability is a physiological capacity, while masticatory behavior is shown by intended or unintended actions. We previously reported (1) that the physical status of children and the influence of their guardians have a significant association with masticatory behavior but have no apparent association with masticatory ability. Hence, indices of masticatory ability and masticatory behavior should be used for evaluation with sufficient consideration of their differences.

Currently, however, the differences in the characteristics “can’t chew” (=ability) and “won’t chew” (=behavior) have not been well identified. In this study, we conducted a dietary assessment of the subjects and investigated the relationship of daily energy, nutrients, and food intake to indices of masticatory ability and masticatory behavior. We finally identified the differences in their association with dietary patterns.

Methods

Subjects and setting. The subjects of this study were 61 5-y-old children from two kindergartens in Morioka City, Iwate Prefecture, Japan. We recruited 5-y-old children for the following reasons: 1. their baby molar tooth eruptions would be complete; 2. the measurements would not be affected by the lack of baby teeth; and 3. the subjects could understand the meaning of the measurement. We explained the investigation to the children’s guardians, including the purpose, method, voluntary participation, and participants’ rights. Written consent was obtained from the guardians of all subjects. The study was conducted from mid-November to early December 2009, on all these 61 5-y olds (34 boys and 27 girls) as the subjects.

Study details.

Physical status and masticatory indices: The physical status of the subjects was determined from the latest records of anthropometric measurements obtained from the kindergartens. The Murata method was used for calculation of the obesity index (2).

The presence of any oral conditions that could affect the measurements was screened by an oral checkup based on a dentist’s mirror inspection immediately before the measurement of the masticatory indices. The oral checkup comprised checking for supportable occlusal statuses, presence of caries, baby molar tooth eruptions, and abnormalities in the temporomandibular joint and dentitions.

In addition, occlusal force (3), a measure of mastica-
Dietary Patterns and Occlusal Force in Children

Occlusal force measurement system (Dental Prescale® type 50HR, size S, GC Ltd.) and a dental occlusal force meter (Occluzer® FPD-707, Fujifilm Corp.) (4). The measurements were conducted with the following considerations: the children were required to sit without leaning against the chair; both feet had to be closely attached to the floor; the intercuspal position had to be steady, and duplicated measurements were taken after the pretests.

The number of chews and time taken for eating the test meal were measured using a portable chewing counter (Kamikami Sensor. S-size, NITTO KAGAKU Co., Ltd.) for children. The applicability of this device for measurement and reproducibility of this measurement in children have already been shown (5). The procedure of the measurement was as follows: 1. the subjects put on the sensor themselves; 2. the staff checked the condition of the sensor; 3. measurement began when the subjects started eating the test meal; 4. three examiners carefully observed the subjects and responded promptly at any instances of removal of the sensor; trouble for counting, etc.; 5. the measurement ended when the subjects finished eating all of the test meal; and 6. the presence of any leftovers was recorded.

All measurements were done in the kindergarten.

Food intake: The subjects’ food intake was determined from a dietary record completed by their guardians as surrogate respondents, using a method of food recording by portion size (6). The survey was conducted in November 2009, in 2-d periods covering holidays and weekdays. Special days, such as events and celebrations, were excluded. The questionnaires were distributed and collected via the kindergartens.

Details of the dietary assessment: The dietary assessment included all foods and drinks consumed by the subjects from the time of getting up to that of going to bed. The guardians were asked to record the dish names, foodstuff names and approximate quantity by meal (breakfast, lunch, dinner, snacks). In addition, they were asked to record the names of any processed foods, amount of seasonings applied, and name and approximate portion size of any meals taken outside the home. All subjects ate school lunch (lunch boxes from a contractor) on weekdays. We therefore estimated each subject’s lunch intake during the survey period from records (taking extra helpings and leftovers into account) made by the kindergartens, based on the food weight per capita taken from menu plan tables obtained from the contractor.

Data handling of dietary records: The collected dietary records were processed based on the methods of the National Health and Nutrition Survey, Japan (7). In the calculation of food intake, foodstuffs that typically increases in weight due to the cooking process (e.g., rice, dry noodles) were converted to their equivalent cooked forms (cooked rice, boiled noodles). Items that may be processed with a mixture of uncooked and cooked weights (raw/boiled, etc.) were calculated as uncooked forms according to the conversion table included in the Standard Tables of Food Composition in Japan, 5th Revised and Enlarged Edition (8), taken in their uncooked state (e.g., tubers, vegetables, fish and shellfish, and meat). Items that were already swollen before cooking (e.g., dried seaweeds and other dried foods) were calculated after having been soaked.

Dietary data were handled by a proficient registered dietician. The compilation consisted of confirming the recorded content, converting the portion sizes to weights, and assigning food and cooking codes. Completed dietary records were examined by the authors. Finally, information on lunch menus and intake according to the date of each subject’s dietary assessment was added to complete the 2-d dietary records. Nutrient values and intake for each foodstuff were calculated using the Standard Tables of Food Composition in Japan, 5th Revised and Enlarged Edition, based on the National Health and Nutrition Survey as previously mentioned.

Production of the food list: This study used a newly produced list of 90 foods thought to affect chewing, to clearly indicate the relationship between two masticatory indices (ability and behavior) and food intake. We first produced the food list based on previous research (9), assigning two values: those ranked by the measurement of texture (for 145 selected foods) and those determined from sensory tests in adults. Further, we categorized meats from different body regions (e.g., pork; fillet and ham) and ground fish products (e.g., tsumire and chikuwana) as the same item, and classified all vegetables as the same item, regardless of their variations in seasoning (e.g., cabbage), parts (e.g., leaves/stems), or cooking style (e.g., raw/sauteed/pickles). Although this study targets children in a developmental stage of masticatory ability, the foods in our primary list are based on a list judged by adults in the previously cited research to have above-average hardness: ≥1.0 kg for the V-type plunger and ≥2.0 kg for the φ-type plunger. Furthermore, since the report cited was released before 25 y, trends in the production and composition of the foods consumed are thought to have greatly changed. Taking this into account, 25 foods thought to be consumed frequently at home in the recent years were added to the list, based on statistical reports by the Ministry of Agriculture, Forestry and Fisheries (10) and the Forestry Agency (11). Moreover, 7 foods were added to the list as different items, such as foods that consist of leaves and roots, and foods that are cooked by using a different process. Foods that are not normally eaten in the state listed (e.g., brown rice [raw], potato [uncooked], pumpkin [uncooked], and bread crumbs) were excluded from the list. Confectioneries were not included. The completed food list has 90 items (Table 1).

For educational approaches for children, two issues were considered: first, there was an abundance of insoluble dietary fiber to promote chewing and second, there was a healthy selection of foods, such as tubers, vegetables, and mushrooms. We therefore designated two subsets of food groups containing an abundance of insoluble dietary fiber (set A: tubers and vegetables; set B: tubers, vegetables, and mushrooms) for further analysis.
<table>
<thead>
<tr>
<th>Cereals (5 items)</th>
<th>Vegetables: continued</th>
<th>Mushrooms (10 items)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardtack</td>
<td>Burdock</td>
<td>Mushroom</td>
</tr>
<tr>
<td>Pizza crust</td>
<td><em>Komatsuna</em> (<em>Brassica campestris</em> L.²)</td>
<td><em>Mushroom</em> (<em>Enokidake</em>)¹</td>
</tr>
<tr>
<td>Brown rice</td>
<td>Green pepper</td>
<td><em>Mushroom</em> (<em>Kikurage</em>)¹</td>
</tr>
<tr>
<td>Well-milled rice with embryo</td>
<td><em>Shungiku</em> (<em>Chrysanthemum coronarium</em> L.²)</td>
<td><em>Mushroom</em> (<em>Shiitake</em>)⁹</td>
</tr>
<tr>
<td>Rice cake</td>
<td>Ginger</td>
<td><em>Mushroom</em> (<em>Nameko</em>)¹</td>
</tr>
<tr>
<td>Tubs (6 items)</td>
<td>Celery</td>
<td><em>Mushroom</em> (<em>Bunashimezi</em>)¹</td>
</tr>
<tr>
<td>Amorphophallus konjac (devil's tongue Konjac)</td>
<td>Broad bean</td>
<td><em>Mushroom</em> (<em>Hiratake</em>)⁹</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>Chinese white leaf</td>
<td><em>Mushroom</em> (<em>Eringi</em>)¹</td>
</tr>
<tr>
<td><em>Tatos</em> (<em>Satuto1, Mizuto1, Yatsuhi1</em>)</td>
<td>Chinese white radish</td>
<td><em>Mushroom</em> (<em>Maitake</em>¹)</td>
</tr>
<tr>
<td>Potato</td>
<td>Bamboo shoot</td>
<td><em>Mushroom</em> (<em>Matsutake</em>¹)</td>
</tr>
<tr>
<td>Chinese yam (<em>Nagun1, Yamato1</em>)</td>
<td>Onion</td>
<td></td>
</tr>
<tr>
<td>Japanese yam (<em>Yamato1</em>)</td>
<td><em>Qing gen cai</em> (<em>Brassica campestris</em> L.²)</td>
<td>Seaweeds (2 items)</td>
</tr>
<tr>
<td>Nuts and seeds (2 items)</td>
<td><em>Sweet corn</em></td>
<td><em>Seaweed</em> (<em>Konbu</em>)¹</td>
</tr>
<tr>
<td>Almond</td>
<td><em>Tomato</em> (<em>Tomato, Cherry tomato</em>)</td>
<td><em>Seaweed</em> (<em>Wakame</em>)¹</td>
</tr>
<tr>
<td>Peanut (fried)</td>
<td><em>Eggplant</em></td>
<td>Fish and shellfish (11 items)</td>
</tr>
<tr>
<td>Vegetables (42 items)</td>
<td><em>Chinese chive</em></td>
<td><em>Sardine</em></td>
</tr>
<tr>
<td>Scallion</td>
<td><em>Carrot</em></td>
<td><em>Mirinboshi</em>¹ (Added seasoning and semi-dried oily fishes)</td>
</tr>
<tr>
<td>Asparagus</td>
<td><em>Garlic</em></td>
<td><em>Namariibushi</em>¹ (Skipjack tuna products)</td>
</tr>
<tr>
<td>String bean</td>
<td><em>Leek</em></td>
<td><em>Atlantic capelin</em></td>
</tr>
<tr>
<td><em>Udo</em>¹ (<em>Aralia cordata Thunb²</em>)</td>
<td><em>Chinese cabbage</em></td>
<td><em>Megkinishin¹</em> (Semi-dried pacific herring)</td>
</tr>
<tr>
<td><em>Edamame¹</em> (Young green soybeans)</td>
<td></td>
<td><em>Tuna</em></td>
</tr>
<tr>
<td>Peas (Peas, Field peas, Snap field peas)</td>
<td><em>Green sweet pepper</em></td>
<td><em>Scallop</em></td>
</tr>
<tr>
<td>Turnip leaf</td>
<td><em>Japanese butterbur</em></td>
<td><em>Shrimp</em></td>
</tr>
<tr>
<td>Turnip</td>
<td><em>Broccoli</em></td>
<td><em>Squid</em></td>
</tr>
<tr>
<td>Pumpkin</td>
<td><em>Spinach</em></td>
<td><em>Octopus</em></td>
</tr>
<tr>
<td>Cauliflower</td>
<td></td>
<td><em>Ground fish product</em> (<em>Tsumire¹, Chikuwa¹, Kamuboko²</em>)</td>
</tr>
<tr>
<td>Cabbage</td>
<td><em>Fruit</em> (2 items)</td>
<td>Meats (5 items)</td>
</tr>
<tr>
<td>Cucumber</td>
<td><em>Pear</em></td>
<td><em>Beef</em></td>
</tr>
<tr>
<td></td>
<td><em>Apple</em></td>
<td><em>Pork</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Chicken</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Ground meat</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Ham</em> (Ham, Sausage)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Milk and dairy products (1 items)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Cheese</em></td>
</tr>
</tbody>
</table>

¹Japanese name.
²Scientific name.
Statistical analysis. Since the pretest pressure sensitivity for occlusal force was not sufficiently stable, duplicated measurements were conducted and the larger of the two values was used for analysis.

We used the time-adjusted number of chews, which was a new indicator proposed by the authors in a previous report (1): time-adjusted number of chews=(a)+(b), where a=the residual for subjects from regression models with the number of chews as the dependent variable and time taken for eating the test meal as the independent variable and b=the expected number of chews for person with the mean time taken for eating the test meal. In this case, a=10.1×X (observed time taken for eating the test meal) and b=306.5.

The intake of nutrients and intake by food groups were taken as the average values over 2 d. The subjects were divided into tertile groups according to the intake values, to compare differences in the masticatory indices across the groups. The Shapiro-Wilk test, which was carried out to determine whether the data followed a normal distribution, showed that none of the data was normally distributed (all having p<0.05); hence, non-parametric statistics were used, including multiple comparisons of the values across the three groups with consideration of statistically significant levels. Spearman’s correlation coefficients were calculated to determine the relationship between masticatory indices and intake values, while the Mann-Whitney U test was used to determine the tertile groups’ significance levels, which were adjusted using the Bonferroni method.

Statistical processing was carried out using the statistical analysis software, SPSS 16.0 for Windows (SPSS Japan Inc.). The significance level was set at 5%.

Ethical considerations. This study was approved by the Aomori University of Health and Welfare Research Ethics Review Committee (No. 09055) in accordance with the concept of the Helsinki Declaration. After obtaining authorization, written informed consent was obtained from the subjects’ guardians.

Results
The response rate for the dietary assessment was 85.2% (52 subjects). Of these respondents, the 45 subjects for whom data were available on the primary endpoint of the present analysis, occlusal force, were used in the analysis.

Table 2 shows the subjects’ basic characteristics and dental/masticatory conditions. The anthropometric data of the subjects are thought to be around the average levels of the measurements in national statistical data (12) for this age group.

Table 3 shows the median values for the intake of main nutrients and intake by food groups and subsets using the food list. Among the Spearman’s correlation coefficients calculated for the relationship between masticatory indices and intake values, only occlusal force was significantly correlated with several intake values: dietary fiber (r=0.312), insoluble dietary fiber (r=0.354), vegetables (r=0.312), the 90 listed items (r=0.327), set A (r=0.328), and set B (r=0.322). The time-adjusted number of chews and time taken for eating the test meal were not associated with any intake values (r=−0.152–0.213).

Table 4 shows the differences in occlusal force by the tertile groups of the intake. Significant differences were found between high and low intake for dietary fibers (total, insoluble), vegetables, the 90 listed items, sets A and B. There was no significant difference identified for the time-adjusted number of chews or time taken for eating the test meal.

Discussion
Indices for masticatory ability and masticatory behavior have not been appropriately applied to the evaluation of expected outcomes in many practices and studies. Hence, this study has focused on food intake, which is thought to affect chewing, to evaluate the associations between masticatory indices and dietary intake.

Analysis based on the intake of nutrients and intake by food groups
This study used occlusal force, the time-adjusted number of chews, and the time taken for eating the test meal as the masticatory indices, to analyze their associations with the intake of main nutrients and intake by food groups. The results showed a significant relation-
Table 3. Energy, nutrients and food intake and associations with occlusal force in 45 Japanese preschool children aged 5–6 y.

<table>
<thead>
<tr>
<th>Food groups¹</th>
<th>Median (25%, 75%tile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>1,399 (1,218, 1,553)</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>47.5 (41.7, 54.6)</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>46 (36.1, 52.8)</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>196 (168, 222)</td>
</tr>
<tr>
<td>Dietary fiber (g)</td>
<td>9.9 (8.7, 11.7)*</td>
</tr>
<tr>
<td>Soluble fiber (g)</td>
<td>2.4 (2.1, 2.9)</td>
</tr>
<tr>
<td>Insoluble fiber (g)</td>
<td>7.2 (5.9, 8.0)*</td>
</tr>
</tbody>
</table>

Food groups²
- Cereals: 283 (244, 317)
- Tubers: 25 (14, 41)
- Sugars and sweeteners: 3 (2.5)
- Pulses: 27 (18, 41)
- Nuts and seeds: 0 (0)
- Vegetables: 155 (115, 207)*
- Fruit: 126 (66, 195)
- Mushrooms: 6 (2, 11)
- Seaweeds: 14 (1, 21)
- Fish and shellfish: 35 (13, 55)
- Meats: 57 (41, 70)
- Eggs: 22 (13, 32)
- Milk and dairy products: 166 (118, 247)
- Fats and oils: 9 (5, 12)
- Confectioneries: 38 (19, 65)
- Beverages: 199 (63, 321)

Food groups in the list³
- Listed 90 items: 229 (183, 270)*
- Cereals (5 items): 0 (0, 0)
- Tubers (6 items): 20 (10, 33)
- Pulses (4 items): 8 (3, 15)
- Nuts and seeds (2 items): 0 (0, 0)
- Vegetables (42 items): 116 (86, 159)
- Fruit (2 items): 0 (0, 13)
- Mushrooms (10 items): 5 (1, 9)
- Seaweeds (2 items): 11 (0, 21)
- Fish and shellfish (11 items): 0 (0, 5)
- Meats (5 items): 34 (26, 45)
- Milk and dairy products (1 item): 0 (0, 4)

Subsets; Combination of food groups in the list
- Set A ¹³⁴⁴: 144 (100, 188)*
- Set B ¹³⁵⁴: 154 (105, 189)*

¹ Food items are taken from “Major food groups” in the Standard Tables of Food Composition in Japan, 5th Revised and Enlarged Edition (Excluding “seasonings and spices” and “prepared foods”).
² Food items are based on the list with 90 items.
³ Tubers and vegetables.

Spearman’s correlation coefficients were calculated for the relationship between each intake value and masticatory indices: occlusal force, time-adjusted number of chews and time taken for eating the test meal. Significant correlation to occlusal force was found (*) for nutrients, food groups and food groups in the list.

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Ship of dietary fiber and vegetable intake to occlusal force (Tables 3 and 4).

Okazaki and Yanaginuma have already reported an association between occlusal force and dietary fiber intake in children (13). This result is similar to that of the present study. However, the current study differs in that it also focused on insoluble dietary fiber and vegetables. Therefore, desirable health outcomes may be obtained in an approach to improving masticatory ability by increasing the consumption of foods including vegetables recommended in the dietary guidelines of WHO (14) and Japan (15).

Analysis based on the food list

We observed significant positive associations between the masticatory indices and intake values based on the newly produced food list including the two food group subsets. This suggests the external validity of the food list produced to measure food intake thought to affect chewing because of its association with occlusal force as an independent biomarker.

Moreover, it seems that keeping children’s dietary records is a large burden for their guardians, and so, studies should focus on the necessary elements that assess masticatory ability and produce an easier and more compact survey that is able to maintain the quality of the assessment. In this sense, the food list and its subsets seem to be useful.

Difference between the indices of masticatory ability and masticatory behavior in their association with dietary patterns

Since the current study had a dietary assessment period of only 2 d, there was some intra-individual variation in food intake; the tertile division of food intake may have been a misclassification. This misclassification may have led to a dilution bias, reducing the power to detect expected differences. However, the same tertile divisions of selected nutrients and food intake were used to investigate the associations between that food intake and three masticatory indices (Table 4). Therefore, the significant associations observed for occlusal force, but not for the time-adjusted number of chews or time taken for eating the test meal, could demonstrate the difference between masticatory ability and masticatory behavior in terms of the influence of dietary patterns.

Furthermore, in a previous report by the authors (1), a significant association of the obesity index and behavior of the guardians and surrounding adults was found with masticatory behavior, but not with masticatory ability. This shows that the factors related to the two indices are different. Hence, considering even the β-error (Type II error) that was possibly caused by insufficient sample size (n=45), misclassification, and dilution bias due to measurement error, we can conclude that the indices of masticatory ability and masticatory behavior have different significances.

This first demonstration is thought to be useful in choosing appropriate indicators for masticatory variations that consider the difference in application as well as practice.
Conclusions

The results of this study confirmed the following:

1. A significant positive correlation was found between occlusal force and the intake of dietary fiber (total, insoluble), vegetables, the 90 listed items, set A (tubers and vegetables) and set B (tubers, vegetables and mushrooms).

2. No significant correlation was found between the two indices of masticatory behavior (the time-adjusted number of chews and time taken for eating the test meal) and dietary intake.

Hence, we conclude that the indicators of masticatory ability and masticatory behavior have different characteristics and implications in their association with dietary patterns in children.

Acknowledgments

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REFERENCES


