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RESEARCH ARTICLE

Effect of Handle Design on Fatigue Development and Resolution in Dental Hygienists: Clinical Implications

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Background: Musculoskeletal disorders (MSDs) affect most dental hygienists. While advances in design can reduce the biomechanical strain associated with instrumentation, the literature offers little guidance on rest-break parameters, or on how instrument design may modify those requirements. Goal was to map the effect of rigid vs adaptive handle design on fatigue development and resolution related to dental scaling.

Methods: This study featured a crossover design in which 20 dental hygienists completed two study arms, each consisting of four 2-minute scaling intervals separated by 30-second breaks, followed by 30 minutes of monitored rest. One study arm was completed using an adaptive silicone-over-steel curette, the other tested a rigid stainless-steel curette. The order of instrument use was randomized. Surface electromyography (sEMG) recorded muscle activity continuously in 4 muscles (abductor pollicis brevis, first dorsal interosseous, flexor pollicis longus, and extensor digitorum communis) through active intervals and rest periods. Linear mixed-effects models were used to test the primary sEMG outcome, with Bonferroni-corrected post-hoc comparisons. Recovery time was compared by Wilcoxon signed-rank test; Significance was set at $p<0.05$.

Results: Over the course of scaling, muscle activity increased significantly more with the rigid curette vs. the adaptive ($p<0.0001$; $\eta^2=0.46$). Each 30-second break achieved 24~28% recovery towards baseline levels of muscle activity with the rigid curette vs. 39~44% with the adaptive curette. By the end of the 30-minute monitored recovery period, muscle activity remained 13.9% above baseline for the rigid curette vs. 4.6% for the adaptive. The amount of time needed to recover to baseline levels of muscle activity was significantly quicker for the adaptive curette (155 seconds) vs. the rigid (295 seconds) ($p=0.0003$, $r=0.61$).

Conclusion: Thirty-second breaks are inadequate for full neuromuscular recovery even after only 2 minutes of scaling. As the typical prophylaxis appointment lasts 30~60 minutes, additional studies are needed to develop effective rest protocols to support neuromuscular recovery in healthy hygienists, and also in those with MSDs. An ergonomic adaptive handle design can reduce and support quicker recovery from muscle fatigue. Instrument selection is an important variable in maintaining a clinician's neuromuscular health and clinical performance.

Key Words: Dental hygienists, Electromyography, Equipment design, Ergonomics, Muscle fatigue

Introduction

Between 64% and 93% of dental hygienists are affected by musculoskeletal disorders (MSDs)[1-3]. Many biomechanical risk factors are inherent to periodontal instrumentation, including extended non-neutral wrist postures, rapid and repeated movements of the hands and fingers, strong and sustained working forces that can measure up to 24~36 N, and prolonged static muscle contractions in the small intrinsic muscles of the hand and forearm[4-7]. Unsurprisingly, these chronic stressors adversely affect clinicians, causing pain and functional limitations, the inability to work a full

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day, suboptimal clinical outcomes, and a shortened career span[1,2].

A growing body of research addresses the effects of variables such as handle diameter, weight, surface material, and shape on grip force and muscle activity during scaling[8-11]. Handle weight and diameter affect muscle load and pinch force[8], handle shape modulates grip force during scaling[9,10], and larger-diameter, lighter curette handles are associated with reduced pain[11]. Recent clinical studies using surface electromyography (sEMG) have demonstrated that an adaptive silicone-overlaid handle design, which allows the instrument to adapt to the shape of the hand, reduces total muscle activity by 38～51% and grip force by 24～36% compared to a rigid stainless-steel curette, with comparable deposit removal between instruments[12-14].

These previous studies do not report the trajectory of instrumentation-related fatigue and recovery over time. Yet understanding how and when fatigue develops, and how quickly and completely it resolves, is essential for establishing evidence-based rest-break guidelines. Current recommendations are based largely on convention, not physiological data, and do not account for fatigue that may accumulate across successive intervals if breaks are too brief. This matters clinically because incomplete recovery between exertions is thought to contribute to the cumulative microtrauma underlying many work-related MSDs. While there is little information on this topic in the dental literature, the biomechanics literature reports that hand and forearm muscle recovery following prolonged gripping can require considerable time[15,16], and that fatigue accumulates progressively across repeated exertion when rest breaks are insufficiently long[16]. If instrument handle design affects both the magnitude of fatigue and the speed of recovery, this represents an additional variable that must inform rest-break guidelines, ergonomic instrument design, and MSD-prevention strategies.

The goal of this study was to compare the development and resolution of neuromuscular fatigue during standardized typodont scaling with a rigid stainless-steel curette and an adaptive silicone-overlaid stainless-steel curette. The study design was based on the following hypotheses: (1) the size of the sEMG signal (amplitude at the start of successive scaling activities will rise progressively over time with both instruments if rest breaks are inadequate and (2) this progressive rise, and the post-session recovery time, will be significantly smaller with the adaptive curette than with the rigid curette.

Materials and Methods

1. Design and participants

This protocol qualified for University of California Irvine Institutional Review Board Exempt Self-Determination under Category 3 (December 10, 2019). Only de-identified, coded data were recorded during testing in typodont models.

Twenty participants were recruited by word of mouth and provided written informed consent prior to study commencement. Because of the novelty of this research, insufficient data were available to conduct a priori sample size calculations; a convenience sample was therefore used. Testers were paid a $40 incentive at study end. Inclusion criteria were as follows: female, right-handed, small-to-medium glove size, ≥5 years' clinical experience at ≥3 days/week, no upper-extremity MSD history within 6 months, and no lifetime MSD diagnosis. Exclusion criteria included: anti-inflammatory/analgesic use, diabetes or thyroid disease, pregnancy, or skin conditions precluding electrode placement.

2. Instruments

Two instruments with similar stainless-steel blades were sharpened by the same hygienist before each study arm. The Hu-Friedy Nevi® (Hu-Friedy, Chicago, IL, USA) features a rigid stainless-steel handle, whereas the ErgoFlex Elite® (Dentium Co. Ltd., Seoul, Korea) is fitted with a silicone-overlaid stainless-steel handle. The order of instrument use was randomized Research Randomizer (Randomizer.com).

3. Protocol

Standardized amounts of artificial calculus (Kilgore International, Coldwater, MI, USA) were applied to 12 anterior teeth mounted in typodont models (Acadental, Overland Park, KS, USA) 18 hours before testing[12,13]. During each of the 2 test arms, participants completed four

2-minute scaling intervals with one instrument (facial-owards, facial-away, lingual-towards, lingual-away), with the operator seated in 7～9 o'clock and 12 o'clock seated positions, respectively. Scaling intervals were separated by 30-second rest breaks, and each test arm (total 9.5 minutes) was followed by 30 minutes of recovery. Each tester performed the entire study in one day. Grip force was not standardized; participants were free to apply whatever force felt most natural to them, consistent with the study's goal of maximizing clinical applicability. This decision was deliberate and rests on three considerations. First, standardizing grip force during instrumentation would interferes substantially with clinicians' customary strokes and techniques, reducing ergonomic validity. Second, grip force is itself an ergonomic outcome of interest rather than a variable to be held constant; constraining it would compromise the very measurements the study was designed to capture. Third, allowing autonomous force regulation permits the muscle activity differences observed to reflect genuine handle-design effects under realistic conditions of use, rather than an artefact of an imposed protocol.

Participants could not be blinded to instrument given the distinct handles, but all data extraction and analysis was performed by a single blinded investigator. Recovery monitoring using sEMG continued throughout every rest and recovery period.

4. Measures

Surface EMG allows direct mapping of muscle activity during activities such as periodontal instrumentation. sEMG electrodes (FREEEMG; BTS Bioengineering, Quincy, MA, USA) were placed on the skin to record electrical activity from the abductor pollicis brevis, first dorsal interosseous, flexor pollicis longus, and extensor digitorum communis during and after instrumentation, as described in previous publications (Fig. 1)[12,13]. These four muscles were selected because they are primary intrinsic and extrinsic hand and forearm muscles recruited during the precision pinch grip and repetitive wrist/finger movements required for periodontal instrumentation. The electrodes transmitted signals wirelessly to a laptop. Electrode placement was guided by live muscle function tests, and a 15 seconds maximum voluntary isometric contraction was recorded for each muscle to serve as the 100% activity threshold against which all sEMG data were compared (normalized). The mean size of the sEMG signal from all 4 muscles at any specific timepoint (root mean square amplitude [RMS]) was used as primary outcome measure for muscle activity, as it provides a snapshot of the muscle activity expended in all 4 muscles at a specific timepoint.

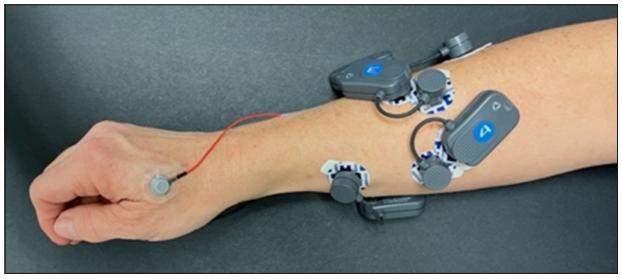

Fig. 1. Surface electromyography electrode placement on clinician's hand and arm.

5. Statistical analysis

Linear mixed-effects models (interval×instrument fixed effects, participant random effect) were used to test the primary sEMG outcome, with Bonferroni-corrected post-hoc comparisons. Recovery time was compared by Wilcoxon signed-rank test; Significance was set at $p < 0.05$.

Results

All 20 participants completed the protocol. Mean age was 33.9 years, ranging from 27.6～41.2 years. On average, the clinicians had 8.6 years (range 5.3～12.8) of experience in clinical practice.

1. Fatigue accumulation over time

For each curette, the mean level of muscle activity recorded by sEMG immediately before the first 2-minute scaling interval (Interval 0) was set at 100%. At the beginning of the first rest break, mean muscle activity had increased significantly to 108% of baseline for the rigid curette, rising further to 114% and 119% at the beginning of the second and third rest breaks, respectively (Table 1). Mean muscle activity increases at the beginning of each

Table 1. Mean Electrical Muscle Activity (sEMG Amplitude) at the Beginning of Each of the Four 2-Minute Scaling Intervals, Comparing the Rigid against the Adaptive Curette

Interval	Rigid (Nevi), % of baseline (SD)	Adaptive (ErgoFlex), % of baseline (SD)	p-value (rigid vs. adaptive)
0 (Before scaling begin)	100 (Normalization reference)	100 (Normalization reference)	-
1 (Begin 1st 30 s rest break)	108 (4.1)*	103 (2.8)	0.012
2 (Begin 2nd 30 s rest break)	114 (5.8)**	106 (3.9)	0.0008
3 (Begin 3rd 30 s rest break)	119 (7.2)***	108 (4.6)*	＜0.0001
Progression 0→	+19%	+8%	＜0.0001

Data normalized to 100% at interval 0.
SD: standard deviation, sEMG: surface electromyography.
*p＜0.05; **p＜0.01; ***p＜0.001 vs. interval 0, Bonferroni-corrected.

Table 2. Mean Muscle Activity at the Beginning of Each 30 Seconds Rest Break and after the 30 Minute Post-Arm Recovery

Timepoint	Increase in muscle activity above baseline at beginning of each rest period, % of baseline (SD)	Increase in muscle activity above baseline after each rest period, % of baseline (SD)
30 s Interval 1: Rigid	11.0 (4.2)	8.0 (3.0)
30 s Interval 1: Adaptive	5.2 (3.0)	3.0 (1.7)
30 s Interval 2: Rigid	19.2 (7.3)	14.0 (5.3)
30 s Interval 2: Adaptive	10.4 (6.0)	6.0 (3.5)
30 s Interval 3: Rigid	26.1 (9.9)	19.0 (7.2)
30 s Interval 3: Adaptive	13.8 (7.9)	8.0 (4.6)
30 min Post-arm: Rigid	19.0 (7.2)	13.9 (5.3)
30 min Post-arm: Adaptive	8.0 (4.6)	4.6 (2.7)

SD: standard deviation.

rest break were smaller with the adaptive curette, measuring 103%, 106%, and 108%, respectively (Table 1). A significant interaction between instrument type and interval number was found ($p < 0.0001$; $\eta^2=0.46$).

2. Fatigue recovery over time

During each 30-second rest break, mean muscle activity decreased by 24～28% from the level recorded during instrumentation with the rigid curette, compared with 39～44% with the adaptive curette (Table 2). The median time for muscle activity to return to within 95% of baseline after each study arm was 295 seconds for the rigid curette versus 155 seconds for the adaptive curette ($p=0.0003$, $r=0.61$). For both instruments, mean residual muscle activity following each 30-second rest interval remained above baseline levels recorded at study begin (Table 2, Fig. 2).

Discussion

The findings from this study demonstrate that, in healthy dental hygienists, a 30-second rest break is too short to permit full recovery from the neuromuscular fatigue induced by two minutes of scaling, regardless of instrument design. With both curettes, the level of muscle activity following each 30-second rest break remained well above the baseline level measured at study onset, indicating that this rest interval was insufficient to permit a full return to resting levels. Muscle activity entering and leaving each break increased progressively across successive intervals for both instruments, confirming that the muscles had not fully relaxed and recovered during the preceding rest period; this progressive rise was significantly smaller with the adaptive curette than with the rigid instrument. Table 2 explains the mechanism underlying this progressive increase. For the rigid curette, a 30-second break cleared only one quarter of the accumulated muscle activity, leaving the muscles no opportunity to relax and recover

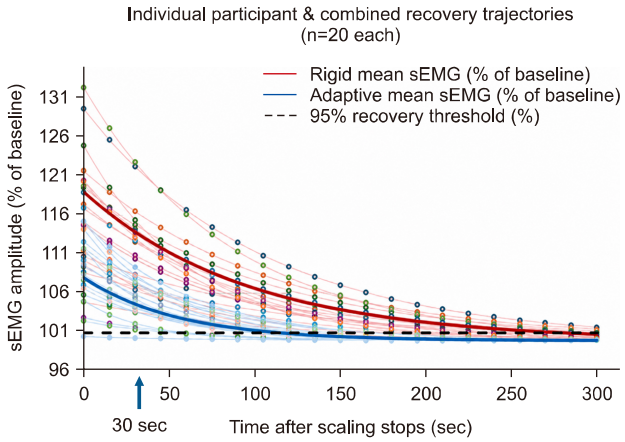

Fig. 2. Individual participant and combined recovery trajectories following instrumentation. Mean surface electromyography (sEMG) amplitude (normalized to pre-scaling baseline=100%) is plotted against time after scaling stops for all 20 participants in each instrument arm. Thin dotted lines with open circles represent individual participant trajectories; bold lines represent the group mean recovery curve for the rigid curette (red) and the adaptive curette (blue). The dashed horizontal line marks the 95% recovery threshold. The arrow at 30 seconds indicates the duration of the standard inter-interval rest break used during the scaling protocol.

fully between successive 2-minute scaling tasks; each subsequent task therefore began from a less-rested baseline than the last. The adaptive curette's greater recovery during each break occurred from an already significantly lower level of scaling-related muscle activity, meaning its advantage was twofold: reduced muscle activity during instrumentation, and a shorter recovery period required afterward. These two advantages compounded to the clinician's benefit and explain the nearly 50% faster recovery time observed for the adaptive curette compared with the rigid instrument.

Both study arms were completed by each participant on the same day, separated by the 30-minute monitored recovery period following the first arm. This was a deliberate design choice, not a limitation of convenience: it approximates the back-to-back patient scheduling typical of clinical practice and addressed directly the question whether fatigue accumulates across sequential instrumentation sessions rather than fully resolving between them-a phenomenon that a longer washout might have obscured. Instrument order was randomized to distribute sequence effects evenly, but carryover from the first arm influencing results in the second cannot be excluded, particularly since muscle activity had not returned fully to baseline even after 30 minutes. This study was designed as an initial exploration of the implications of inadequate rest between sequential patients, and future work should more rigorously differentiate within-session fatigue from between-session carryover, for example, via a dedicated instrument×order analysis, standardized washout periods, or separate-day testing.

The observed pattern of progressive fatigue accumulating across repeated scaling bouts despite intervening rest is consistent with findings in other intermittent-exertion studies. Eksioglu's work on intermittent handgrip tasks found that muscle activity could require minutes or even hours to return to baseline after exertion, depending on the nature and severity of the task[15]. Other researchers similarly reported cumulative effects of fatigue across a work session, underscoring that rest breaks calibrated to a single exertion event do not necessarily protect against fatigue accumulation over multiple bouts of activity of the kind observed in periodontal instrumentation[16]. This is consistent with other intermittent-exertion work showing that structured micro-breaks can meaningfully reduce cumulative upper-extremity strain[17], and that recovery from localized muscle fatigue is more strongly influenced by the presence and timing of rest within a work cycle than by mean workload alone[18]. Our study data for the first time extend this principle to dental treatment, albeit to a simplified and abbreviated model of clinical scaling. We see this model as a successful first step in developing a representative model for the start-stop rhythm of routine scaling and the body's neuromuscular response to it, with the long-term goal of developing knowledge-based guidelines for instrumentation routines and ergonomic instrument design.

The recovery times reported here are longer than those described for other muscle groups using comparable techniques[19]. The substantially slower recovery of the small intrinsic hand and forearm muscles observed in the present study may reflect differences in fiber-type composition, vascular supply, and the sustained, forceful, high-precision contraction pattern characteristic of periodontal instrumentation, as opposed to the brief, axial contractions used in other fatigue models. This distinction reinforces

the need for studies that generate data specific to the hand and forearm musculature, rather than attempting to transfer rest-break guidelines from other anatomical regions.

Our findings build directly on previous studies, which established that an adaptive silicone-overlaid handle reduces total muscle activity and grip force relative to a rigid stainless-steel curette without compromising deposit removal[12-14]. The present data add information on what happens over time: handle design does not only affect the magnitude of fatigue generated during instrumentation, but also the timeline of post-instrumentation recovery during rest. The sEMG data recorded in this study (RMS) measured the size of the muscle activity on an ongoing basis throughout instrumentation and rest, whereas total muscle activity over the full instrumentation period (area-under-the-curve [AUC]) was measured in previous studies[12,13]. The two measures are complementary: AUC addresses whether a given interval of scaling itself becomes progressively more effortful, while the interval-tart RMS techniques used in this study address whether the intervening rest period was sufficient to restore baseline function. Future study designs should include both measures to capture workload and recovery completeness.

The clinical relevance of these findings is underscored by the substantial gap between the experimental protocol and routine clinical practice. The active scaling time studied here (9.5 minutes per arm) is brief compared to a typical prophylaxis appointment, which generally spans 30～60 minutes and often includes 20 minutes or more of continuous hand instrumentation. If healthy clinicians cannot achieve full neuromuscular recovery from each scaling task, the cumulative, multi-hour fatigue exposure of a full clinical day is likely to be considerably greater than current ergonomic guidance assumes. Clinicians who have already developed MSDs may exhibit further impaired or delayed recovery.

Several limitations should be acknowledged. The study population was restricted to healthy, right-handed female hygienists with no recent history of upper-extremity MSDs, so the recovery pathways observed here may not generalize to clinicians with pre-existing musculoskeletal pathology. Moreover, sex-based differences in musculoskeletal anatomy can affect hand size and grip strength. The typodont-based protocol, while standardized and reproducible, does not capture the postural variability, psychological stress, and procedural complexity of live clinical practice. Considerable inter-individual variability in the recovery trajectory was also observed, suggesting that a single fixed rest-break duration is unlikely to be optimal for all clinicians, and that individualized or adaptive rest-break protocols may warrant investigation. Future research should extend this model to live clinical settings, evaluate muscle-specific recovery patterns, and test individualized or adaptive rest-break protocols across clinicians with varying MSD histories, hand sizes, and years of practice.

In conclusion, the findings of this study indicate that handle design is not solely a determinant of how much fatigue is generated during instrumentation, but also of how quickly that fatigue resolves–two separate but cumulative contributions to a clinician's entire neuromuscular load across a working day. Thus, rest-break guidelines for periodontal instrumentation should be developed from muscle-specific recovery kinetics that include instrument selection as a modifiable variable within that framework.

Notes

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Ethical approval

This study was granted exempt status review by the University of California Irvine Institutional Review Board.

Author contributions

Conceptualization: Petra Wilder-Smith, Cherie Yvette Wink, Kairong Lin, Susan Meishan Yang, and Benjamin Emerson Dolan. Data acquisition: Petra Wilder-Smith, Cherie Yvette Wink, Winston Kimball Doud, Jae Kyung Shim, Beatricia Wu Lam, Susan Meishan Yang, and Kairong Lin. Formal analysis: Petra Wilder-Smith, Winston Kimball Doud, and Kairong Lin. Funding: Petra Wilder-Smith. Supervision: Petra Wilder-Smith and Cherie

Yvette Wink. Writing-original draft: Petra Wilder-Smith and Winston Kimball Doud. Writing-review & editing: Petra Wilder-Smith and Winston Kimball Doud.

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Data availability

Raw data is provided at the request of the corresponding author for reasonable reason.

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