Hand motor functions on the presence of red fluorescent dental biofilm in older community-dwelling Koreans

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A B S T R A C T

Background: The Quantitative Light-induced Fluorescence-Digital (QLF-D) system visualizes old and mature dental biofilm as red fluorescence. Risk factors for poor oral hygiene have been identified, however, few studies have evaluated the relationship between mature dental biofilm and hand motor functions. This study aimed to investigate the effects of two important manual motor functions for object manipulation —handgrip strength and manual dexterity— on the presence of red fluorescent dental biofilm in older community-dwelling Koreans using QLF-D, an optical device that reveals dental biofilm.
Methods: This cross-sectional study included 70 Korean participants aged ≥ 65 years, all of whom completed questionnaires and were tested for handgrip strength and manual dexterity. In total, 840 dental surfaces were photographed using QLF-D, and ΔR_{20} values, which reflect mature dental biofilm accumulation, were calculated. The t-test was performed to analyze the differences in the ΔR_{20} values according to sociodemographic characteristics, health-related characteristics and hand motor functions, while multiple linear regression analysis was used to investigate the effects of hand motor functions on the ΔR_{20} values.
Results: Multivariate regression analysis revealed that handgrip strength ($\beta = -0.294$) was the factor most strongly affecting mature dental biofilm accumulation (ΔR_{20}), followed by tooth-brushing time ($\beta = -0.262$) and manual dexterity ($\beta = -0.241$).
Conclusions: Reductions in handgrip strength and manual dexterity were independent risk factors for pathogenic dental biofilm accumulation. The results of this investigation suggest that programs designed to prevent the decline, as well as improve, handgrip strength and manual dexterity might improve the oral hygiene of older adults.

1. Introduction

Oral health impairment during aging is not inevitable [1]. However, older adults are of course exposed to risk factors for oral diseases for longer periods [2] and they show poorer oral health behavior [3]. Thus, oral diseases are common throughout this population. Oral diseases are often caused by dental biofilm, which consists of more than 700 species of bacteria, fungi, and viruses [4]. If dental biofilms are not regularly removed, new bacterial species invade and cause maturation of the biofilm [5]. Poor oral health directly and indirectly affects systemic health, particularly in older adults [4]. Periodontal diseases are associated with life-threatening conditions including diabetes and cardiovascular disease [5]. Dental biofilm, which acts as a bacterial reservoir, is a significant risk factor associated with aspiration pneumonia, which

represents a leading cause of death in frail older adults [6]. Unfortunately, older adults are more likely to have factors that expedite accumulation of dental biofilm, including hyposalivation [7]. They are also not interested in oral hygiene [8] and consequently, regular tooth-brushing is less common in older adults than in younger adults [9]. Dental professionals should therefore be aware of the impact that poor oral health exerts upon systemic health and endeavor to identify the factors hindering older adults from engaging in oral hygiene activities.

Hand motor function has been regarded as a critical factor with respect to independent engagement with daily activities [10]. In particular, impairment of the digits or joints has been reported a significant cause of poor oral hygiene in institutionalized older adults [11,12]. Although the decline in hand manipulation skills commences in adults between the ages of 40–55 years, it becomes notably more severe

around the age of 65 years [13], there have been few studies that have investigated the relationship between oral hygiene status and hand motor functions in home-dwelling older adults. A recent investigation reported the association between reduced manual dexterity and the quantity of dental biofilm accumulated upon the lingual surfaces of teeth in independent older adults without hand disabilities [14]. However, the investigation did not consider the influence of handgrip strength, a key skill required in order to carry out oral self-care [15]. Handgrip strength, as a representative measure of whole-body muscle weakness, is associated with the number of remaining teeth [16] and various oral functions such as swallowing ability and masticatory performance [17]. Thus, in order to diagnose the hand motor functions of independent community-dwelling older adults, manual dexterity and handgrip strength must be examined respectively.

Thus far, disclosing agents that make colorless dental biofilm observable to the naked eye have been used for the assessment of oral hygiene status. This method, however, may not be reliable due to its low objectivity and sensitivity [18,19]. These agents stain not only dental biofilm but also soft debris and oral tissues [18]. Furthermore, since the process of applying and removing the agent to and from tooth surfaces is complex, it may be of limited use in an epidemiological survey. In order to overcome these limitations, the use of a quantitative light-induced fluorescence-digital (QLF-D) (QLF-D Biluminator™, Inspektor Research Systems BV, Amsterdam, the Netherlands) system, an optical device used to visualize dental biofilm, has been increasingly used for oral hygiene evaluation [20,21]. This system uses blue light at 405 nm to detect endogenous porphyrins, a metabolite produced by oral bacteria [22] and visualizes dental biofilm as red fluorescence [23] (Fig. 1). The intensity of red fluorescence increases with the maturation of the dental biofilm, which is a significant advantage of this technology [23]. Using the QLF-D, several studies have identified the risk factors of poor oral hygiene; however, there has been limited research that investigates the amount of pathogenic dental biofilm, demonstrated by red fluorescence, in relation to handgrip strength.

The purpose of this study was to evaluate the effects of handgrip strength and manual dexterity on the accumulation of red fluorescent dental biofilm, using the QLF-D optical device, in independent community-dwelling older adults in South Korea.

2. Materials and methods

2.1. Participants

This study was cross-sectional in design and approved by the Gachon University Institutional Review Board (No. 1044396-201705-HR-084-01), which adhered to all relevant tenets of the World Medical Association Declaration of Helsinki. All participants gave written informed consent and they were informed that they could withdraw from the study at any time.

Using the G*power 3.1 program (Informer Technologies, Düsseldorf, Germany), the minimum sample size for multiple linear regression was calculated using the following parameters: 90% power, 5% significance level, 0.35 effect size [24] and eight predictors. The minimum sample size required was 63. To recruit the participants, five senior welfare facilities in Incheon Province and Gyeonggi Province in South Korea were selected via convenience sampling. The examiner explained the study in detail to facility visitors who were older than 65 years, living independently, right-handed and had six index teeth. The 109 participants who indicated that they wished to participate were surveyed via a questionnaire and hand motor functions and dental biofilm accumulation were assessed. 34 participants were excluded from the study due to the following factors related to dental biofilm accumulation: those diagnosed with disorders of the upper extremities or cognitive impairments; those who had taken antibiotic treatments in the previous 30 days; those who had consumed at least half a glass of alcohol every day for 6 years; those who suffered from hyposalivation (unstimulated salivary flow rate < 0.1 mL/min) [25]; and those who had prosthetics or dental crowding of their index teeth. An additional five participants requested to be removed from the study due to discomfort. Therefore, the data of 70 participants, excluding 39 participants, were used in the final analysis.

2.2. Measurements

Four types of data were collected; sociodemographic characteristics (gender, age, marital status, residential status, and educational level); health-related characteristics (systemic diseases, daily medication, smoking status, cognitive status, tooth-brushing frequency, tooth-brushing time, use of interdental cleaning devices, recent dental check-ups, recent dental scaling, and periodic dental scaling); hand motor functions (manual dexterity and handgrip strength); and mature dental biofilm accumulation. Data were collected from May 25, 2017 to April 30, 2018.

The survey was administered by a single trained examiner through structured face-to-face interviews. The questionnaire explored general and health-related characteristics. The Korean Mini-Mental State Examination (K-MMSE) was used to assess cognitive status [26]. Additionally, handgrip strength and manual dexterity, two important motor skills of the hand for object manipulation, were assessed [27]. In particular, handgrip strength refers to the static force applied by the hand to pull or suspend an object, which is an important aspect of hand motor function [28]. A Baseline Hydraulic Hand Dynamometer (Fabrication Enterprises Inc., Irvington, NY, USA) was used to assess handgrip strength [29] using the standardized testing position suggested by Mathiowetz et al. [30]. Each participant was seated with the shoulders adducted and neutrally rotated, elbows flexed to 90°, forearms in the neutral position, and wrists at 0–30° of dorsiflexion; the examiner measured the dominant (right hand) grip. Each participant was instructed to squeeze the grip for at least 3 s at maximum force. All measurements were repeated three times at intervals of 15 s. The average score was recorded; a higher score indicated better handgrip strength. Manual dexterity is important in terms of hand neuromotor function; good dexterity indicates that objects can be precisely manipulated [31]. The Box and Block Test (Samson & Preston Co.,

Fig. 1. White light image (left) and fluorescence image (right) of dental biofilm captured using a Quantitative Light-induced Fluorescence-Digital (QLF-D) system.

Table 1

ΔR_{20} values by sociodemographic characteristics.

Variable	n	ΔR_{20}	
		M ± SD	p
Gender			
Male	18	127.27 ± 123.97	0.724
Female	52	114.46 ± 134.97	
Age (years)[a]			
75	37	96.05 ± 92.33	0.159
≥ 75	33	142.09 ± 162.86	
Marital status			
Married	41	127.80 ± 153.44	0.414
Divorced/widowed	29	103.55 ± 92.75	
Residential status			
Living alone	25	111.12 ± 108.74	0.755
Living with spouse/offspring	45	121.44 ± 143.58	
Educational level			
≤ Primary school	27	108.37 ± 147.43	0.639
> Primary school	43	123.65 ± 121.85	

p-value derived via *t*-tests.

[a] Using a median cutoff.

Bolingbrook, IL, USA) was used to assess manual dexterity [32]. Each participant was instructed to move as many wooden cubes as possible from a compartment on the right to a compartment on the left within 1 min, using their right hand. The examiner then counted the cubes in the left compartment. A high score indicated better manual dexterity.

The QLF-D was used to assess the maturity of dental biofilm [20]. Six teeth, three on each of the maxillary (right lateral incisor, right first molar, and left first premolar) and mandibular arches (left lateral incisor, left first molar, and right first premolar) were selected as the representative teeth for the study [33]. Each participant was instructed not to eat or engage in oral hygiene activity for a minimum of 4 h prior to the experiment. All lights in the examining room were turned off and the camera cone of the QLF-D was covered with blackout cloth prior to image acquisition [34]. Each participant lay supine in a dental chair and the camera lens was placed vertically on the index teeth. The distance between each tooth and the lens was consistent; all teeth surfaces were dehydrated using compressed air for at least 15 s prior to imaging. The blue light QLF-D conditions were as follows: shutter speed, 1/30 s; aperture, 5.0; and ISO setting, 1,600 [20]. In total, 840 buccal and lingual surfaces of the six index teeth were photographed and QLF-D image analysis software (QA2 ver. 1.24; Inspektor Research Systems BV) was used to calculate the ΔR values that represented the red fluorescence intensity of dental biofilm [20,35]. ΔR value is the percentage difference in the red/green fluorescence ratio compared to a biofilm-free reference value. Referring to the research result of Han et al. [20], ΔR_{20} values were used, among the thirteen threshold levels of the ΔR values, as the criterion of mature dental biofilm that can cause oral diseases. Higher ΔR_{20} values indicate accumulation of more mature dental biofilm on tooth surfaces [20]. QLF-D imaging and all analyses were performed by one trained examiner.

2.3. Statistical analysis

Data were analyzed using SPSS software (ver. 23.0; IBM Corp., Armonk, NY, USA); a *p*-value < 0.05 was considered to reflect statistical significance. The ΔR_{20} values of the buccal and lingual surfaces of the six index teeth were summed and constituted the dependent variables. In order to classify the level of each participant's hand motor functions, the standard scores of handgrip strength and manual dexterity were calculated based on reference values for each target age/gender group that were derived previously [30,36]. The formula used to calculate the standard scores is as follows: $(x-\mu)/\sigma$, where x is the

measured values of the participants, μ is the mean of the target age group and σ is the standard deviation of the target age group. Participants with less than -2 standard score values were considered to have reduced handgrip strength [28]. The threshold for weak manual dexterity was also set at -2 standard score values. We used the *t*-test to compare differences in mature dental biofilm accumulation (ΔR_{20} values) with respect to sociodemographic characteristics, health-related characteristics and hand motor functions. Multiple linear regression analysis was performed in order to explore the effects of risk factors, in particular, handgrip strength and manual dexterity, on the accumulation of mature dental biofilm (ΔR_{20} values) after adjustment for cognitive status. In multiple linear regression analysis, the independent variables were those showing statistical significance based on t-tests ($p < 0.05$). The dependent variable, accumulation of mature dental biofilm (ΔR_{20} values), was normal-transformed to the square root to form a normal distribution. Tolerance (≥ 0.1) and variance inflation factor (< 10) values indicated that this model had no multicollinearity problem.

3. Results

3.1. Mature dental biofilm accumulation (ΔR_{20} values) by sociodemographic characteristics

No significant difference was found in the ΔR_{20} values with respect to gender, age, marital or residential status, or educational level (Table 1).

3.2. Mature dental biofilm accumulation (ΔR_{20} values) by health-related characteristics and hand motor functions

The factors associated with the accumulation of mature dental biofilm (ΔR_{20} values) were cognitive status, tooth-brushing time, the use of interdental cleaning devices, recent dental check-up, recent dental scaling, periodic dental scaling, handgrip strength, and manual dexterity (Table 2). Participants who brushed their teeth for less than 3 min/session, did not use interdental cleaning devices, and showed reduced cognitive function exhibited higher ΔR_{20} values than those of the controls ($p < 0.05$). Those who had not had a dental check-up for 2 years or dental scaling for 3 years, or who did not schedule regular dental scaling, had higher ΔR_{20} values ($p < 0.05$). Furthermore, those exhibiting reduced manual dexterity and weak handgrip strength showed higher ΔR_{20} values ($p < 0.05$).

3.3. Risk factors for mature dental biofilm accumulation (ΔR_{20} values)

The explanatory power of Model 1, including only health-related characteristics, was only 15.0%. In Model 2, including both health-related features and hand motor functions, the factor most strongly affecting ΔR_{20} values was handgrip strength ($\beta = -0.294$), followed by tooth-brushing time ($\beta = -0.262$) and manual dexterity ($\beta = -0.241$; Table 3). The cumulative variance explained by the effects of these three independent variables on mature dental biofilm accumulation was 23.4% ($R^2 = 0.323$; adj. $R^2 = 0.234$). The model therefore significantly predicted accumulation of mature dental biofilm (F = 3.638; $p < 0.01$).

4. Discussion

The thorough control of dental biofilm is essential not only for disease-free dentition but also for general health, especially in older adults [4]. Nevertheless, few studies have explored the general risk factors that trigger the accumulation of mature and pathogenic dental biofilms. Thus, it was hypothesized that reductions in handgrip strength and manual dexterity expedited mature dental biofilm accumulation in independently living older adults. We found that tooth-brushing time

Table 2
ΔR_{20} values by health-related characteristics and hand motor functions.

Variable	n	ΔR_{20} M ± SD	p
Systemic diseases			
Yes	57	123.64 ± 138.47	0.436
No	13	91.92 ± 94.95	
Daily medication			
Yes	55	119.87 ± 141.06	0.799
No	15	110.00 ± 91.41	
Smoking status			
Current and former	10	124.60 ± 122.66	0.860
Never	60	116.61 ± 133.82	
Cognitive status			
Reduced[a]	3	284.33 ± 186.08	0.024
Normal	67	110.29 ± 125.31	
Tooth-brushing frequency (per day)			
≤ 2	37	143.70 ± 155.63	0.073
≥ 3	33	88.66 ± 91.49	
Tooth-brushing time (per session, min.)			
≤ 2	54	130.16 ± 142.92	0.043
≥ 3	16	75.87 ± 70.06	
Use of interdental cleaning devices			
Yes	17	60.00 ± 52.73	0.002
No	53	136.28 ± 143.66	
Recent dental check-up (years)			
≤ 2	46	95.32 ± 110.54	0.047
> 2	24	160.75 ± 158.15	
Recent dental scaling (years)			
≤ 3	56	100.92 ± 125.35	0.031
> 3	14	185.07 ± 138.40	
Periodic dental scaling			
Yes	16	66.81 ± 65.09	0.012
No	54	132.85 ± 142.43	
Handgrip strength[b]			
Normal	24	76.04 ± 89.10	0.027
Low	46	139.52 ± 145.02	
Manual dexterity[b]			
Normal	46	82.21 ± 85.16	0.035
Low	24	174.37 ± 180.48	

p-value derived via *t-tests*.
[a] K-MMSE ≤ 19 points.
[b] By cut-off point (−2 standard scores).

Table 3
Risk factors for mature dental biofilm accumulation (ΔR_{20} values) as revealed by multiple linear regression analysis.

Variable	Model 1		Model 2	
	β	p	β	p
Health-related characteristics				
Tooth-brushing time	−0.210	0.081	−0.262	0.025
Use of interdental cleaning devices	−0.085	0.505	−0.071	0.559
Periodic dental scaling	−0.165	0.176	−0.219	0.066
Recent dental check-up	0.147	0.259	0.149	0.226
Recent dental scaling	0.119	0.362	0.077	0.544
Hand motor functions				
Manual dexterity			−0.241	0.040
Handgrip strength			−0.294	0.017
F	3.030 (p = 0.011)		3.638 (p = 0.002)	
R^2	0.224		0.323	
adj. R^2	0.150		0.234	
R^2 (adj. R^2) change	–		0.099 (0.084)	

Dependent variable: accumulation of mature dental biofilm (ΔR_{20} values).
p-value derived from multiple linear regression adjusted for cognitive status.
Tooth-brushing time (continuous variable), use of interdental cleaning devices and periodic dental scaling (no = 0, yes = 1), recent dental check-up (years) (> 2 = 0, ≤ 2 = 1), recent dental scaling (years)(> 3 = 0, ≤ 3 = 1), manual dexterity and handgrip strength (low = 0, normal = 1).

affected the accumulation of mature dental biofilm. This is unsurprising, because tooth-brushing has been reported to be the most effective method to regularly remove dental biofilm [37]. Moreover, the final multivariate model (Table 3, Model 2) showed that mature dental biofilm accumulated to a greater extent as handgrip strength (β = −0.294) and manual dexterity (β = −0.241) decreased. It is difficult to directly compare the oral hygiene status of our participants to that of participants in previous studies as this investigation utilized a QLF-D system to quantify mature dental biofilm levels; however, our results are in accordance with those of a previous study, despite the fact that it did not evaluate the pathogenic status of dental biofilm. This previous study reported that home-dwelling older individuals with a strong handgrip exhibited better oral hygiene compared to subjects with weak handgrip [15]. The current investigation also supports another earlier study which suggested that reduced manual dexterity compromises tooth-brushing ability, although the subjects in that study were in long-term care [11], unlike our subjects. Therefore, both handgrip strength and manual dexterity directly impact the effectiveness of daily oral self-care, particularly tooth-brushing. An increase in the time taken to brush teeth to a maximum of 3 min was found to enhance dental biofilm removal [38]. Of the various hand motor functions, a decline in handgrip strength that reduces the ability to

firmly grasp a toothbrush handle, causes premature fatigue that decreases tooth-brushing time; this may explain why more mature dental biofilm accumulated in older adults with poor handgrip strength. Furthermore, if dental biofilm is to be removed effectively, the toothbrush filaments should be placed at 45° on the points where the teeth and gingiva meet and moved gently back-and-forth [5]. Older adults exhibiting reduced manual dexterity may be unable to direct toothbrush rotation or fine vibration; the toothbrush strokes may become inappropriate or insufficient in number as a result of poor manual dexterity. We speculate that this compromises the early removal of dental biofilm. Hence, all health professionals including physical therapists must be aware that reduced handgrip strength and manual dexterity impedes upon oral hygiene. Musculoskeletal specialists should ensure that older adults with poor hand motor function receive periodic oral care from dental hygienists. In addition, new screening tools for the early detection of hand disorders should be developed and effective preventive interventions put in place to enhance the hand motor function of older individuals. Dental hygienists should play a significant role in these efforts by providing information regarding hand motor function and identifying resources for middle-aged adults in order to prevent negative outcomes associated with a decline in handgrip strength and manual dexterity. Dental hygienists must provide appropriate oral health instructions and prophylaxes based on information regarding hand motor function status imparted by musculoskeletal specialists. Although interprofessional collaboration among healthcare professionals has long been perceived as important for providing integrated healthcare, collaboration between musculoskeletal specialists and dental hygienists has not been sufficient. Therefore, effective collaboration must be implemented in order to identify the risk factors for poor oral hygiene and offer interventions. The major strength of this study is that we employed QLF-D, which can quantitatively assess the amount of pathogenic dental biofilm and help participants easily recognize and evaluate their poor oral hygiene status. Furthermore, as the ΔR_{20} values were derived, the risk factors for mature dental biofilm accumulation such as reduced hand motor functions were accurately identified. This is the first study to demonstrate that a reduction in handgrip strength inhibit pathogenic dental biofilm removal in independent older adults. There were also a number of limitations associated with this investigation. To begin with, a cross-sectional design was used, therefore causal relationships could not be determined. Furthermore, the sample size was limited and the participants were

drawn from specific regions of Korea; thus, our results may not be generalizable. Although handgrip strength and manual dexterity have been identified as factors that can predict the accumulation of mature dental biofilm, both the association between the variables and the explanatory power of our multiple linear regression models were low. This indicates that factors affecting mature dental biofilm accumulation are much more diverse than the variables used in our multiple linear regression model. In particular, we could not evaluate the participants' tooth-brushing techniques (for example, roll, scrub, and bass techniques), a factor that can help improve their oral hygiene, because the participants did not precisely recognize what motion they were performing every day to brush their teeth. Thus, the study could not comprehensively explore and identify the predictive factors for mature dental biofilm, even though it excluded participants who were previously exposed to factors related to dental biofilm accumulation. Further studies should explore more factors that affect dental biofilm accumulation including tooth-brushing techniques and dental conditions. Moreover, longitudinal studies are required to evaluate whether hand motor function affects mature dental biofilm accumulation; such studies should include larger samples and more systematic sampling methods.

5. Conclusion

Reductions in handgrip strength and manual dexterity were independent risk factors for mature dental biofilm accumulation in older adults. The results of this investigation suggest that intervention programs designed to prevent decreases in handgrip strength and manual dexterity might improve the oral hygiene of older adults.

Declaration of Competing Interest

There is no conflict of interest to be declared associated with this study.

Acknowledgments

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