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Difference of tooth brushing motion between dental hygienists and mothers -Focusing on self-toothbrushing and caregivers'-toothbrushing

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Abstract

Aim: Because of the developing fine motor function of children, caregivers are encouraged to brush children's teeth for them until they develop the skills to do so themselves. However, appropriate techniques for caregivers'-toothbrushing haven't been clarified. This study evaluated the self-toothbrushing and caregivers'-toothbrushing motions of dental hygienists and mothers.

Design: Twenty female dental hygienists and twenty mothers participated in this study. A dental model of deciduous dentition attached to a dental education mannequin was used for caregivers'-toothbrushing with a manual toothbrush. Three-dimensional (3D) motions and forces were recorded using a toothbrush attached with a 3D accelerometer and a strain tension gage. The data were evaluated between the abovementioned two groups.

Results: Dental hygienists demonstrated faster motion with lighter force than mothers during tooth brushing. Additionally, in caregivers'-toothbrushing, the displacement of toothbrush of dental hygienists was significantly shorter than that of mothers. Regarding the intra-individual correlations between self-toothbrushing and caregivers'-toothbrushing, significant correlations were found on the displacement of toothbrush for both groups.

Conclusion: Dental hygienists might change their instructions on the brushing motion for caregivers'-toothbrushing whereas the caregivers'-toothbrushing by mothers is strongly reflected by the characteristics of self-toothbrushing. These findings might contribute to establishing tooth brushing instructions for mothers.

Introduction

Oral health is a vital component of wellbeing throughout life [1], and dental plaque control has become an essential target to keep good oral health [2]. Despite the development of powered toothbrushes, manual toothbrushes remain the primary tool of mechanical plaque removal for the majority of the population. Accordingly, it is well established that correct application of tooth brushing techniques is important for effective results, however, the actual motion of manual tooth brushing has not been fully understood.

In recent years, three-dimensional (3D) motion analysis has attracted attention in the field of sport science and medical science to assess various tasks more objectively [3,4]. Also in the fields of dentistry, several studies have tried to evaluate brushing techniques in terms of tooth brushing motion three-dimensionally [5-8]. Inada, *et al.* demonstrated that tooth brushing motion was controlled by coordinated movements of the arm joints using motion-capture systems [5]. Tosaka, *et al.* demonstrated characteristics of tooth brushing motion and brushing force using a 3D accelerometer and a strain tension gage, and also pointed out the need to analyze the tooth brushing motion at the individual's cycle level because tooth brushing motion is a cyclic movement [6]. However, these previous reports focused only on self-toothbrushing.

As young children lack the ability to clean their own teeth effectively, parents or caregivers are recommended to clean their children's teeth (*i.e.,* caregivers'-toothbrushing) at least until they reach school age [9]. At this age, in most families, mothers are usually the principal caregivers. Thus, dental hygienists are given the task to instruct mothers on how to clean their children's teeth in dental clinics or as a public service. However, this task of demonstrating caregivers'-toothbrushing to mothers is complicated. One of the challenges is that appropriate caregivers'-toothbrushing techniques have not been clarified.

In order to establish appropriate caregivers'-toothbrushing motion, we considered it necessary to evaluate in 3D, the caregivers'-toothbrushing motion by dental professionals and compare it to those by mothers. The aim of this study was to elucidate the difference in tooth brushing motions including force 1) between self-toothbrushing and caregivers'-toothbrushing, 2) between dental hygienists and mothers.

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Key words: *toothbrushing, caregiver's-toothbrushing, 3-dimensional, motion, force*

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Material and methods

Subjects

Twenty female dental hygienists (38.4 ± 7.5 years) who were highly trained professionals for tooth brushing and 20 mothers (36.1 ± 5.5 years) who brush their children's teeth on a daily basis were the subjects in this study. Selection was based on the inclusion criteria: 1) Right-handed 2) No missing tooth in molar regions 3) good general health. The study protocol received approval from the Ethical Committee of the Faculty of Dentistry, Niigata University (25-R23-10-03), and all subjects eligible for study were given oral and written information about the purpose and products of the study. Before entering the study, they gave written informed consent.

Measurement systems

Two kinds of toothbrushes were selected in this study. One was the Butler GUM 211 manual toothbrush (Sunstar Butler®, Chicago, IL, USA) used for self-toothbrushing and the other was the Clear Clean Kid's (KAO®, Tokyo, Japan) used for caregivers'-toothbrushing (Figure 1).

A wireless accelerometer (MVP-RF-8-AC, MicroStone® Inc., Saku City, Nagano Prefecture, Japan) was attached to the tail of the toothbrush, and a strain tension gage (KFG-C15, KYOWA® Inc., Tokyo, Japan) was adhered to the shank of the toothbrush (Figure 1). The strain tension gage attached to each toothbrush was calibrated at 300 g weight individually. Measuring errors of both devices were at most +/- 2% of the measuring range in bench tests. The weight of each sensor was 8 g and 0.5 g, respectively. After synchronizing the wireless accelerometer and the load meter, the tooth brushing acceleration and force were recorded at 100 Hz and sent to a Windows PC.

The coordinate system was defined by the direction of the accelerometer attached to the toothbrush; 1) the X-axis was along the tooth brushing axis (*i.e.,* the anterior-posterior direction), 2) the Y-axis was perpendicular to the X-axis (*i.e.,* in a superior-inferior direction), and 3) the Z-axis was perpendicular to the X-Y plane (*i.e.,* in a buccal-palatal direction). Acceleration data was changed into displacement by integration.

Task of experiments

To compare the motion between self-toothbrushing and caregivers'-toothbrushing, two experiments were carried out. First task was to brush their own teeth themselves to record the self-toothbrushing motion. The second task was to brush the primary teeth dental model (NISSIN DENTAL PRODUCTS INC., Kyoto, Japan) to record the caregivers'-toothbrushing motion. These two motions were executed and measured by all forty participants. The primary teeth model was attached to a dental mannequin (Trunk Unit Set, NISSIN DENTAL PRODUCTS INC., Kyoto, Japan) set on a dental chair in the supine position. Subjects were seated on the top side of the mannequin's head to brush the primary dentition model.

Prior to the experiment, subjects were allowed to brush the model teeth on the mannequin once to become accustomed to the experimental conditions. The common task for both of them was to brush buccal surfaces of the left upper molar region for ten seconds. No other instructions were given to each subject to perform their habitual tooth brushing.

Data analysis

Tooth brushing is a repeated cyclic movement, so the motion and force can be divided into each cycle as shown in Figure 2. The starting frame of each cycle was identified as the frame at the minimum position, and the end frame was defined as the next minimum position through maximum position. Range of displacement was defined as the difference between the maximum and the minimum values of each movement. 3D-range was calculated from the following formula.

$$\text{3D-range} = \sqrt{X\text{- } range^2 + Y\text{- } range^2 + Z\text{- } range^2}$$

Although about 40 cycles were detected from ten seconds of tooth brushing motion, the ten most representative cycles were selected to reduce cycle random variability. This selecting method has been applied to analysis of tooth brushing motion by Tosaka, *et al.* [6].

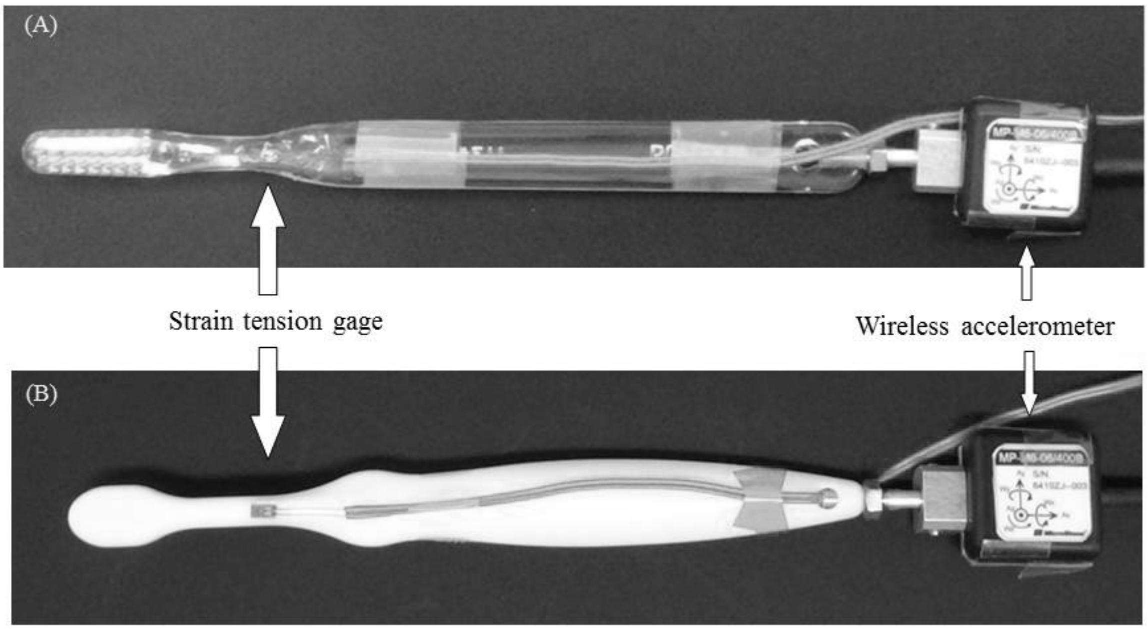

Figure 1. Two kinds of toothbrushes used in this study. Toothbrush for self-toothbrushing (A) and for caregivers'-toothbrushing (B). A wireless accelerometer and a strain tension gage were attached the tale and neck of toothbrushes respectively.

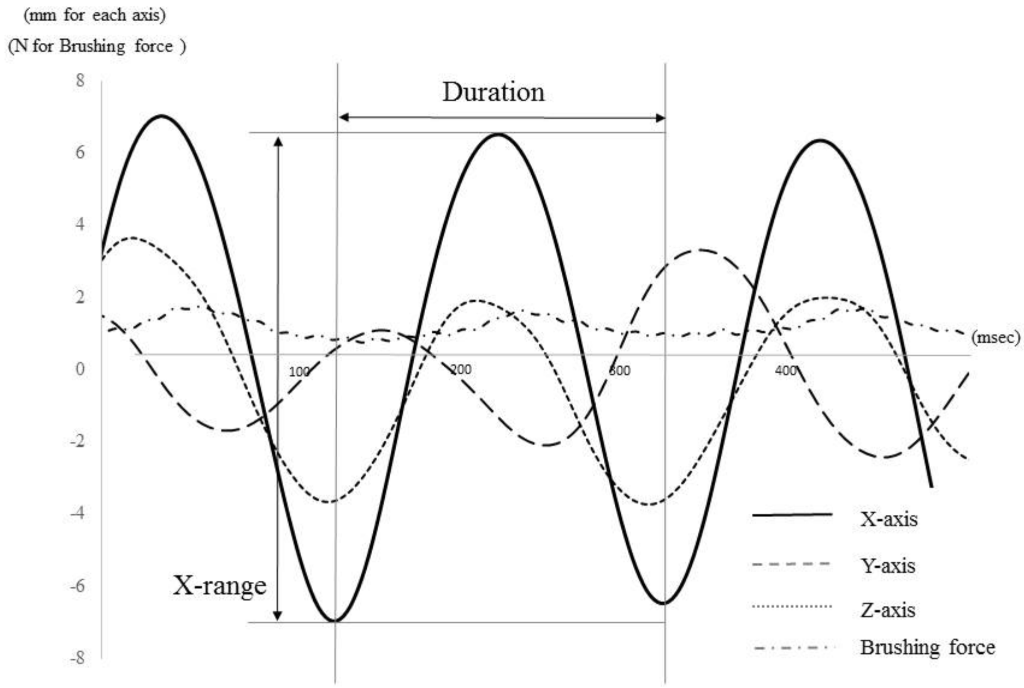

Figure 2. An example of tooth brushing cycles. Each 3D motion and brushing force were described simultaneously. The overall movement for ten seconds was divided into component cycles based on the X-axis motion which was the most dominant component among the 3-axes. An example of one cycle variables (cycle duration and X-range) are explained in this figure.

Statistical analysis

Using the ten most representative cycles from each participant, another computer program calculated cycle durations, the range of displacement for each axis (X, Y and Z axes), the 3D range and the average brushing force. These variables were estimated for each individual's cycles and written, together with identifiers, to a data file for analysis. Then the data were evaluated using multilevel linear statistical models [10] with MLwiN software (ver. 2.24, Centre for Multilevel Modeling, University of Bristol, Bristol, England). The estimation procedure uses iterative generalized least squares. A two-level model, with variation hierarchically partitioned (i) between subjects (or individuals), (ii) between cycles, was used to evaluate systematic differences in durations, displacements and brushing force. In addition, intra-individual correlation between self-toothbrushing and caregivers'-toothbrushing were also calculated. Each analysis was carried out based on 40 subjects, with two kinds of tooth brushing and ten best cycles, for a total of 800 cycles.

Results

Comparison of variables on self-toothbrushing between dental hygienists and mothers

The cycle duration and brushing force on self-toothbrushing by mothers (239.90 msec and 1.67 N) were significantly greater than those by dental hygienists (204.95 msec and 1.03 N). Although the largest difference for displacement ranges for each axis was along the X-axis (2.12 mm), there was no significant difference between dental hygienists and mothers (Table 1).

Comparison of variables on caregivers'-toothbrushing between dental hygienists and mothers

The cycle duration, X-range and brushing force of caregivers'-toothbrushing by mothers (234.85 msec, 13.82 mm and 1.57 N) were significantly greater than those by dental hygienists (209.55 msec, 10.91 mm and 1.10 N). Caregivers'-toothbrushing by mothers had a longer duration, larger ranges of displacements, and larger brushing force than those by dental hygienists (Table 1).

Table 1. Comparison of toothbrushing cycle variables between dental hygienists and mothers.

Self-toothbrushing						
Measures	Dental hygienists		Mothers		Difference	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Cycle duration [msec]	204.95	4.36	239.90	6.62	34.95	9.39**
X-range [mm]	13.54	0.96	15.66	1.13	2.12	1.60
Y-range [mm]	5.07	0.48	5.62	0.61	0.54	0.95
Z-range [mm]	8.27	0.80	7.32	0.67	-0.95	0.95
3D-range [mm]	17.32	1.09	18.84	1.20	1.52	1.70
Brushing force [N]	1.03	0.01	1.67	0.12	0.64	0.17**
Caregivers'-toothbrushing						
Measures	Dental hygienists		Mothers		Difference	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Cycle duration [msec]	209.55	6.94	234.85	7.52	25.30	10.63*
X-range [mm]	10.91	0.62	13.82	1.02	2.91	1.44*
Y-range [mm]	5.46	0.55	7.07	0.53	1.61	0.75
Z-range [mm]	6.39	0.76	6.08	0.68	-0.31	0.96
3D-range [mm]	14.51	0.85	17.38	1.07	2.87	1.51
Brushing force [N]	1.10	0.12	1.57	0.15	0.47	0.21*

S.E. standard error of the estimate *p<0.05, * * p<0.01

Comparison of variables between self-toothbrushing and caregivers'-toothbrushing (Table 2) and intra-individual correlation between them (Table 3)

In dental hygienists, X-range and 3D-range of self-toothbrushing (13.54 mm, 17.32 mm) were significantly greater than those of caregivers'-toothbrushing (10.91 mm, 14.51 mm). By contrast, in mothers, there was no significant difference between self-toothbrushing and caregivers'-toothbrushing (Table 2).

Table 2. Comparison of toothbrushing cycle variables between self-toothbrushing and caregivers'-toothbrushing.

Dental hygienists						
Measures	Self-toothbrushing		Caregivers' -toothbrushing		Difference	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Cycle duration [msec]	204.95	4.36	209.55	6.94	-4.60	8.20
X-range [mm]	13.54	0.96	10.91	0.62	2.63	1.14*
Y-range [mm]	5.07	0.48	5.46	0.55	-0.39	0.73
Z-range [mm]	8.27	0.80	6.39	0.76	1.89	1.10
3D-range [mm]	17.32	1.09	14.51	0.85	2.81	1.38*
Brushing force [N]	1.03	0.01	1.10	0.12	-0.07	0.16
Mothers						
Measures	Self-toothbrushing		Caregivers' -toothbrushing		Difference	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Cycle duration [msec]	239.90	6.62	234.85	7.52	5.05	11.58
X-range [mm]	15.66	1.13	13.82	1.02	1.84	1.82
Y-range [mm]	5.62	0.61	7.07	0.53	-1.45	0.89
Z-range [mm]	7.32	0.67	6.08	0.68	1.24	0.78
3D-range [mm]	18.84	1.20	17.38	1.07	1.46	1.81
Brushing force [N]	1.67	0.12	1.57	0.15	0.10	0.22

S.E. standard error of the estimate *$p<0.05$

Regarding the intra-individual correlation between self-toothbrushing and caregivers'-toothbrushing, significant correlation was found on both of X-range and 3D-range in mothers. Although there was also significant correlation on X-range in dental hygienists, the correlation in mothers was stronger than that in dental hygienists (Table 3).

Between-subject and between-cycle variation of tooth brushing variables in dental hygienists (Table 4) and mothers (Table 5)

That these variations were all significant is indicated by all estimates being more than twice their standard error of the mean. Most of between-subject variation of durations, displacements and brushing force were larger than between-cycle variations in both of dental hygienists and mothers. In addition, mothers showed relatively larger between-subject variations and smaller between-cycle variations compared to dental hygienists.

Discussions

The dominant factor influencing efficacy in plaque removal appears to be the skill of the user [11,12]. However, to request mature fine motor function similar to adults in children is unrealistic, because their dexterity is still developing [13]. Ogasawara reported that it was impossible for children to reach the entire tooth surface until they are 6 years old [14] and Mescher reported that hand function is an age-related factor in subject's tooth brushing ability to perform Bass methods [15]. From this point, many reports recommended that adults perform or supervise oral cleaning for young children, who until approximately 5-10 years of age lack the dexterity and cognition needed for adequate cleaning [15-17]. Therefore caregivers'-toothbrushing is an important factor in maintaining children's oral hygiene.

Tooth brushing for young children by parents or caregivers involves many complicated factors. As toddlers are in a stage of development, it is normal for them to resist assistance with many activities, such as tooth brushing, dressing, feeding, and playing with objects [18]. In addition, lack of children's motivation for tooth brushing makes it hard for caregivers to encourage their cooperation [19]. Another serious factor is that the caregivers'-toothbrushing technique producing the best performance has yet to be determined. Although there is guidance on caregiver's position during caregivers'-toothbrushing [20], recommended tooth brushing motion for caregivers has not been found. This study investigated maternal brushing motion and compared it to that of trained hygienists who are professional tooth brushers. To the authors' knowledge, this study is

Table 3. Intra-individual correlation between self-toothbrushing and caregivers'-toothbrushing.

	Dental hygienists	Mothers
Cycle duration	0.10	0.25
X-range	0.55*	0.82*
Y-range	0.21	0.00
Z-range	-0.02	-0.17
3D-range	0.30	0.72*
Brushing force	0.37	0.31

*$p<0.05$

Table 4. Between subjects and between cycles variances of dental hygienists.

Self-toothbrushing				
Measures	Between subjects		Between cycles	
	Estimate	S.E.	Estimate	S.E.
Cycle duration	350.61	120.38	299.39	31.56
X-range	17.96	5.81	3.95	0.42
Y-range	4.27	1.42	2.35	0.25
Z-range	11.96	4.06	8.64	0.91
3D-range	23.39	7.5	3.34	0.35
Brushing force	0.19	0.06	0.08	0.01
Caregivers'-toothbrushing				
Measures	Between subjects		Between cycles	
	Estimate	S.E.	Estimate	S.E.
Cycle duration	898.35	305	658.94	69.46
X-range	7.33	2.4	2.83	0.3
Y-range	5.45	1.92	6.17	0.65
Z-range	10.37	3.6	10.23	1.08
3D-range	13.48	4.51	7.95	0.83
Brushing force	0.29	0.1	0.08	0.01

S.E. standard error of the estimate

Table 5. Between subjects and between cycles variances of mothers.

Self-toothbrushing				
Measures	Between subjects		Between cycles	
	Estimate	S.E.	Estimate	S.E.
Cycle duration	1371.57	437.37	115.44	12.17
X-range	32.57	10.37	2.32	0.24
Y-range	10.09	3.34	4.51	0.48
Z-range	4.35	1.62	7.6	0.8
3D-range	33.68	10.75	3.21	0.34
Brushing force	0.35	0.11	0.1	0.01
Caregivers'-toothbrushing				
Measures	Between subjects		Between cycles	
	Estimate	S.E.	Estimate	S.E.
Cycle duration	1284.03	409.78	117.95	12.43
X-range	33.52	10.67	2.13	0.22
Y-range	4.47	1.62	6.39	0.67
Z-range	6.58	2.22	4.41	0.46
3D-range	31.02	9.89	2.38	0.25
Brushing force	0.56	0.18	0.07	0.01

S.E. standard error of the estimate

the first article evaluating the 3D motion of caregivers'-toothbrushing. These results are expected to contribute to establishing toothbrushing recommendations for caregivers.

Tosaka analyzed 3D motion of self-toothbrushing by dental hygienists using the same system as this study, demonstrating tooth brushing motion changes depending on the brushed location [6]. It is generally assumed that for a right-handed participant, the right side of the jaw is more difficult to brush than the left side, and also oral sites are assumed to be more difficult to access than the vestibular site [21]. Inada analyzed self-toothbrushing motion of dental hygienists using a motion capture system and suggested that twisting the wrist during buccal right side brushing limited the range of motion and made precise control of tooth brushing motion more difficult [5]. Considering these facts, in order to clarify the difference of the motion between dental hygienists and mothers, we evaluated tooth brushing motion on the left upper molars which are assumed to be easy to brush.

This study clearly demonstrated the differences of tooth brushing motion and force between dental hygienists and mothers. Comparing these two groups, cycle duration and brushing force of dental hygienists were smaller than those of mothers on both self-toothbrushing and caregivers'-toothbrushing.

In previous reports, the tooth brushing force has been reported in various ranges (1.04 N [6], 2.3 N [22], 330 g [23]). This discrepancy might have been due to differences in measuring system or tooth brushing techniques or toothbrushes and so on. Van der Weijden, *et al.* [23] and Hasegawa, *et al.* [24] reported when the brushing force increases, plaque removal effect increases. On the other hand, the fact that excessive brushing force becomes a risk factor of dentin hypersensitivity has also been reported [25]. In this study, mean brushing force of self-toothbrushing and caregivers'-toothbrushing were 1.67 N, 1.57 N in mothers and 1.03 N, 1.10 N in dental hygienists. All variables of the present study were relatively lower than previous reports, but it is noteworthy that mothers' brushing force was 1.5 times greater than that of dental hygienists. It is often recommended to brush using lighter brushing forces to avoid gingival recession or tooth abrasion. Sehmi, *et al.* showed that a tooth brushing force of 400 g caused the greatest increase in the number of exposed tubules after toothbrush abrasion, whereas the 100 g brushing force caused formation of the smear layer, pre- and even post- acid challenge [26]. In that sense, brushing force of dental hygienists in this study may be an appropriate value. Similarly, cycle durations of dental hygienists were significantly shorter than those of mothers on both self-toothbrushing and caregivers'-toothbrushing. Previous reports about brushing behavior mainly based on duration (*i.e.,* brushing time) [27] while studies corresponding to cycle duration are scarce. Although cycle duration are expected to change depending on brushing technique, short cycle duration within same time may actually result in scrubbing teeth many times. In addition, short cycle duration might be related to the short X-range, showing a small and fast tooth brushing motion of dental hygienists. However, further research is required on the relationship between tooth brushing motion and plaque removal effect.

This study also clearly demonstrated the differences of tooth brushing motion between self-toothbrushing and caregivers'-toothbrushing. Especially for dental hygienists, the X-range of caregivers'-toothbrushing was statistically smaller than that of self-toothbrushing. One possibility is that the dental hygienists may change the motion taking into consideration the size of the primary teeth and dentition.

Most of between-subject variances were greater than between-cycle variances on both dental hygienists and mothers, suggesting that each individual has a characteristic tooth brushing motion. Past reports also described self-toothbrushing motion was stable within an individual [5,6,21]. Our results showed the same findings in not only self-toothbrushing but also caregivers'-toothbrushing.

In this study between-subject variance on mothers was largest among two levels for both participants. And one more interesting finding was smaller between-cycle variance in mothers. In addition, regarding intra-individual correlation between self-toothbrushing and caregivers'-toothbrushing, X-range and 3D-range of mothers had great significant correlation. From these findings it was suggested that mothers' brushing motion varies among individuals, however there was monotony in not only self-toothbrushing but also caregivers'-toothbrushing. Probably, the dental hygienists change the tooth brushing motion taking into consideration the shape or size of the tooth and the remaining plaque areas, whereas the mother's tooth brushing motion strongly reflects the characteristics of the individual.

Claydon, *et al.* concluded that the user was by far the most significant variable of plaque removal rather than toothbrush [28]. Tooth brushing behavior can be considered to belong to those automated behaviors incorporated in the motor program known by movement sciences to show high resistance against spontaneous changes [29]. So many researches demonstrated that tooth brushing behavior was not easily altered, even after professional instructions [21]. However, tooth brushing behavior of young children has not been established yet. Mothers play a key role not only as facilitators of oral cleaning in young children, but also as transmitters of oral health behavior to them [9]. Generally, it has been known that children learn oral self-care in the course of primary socialization [30]. There might also be a possibility that young children could learn tooth brushing rhythm and force neurophysiologically by receiving caregivers'-toothbrushing.

Another interesting finding in the present study is that the X-range of mothers has a statistically significant intra-individual correlation between self-toothbrushing and caregivers'-toothbrushing. This indicates the possibility that both self-toothbrushing and caregivers'-toothbrushing motion can change simultaneously by instructing mothers either on self-toothbrushing or caregivers'-toothbrushing.

Some studies have reported that the tooth brushing monitoring system which visualizes tooth brushing movement was more effective than traditional tooth brushing instruction [7,21]. Our measuring system used in this study can monitor tooth brushing motion, including brushing force, conveniently in clinic, so in the near future, we would like to evaluate the change of motion and force after the tooth brushing instructions are given using this method.

Conclusion

This study evaluated the self-toothbrushing and caregivers'-toothbrushing motion 3-dimensionally, and demonstrated significant difference of motion and force between dental hygienists and mothers. Dental hygienists demonstrated faster motion and lighter force than mothers. Additionally, in caregivers'-toothbrushing, the displacement of toothbrush of dental hygienists was shorter than that of mothers.

Regarding the intra-individual correlation between self-toothbrushing and caregivers'-toothbrushing, strong correlations were found on the displacement of toothbrush in especially mothers. From these findings, it is suggested that dental hygienists may need to change their instructions on the tooth brushing motion for caregivers whereas the caregivers'-toothbrushing by mothers might be strongly reflected by the characteristics of self-toothbrushing.

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