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Original Article

Effect of scan delay on measurements of an occlusal pressure sensitive film: An in-vitro study

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Abstract *Background/purpose:* While scan delay may affect the measurements of an occlusal pressure-sensitive film, Dental Prescale II (DPS2), the duration of scan delay was rarely reported in previous studies. This study aimed to clarify the effect of scan delay on DPS2 measurements. *Materials and methods:* Two experiments were performed to clarify the effect of 0- to 10-min scan delay after DPS2 force registration. In both experiments, 11 loads were applied separately on a DPS2 film at 1-min interval between loads. Scanning was performed immediately after the 11th load in the 1-scan experiment and immediately after each load in the 11-scan experiment. A 300-N load was applied with a universal testing machine on 10 DPS2 films in each experiment and the DPS2 film was scanned with Bite Force Analyzer. Load measured, contact area, mean pressure, and maximum pressure were reported. ANOVA and Scheffé test were performed to compare the effect of number of scans and delay scan duration on these measurements with the critical value set at $P \leq 0.05$.

Results: Number of scans had no significant effect on the four measurements studied. However, all measurements, except contact area, were significantly affected by scan delay; the longer the scan delay, the greater the increase in measurements. The load measured showed a rapid increase (13%) in the first 2 min, followed by a gradual increase from 2 min to 10 min (10%).

Conclusion: Scan delay does affect DPS2 measurements, and it is important to standardize and report scan delay duration in clinical studies.

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Introduction

Bite force is one of the important parameters for objective evaluation of the masticatory system. The bite force of an entire dentition can be measured by a minimally invasive chairside occlusal measurement system, the Dental Prescale system (DPS; Fuji Film Co., Tokyo, Japan). Various findings on maximum bite force have been obtained through studies using DPS.^{1–6} However, DPS became obsolete when Dental Prescale II (DPS2) and Bite Force Analysis System (GC, Tokyo, Japan) were introduced in 2018. Subsequent studies performed with DPS2 validated it as a reliable and reproducible system.^{7–11} A correlation between the maximum occlusal forces measured by DPS and DPS2 was suggested, and comparison between the two measurements could be made by applying corrections using a regression equation.¹¹ In 2016, the Japanese Society of Gerodontology proposed a definition of and diagnostic criteria for “oral hypofunction”.¹² One of these diagnostic parameters is reduced occlusal force, a force of <200 N, which can be tested by measuring the occlusal force of the entire dentition with a pressure-sensitive film (DPS 50H type R pressure-sensitive film, GC, Tokyo, Japan).^{12,13} The new DPS2 has been widely used since 2018 when the testing and management of oral hypofunction were covered by the Japanese national health insurance system.⁷

Dental Prescale II (DPS 2) is a 150- μm -thick pressure measurement film comprising three layers of polyethylene terephthalate (PET) covering a developer layer and a microcapsule layer. The microcapsules vary in size and thickness. They break and release a colorless, clear white dye in response to an applied pressure ranging from 10 MPa to 120 MPa. The dye reacts with the developer layer to create a red color change, and the shade is in proportion to the number of microcapsules that break under the applied pressure. The film can be scanned after recording, and analyzing changes in color on the film can reveal bite force, occlusal contact area, average bite pressure and maximal bite pressure. The initial dye released by microcapsules may spread and alter both color intensity and resolution with time; hence, variations in scan delay between recording and scanning may yield different measurements. While scanning “as soon as possible” is recommended by the film manufacturer, it is sometimes difficult to maintain the same scan delay in a clinical study. It was also mentioned in another research that DPS should be kept in a cool, dark place for 24 h prior to analysis.² While the extent of impact of scan delay on measurements remains unclear, the duration of scan delay has rarely been reported in previous studies using DPS or DPS2. The purpose of this study was to clarify the effect of scan delay on the measurements of Dental Prescale II.

Materials and methods

Experimental design

In this study, scanning time dependency was examined with measurements made immediately after loading and at 1-min increment after loading till 10 min. Two *in vitro* experiments were performed: 1-scan experiment and 11-scan experiment (Fig. 1). In the 1-scan experiment, 11 loads

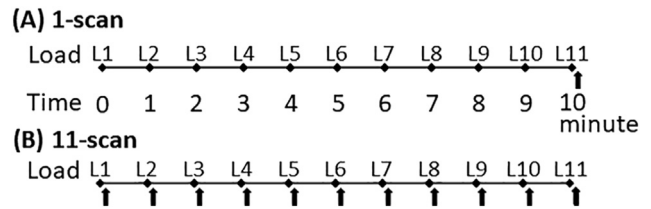


Figure 1 Experiment flow chart on each DPS2 film (A) 1-scan experiment (B) 11-scan experiment. The load was added with 1-min increment, and the black arrow represents a scan being performed.

were separately applied on a DPS2 film with 1-min interval between loads, and scanning was performed immediately after the 11th load. Analysis of data thus obtained would reveal the results of 11 loads with scan delay of 0–10 min. In the 11-scan experiment, 11 loads were also applied separately on a DPS2 film with 1-min interval between loads. However, scanning was performed immediately after each load. Thus, analysis of data thus obtained would reveal the results of the same load point with scan delay of 0–10 min. Between each load test or scan, DPS2 films were kept in a dark container. Statistical analysis was performed to compare the results of the load mark scanned once in the 1-scan experiment and that scanned repeatedly in the 11-scan experiment to shed light on the effect of number of scans on the measurements obtained.

Experimental setup, recording, and analysis

A Universal Testing System (Instron 5566, Instron Corp., Canton, MA, USA) was used in a compression mode (Fig. 2). The load cell used was able to provide forces up to 5 kN. A 12 mm² stainless steel circle flat head was attached to the load cell and a 300-N load was applied downwards onto a fixed flat stainless plate with a DPS2 film placed in between the two surfaces. With a controlling software (Bluehill v2.3, Instron Corp. Canton, MA, USA), the load was applied with a crosshead speed of 30 mm/min till 10 N load was detected, then the load was increased in a second to 300 N and maintained for 3 s to complete one test. Two experiments were performed according to the Experimental Design detailed in previous section. The number of applied loads, the duration of scan delay and the number of scans followed the experimental design described. All samples were scanned by the recommended color scanner (Perfection V600 Photo, Epson, Nagano, Japan) and the scan results were analyzed using the GC Bite Force Analyzer software installed in a PC computer. Load measured, contact area, mean pressure, and maximum pressure were obtained from the Bite Force Analyzer for each load mark. The data were analyzed using the improved Bite Force Analyzer which has a pressure filter function that automatically excludes areas of red color likely to be generated by a bending force other than occlusal contact.

Statistical analysis

Effects of number of scans and scan delay

Totally, 10 DPS2 films with 11 load marks at 1-min interval on each film were analyzed in both experiments. In the 1-

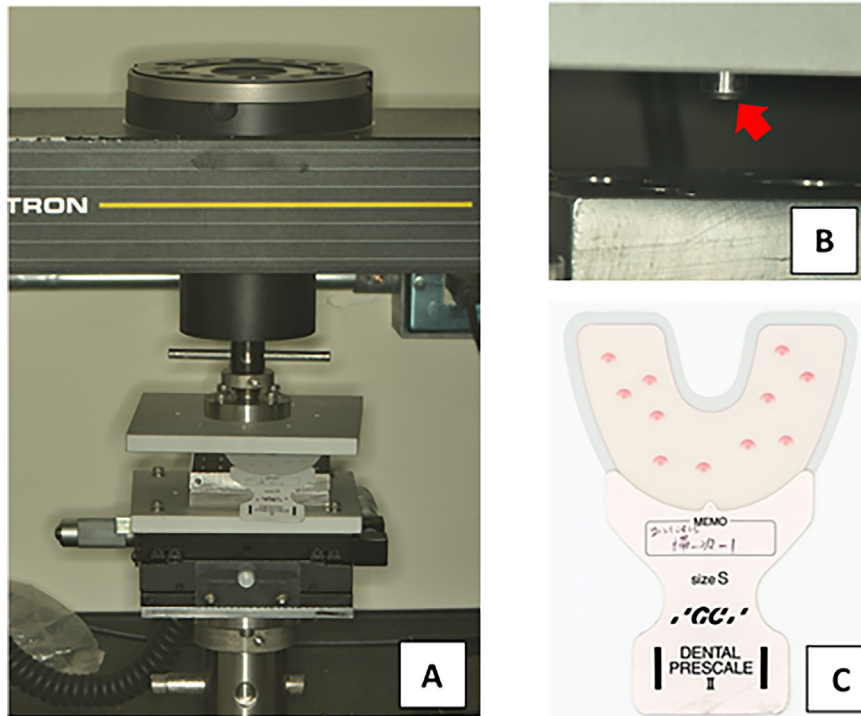


Figure 2 (A) Experimental setup using Instron machine with a 12 mm² stainless steel circle flat head attached to the load cell and applying a 300-N load downwards onto a fixed flat stainless plate with a DPS2 film placed in between (B) the circle flat surface head (arrow) attached to the load cell, and (C) 11 load marks on a DPS2 film.

scan experiment, only one scan was performed immediately after the 11th load; in the 11-scan experiment, 11 scans were performed, one immediately after each load. Comparison between results of both experiments was made using two-way ANOVA (IBM SPSS Statistics, Version 27, Armonk, NY, USA) to shed light on the effect of number of scans and scan delay on the load marks. Scheffé test was used as the post-hoc test. The critical value was set at $P \leq 0.05$. Measurements obtained in both experiments including load, area, average pressure, and maximum pressure were also compared.

Effects of scan delay from normalized data

In the 11-scan experiment, the DPS2 film was repeatedly scanned after each load during the 10-min period. There were a total of 11 load marks made and 11 scanning was performed. In other words, each load mark was repeatedly scanned with 1-min increment after load application until the 11th scan. Analyzing the load mark at each scan can reveal the effect of scan delay through within-subject normalization. Therefore, the scan delay effects were also evaluated by normalizing the data of different scan delay periods to that of the 0-min scan delay for each load mark.

Results

Fig. 3 shows the measured load, contact area, mean pressure, and maximum pressure over different scan delay durations in both experiments. Table 1 summarizes the statistical results. As can be seen, number of scans did not

have statistically significant effect on the four measurements, while all measurements, except contact area, were significantly affected by scan delay, and the longer the scan delay, the greater the increase in measurements (Table 1, Figs. 3 and 4). Of note is that the measured loads were about 70% (211.9 ± 10.9 N, mean \pm sd) of the 300-N load applied at 0-min scan delay and about 84% (253.15 ± 6.75 N) at 10-min scan delay. In view of the insignificant effect of number of scans on measurements, the data can be normalized by dividing the measurement from the same load point at different scan delay durations by the 0-min scan delay. Fig. 5 shows the normalized results of load measured over different scan delay durations, indicating a trend similar to that seen in Fig. 3A. As shown, there was a rapid increase in load measured (13%) in the first 2 min, followed by a gradual increase from 2 min to 10 min (10%) (Fig. 5). The same trend was also observed for mean pressure (0–2 min: 13%; 2–10 min: 8%) and maximum pressure (0–2 min: 14%; 2–10 min: 16%) (Fig. 3).

Discussion

DPS and DPS2, pressure-sensitive films showing the total force, contact area, mean contact pressure and maximum contact pressure in the areas of interest, are recommended for use in occlusal analysis.^{14,15} The DPS2 has a thicker pressure-sensitive sheet (~ 150 μ m) than the conventional DPS (~ 100 μ m), so the colored area is increased by applying pressure to occlusal proximity and the occlusal force value is higher.^{7,9,11} According to the manufacturer, the DPS2 has a better production yield rate and Bite Force

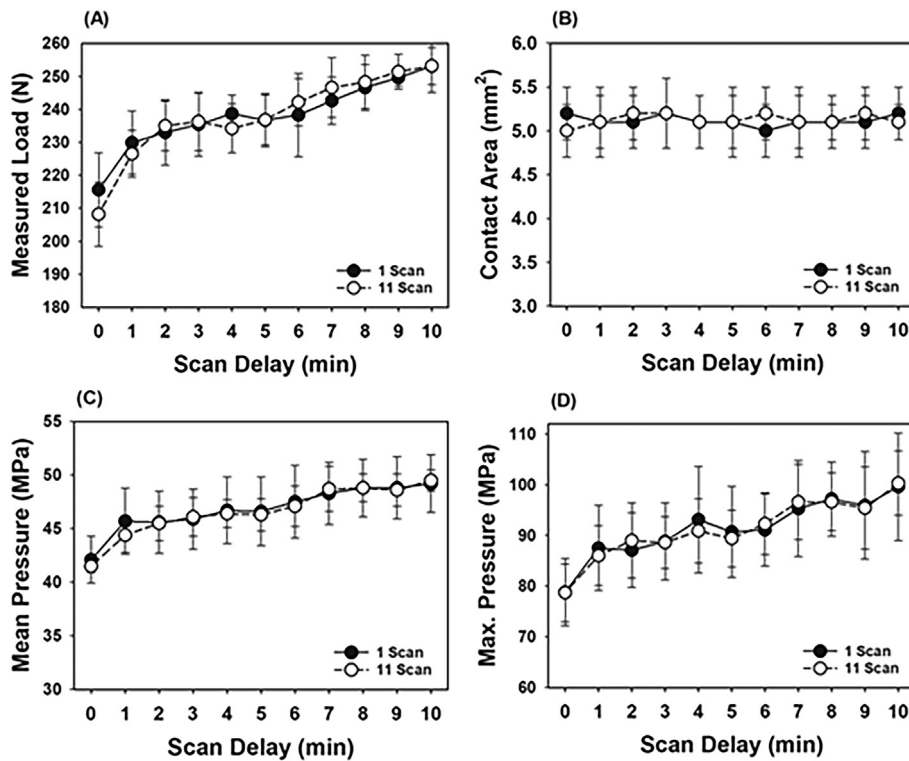


Figure 3 Measured load, contact area, mean pressure, and maximum pressure over different scan delay durations. Filled circles represent results from one scan in 1-scan experiment and open circles represent results from 11 scans in 11-scan experiment (vertical bar: sd).

Analyzer improves the quality of data analysis.⁷ The main DPS2-associated disadvantages in occlusal analysis include film thickness (150) which may cause overestimation of the occlusal contact area, and inability to register dynamic

Table 1 Summary of ANOVA results.

	Measured load	Contact area	Mean pressure	Maximum pressure
Scan delay	P < 0.001	P = 0.993	P < 0.001	P < 0.001
No. of scans	P = 0.192	P = 0.124	P = 0.202	P = 0.254
Scan delay x No. of scans	P = 0.678	P = 0.992	P = 0.994	P = 0.995

Parameters	Scan delay (min)	0	1	2	3	4	5	6	7	8	9	10
Measured load (N)			—	—	—	—	—	—	—	—	—	—
Mean pressure (MPa)			—	—	—	—	—	—	—	—	—	—
Maximum Pressure (MPa)			—	—	—	—	—	—	—	—	—	—

Figure 4 Summary of post-hoc test (Scheffé test) of measured load, mean pressure and maximum pressure over different scan delay durations. Scan delay durations connected with a line suggested a non-significant difference between the scan delay in the parameter.

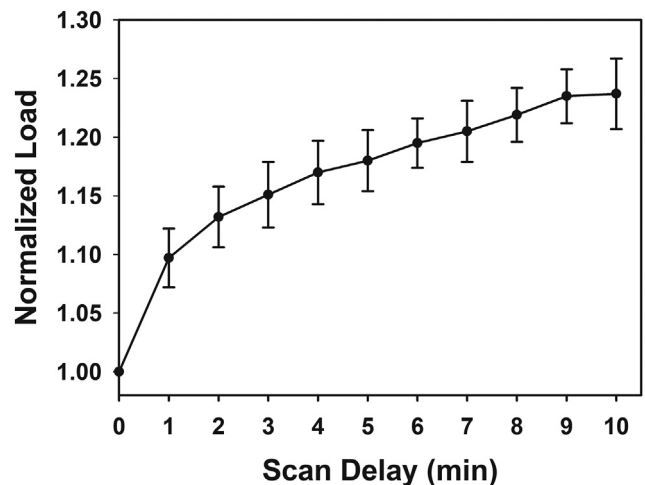


Figure 5 Normalized load over different scan durations in 11-scan experiment (vertical bar: sd).

contacts and mark the contacts directly on the teeth for adjustment. On the other hand, DPS and DPS2 can measure the total occlusal force and occlusal contact area close to the position between the teeth, and do not significantly increase the occlusal vertical dimension when measuring the occlusal force.¹⁵

Since 2016 when the Japanese Society of Gerodontology proposed the definition and diagnostic criteria for “oral hypofunction”,¹² DPS and DPS2 have been widely used in studies on testing and management of oral hypofunction for

occlusal force measurement.^{6–11} Although the initial dye released by microcapsules in the pressure-sensitive film may spread and alter both color intensity and resolution with time, the film manufacturer (GC, Tokyo, Japan) only recommends scanning “as soon as possible”. While the extent of impact of scan delay duration on measurements remains unclear, scan delay duration has rarely been reported in previous studies using DPS or DPS2. This study is the first in demonstrating the effect of scan delay duration on measurements and highlighting the importance of standardizing and documenting scan delay duration in related research. The present findings indicated that the loads measured would only be 70–84% of the load applied (300 N) during the period of 0- to 10-min scan delay.

The mean contact areas ranging from 5.08 mm² to 5.15 mm² were less than the size (12 mm²) of the stainless steel circle flat head. The discrepancy may be caused by the difficulty in achieving a perfectly flat surface on the contacts. Using a head with a profile more similar to occlusal shapes might be ideal for verifying the force profile. In addition to the load measured, the mean pressure and maximum pressure also increased with increase in scan delay duration.

In most studies, DPS or DPS2 films were usually scanned only once after a biting test. Through analyzing a load mark repeatedly scanned according to the designed scan delay, this study investigated whether measurements would be affected by repeated scanning and found no significant difference between one scan and eleven scans. In most DPS/DPS2 studies, occlusal force was observed; hence, the effects of scan delay on the measured load were investigated with normalized data. Normalized data can reduce the variation in load applied by an Instron machine and maximize the effect of scan delay. Results showed that the load had a rapid increase (13%) in the first 2 min, followed by a gradual increase from 2 min to 10 min (10%) and the change was only around 4% between 2 and 5 min. Taken together, the study results indicate that scan delay duration affects measurements. Thus, it is important to standardize and report scan delay duration for data comparison. In a clinical setting, precise time control in scan delay is hard. Nevertheless, the present results indicate insignificant variations in measurement due to scan delay of 2–5 min. If the scanner was not nearby, our preliminary in-vivo data suggest a 27% increase at 2-h scan delay compared with that at immediate scan.¹⁶ Since our results suggested that repeated scanning may not affect the DPS2 measurements, similar approach can be applied in future studies to clarify the effects of a longer scan delay in clinical situations.

In conclusion, in this in vitro study, scan delay was found to affect DPS2 measurements, and the load measured, mean pressure, and maximum pressure all increased with increase in scan delay duration from 0 to 10 min. In a clinical setting, scan delay duration varying between 2 and 5 min does not cause too much effect, but in research studies, scan delay should be standardized and reported. Whether the effect of scan delay persists with changes in amount of force merits further investigation and in vivo studies are also warranted.

Declaration of competing interest

The authors have no conflict of interest relevant to this article.

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