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Effect of Handle Design and Material on the Ergonomic Performance of a Dental Sickle Scaler

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Abstract

Background: Because musculoskeletal disorders (MSDs) are common among dental clinicians, there exists an urgent need to re-visit the design of dental hand instruments, which are considered a primary cause for work-related disabilities.

Objective: To evaluate in 11 hygienists, the effect of 4 different dental scaler handles on muscle work and fatigue related to a standardized scaling task using an SH 6/7 scaler.

Results: Overall, a silicone adaptive handle that conforms to the shape of the individual user's hand demonstrated the most favorable ergonomic performance.

Conclusion: An adaptive silicone handle can significantly reduce muscle work and fatigue during scaling procedures.

Keywords

Dental Sickle Scaler; Musculoskeletal disorders; Handle Design

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Introduction

Musculoskeletal disorders (MSDs) are considered to be one of the most prevalent occupational hazards for workers, only second to issues with the respiratory system [1]. MSDs can be attributed, in some cases, to trauma [2, 3]. However, the most common cause is repetitive activity, affecting muscles and surrounding structures, nerve endings, and vascular terminals [4]. The ultimate results include loss of functionality, pain, discomfort, lack of sensation, disability, and even external wounds [4].

The medical and dental fields are not exempt from MSDs [5]. Professionals such as general and reconstructive surgeons have a high incidence of occupational complications stemming from poor ergonomics and high workloads [6]. In dental offices, the intensity of work and the need for precision can lead to musculoskeletal injuries and extensive functional, social and financial burdens [7]. Dental hygienists are especially at risk for occupational injuries for several reasons: the need to adopt unergonomic postures to achieve adequate operative access, the daily use of repetitive small and precise motions requiring considerable force, and vibration from motor-driven tools [8]. In recognition of the musculoskeletal injuries experienced on a daily basis by hygienists, dental instrument design and materials are undergoing considerable re-evaluation to address the growing numbers of dental hygiene professionals who develop MSDs, especially carpal tunnel syndrome [9]. Variables under review include instrument diameter, texture, weight, and even temperature of the handle. [10] Surface electromyography (sEMG) techniques are being used to evaluate muscle work expended in different muscle groups during instrumentation with different handle designs and materials [2,14]. Other studies have characterized body ergonomics [2, 15,16], as well as grip and grasp strengths [10,18]. related to the use of different instrument designs and materials.

Additional research is urgently needed to identify and validate specific ergonomic instrumentation features that will improve the longevity of dental hygiene practitioners' careers and reduce instrumentation-related pain, disabilities, poor work satisfaction and diminished quality of life from MSDs. The purpose of this study was to compare instrumentation-related muscle work and fatigue related to the use of 4 dental hand scalers with different handle designs and materials.

Materials and Methods

This study was reviewed and granted exempt status, as only de-identified, coded data were recorded during testing in typodont models.

Testers

Eleven first- and second-year dental hygiene students at Concorde Career College, Garden Grove were randomly selected out of a group of volunteers to participate in this study. Individuals with pre-existing conditions or symptoms within the last six months that might involve musculoskeletal injuries of the arms, fingers, wrists were excluded. All testers selected were right-handed for purposes of standardization. The aim in selecting dental hygiene students for this study was to eliminate the possible disparity in experience, routine, and neuromuscular accommodation between the rigid and adaptive test instruments, which might occur with more seasoned clinicians.

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Protocol

In order to standardize the testing process as much as possible, each student utilized the same model of typodont (Kilgore 500HPRO, Kilgore International Inc., Coldwater, MI, USA), which was mounted to a dental unit. The tester and simulator were positioned in accordance with standard positioning guidelines, with the clinician adopting an ergonomic position sitting straight up, with the neck straight, the forearms parallel to the floor and knees at a slightly downward slope. Testers were instructed to change their own and the mannequin's positions as needed in between each of the 1-minute instrumentation tasks, and to avoid re-positioning the typodont during the duration of the timed scaling task.

The four instruments included in this study were all fitted with SH 6/7 stainless steel blades (no sharpen-free technology used). The order of instrument use was randomized using the Research Randomizer software https://www.randomizer.org/. The instruments' brand name was concealed with tape and labeled as follows: 1- stainless steel rigid; 2- resin rigid; 3- silicone rigid; 4- silicone adaptive. Nevertheless, testers could not be blinded effectively with regard to instrument identity because of the very different appearance and functionality of the curettes.

One designated clinician sharpened all the instruments between each use to ensure equal sharpness of the cutting edges during each study arm. Participants were instructed to scale each of the designated areas for 1 minute utilizing a light calculus removal stroke. The facial aspects, surfaces towards, of teeth #22-27 were scaled using the SH 6/7 sickles. Testers were given a 3- minute rest period between each testing arm. SEMG readings confirmed a return to baseline muscle activity before the begin of each new study arm.

Instruments

Four SH 6/7 sickles were evaluated, all with stainless/ no sharpen-free blades (Figure 1): Instrument A: conventional rigid stainless steel (Sterling®, Menlo Park, Gauteng, South Africa); Instrument B: conventional rigid resin (Paradise Dental Technologies, Missoula, MT, USA); Instrument C: rigid conventional rigid silicone (Iris 4696-500 0619, Benco Dental, Pittston, PA, USA); Instrument D: flexible silicone instrument (ErgoFlex®, DoWell Dental Products, Rancho Cucamonga, CA, USA) with universally adjustable, adaptive core that allows the instrument to adapt to the curvature of the hand and fingers.

Data collected included: (a) VAS questionnaires on a scale of 0 (best)-10 (worst) to evaluate instrumentation-related tester fatigue in thumb, fingers, palm and wrist; (b) sEMG traces to measure muscle work expended during instrumentation.

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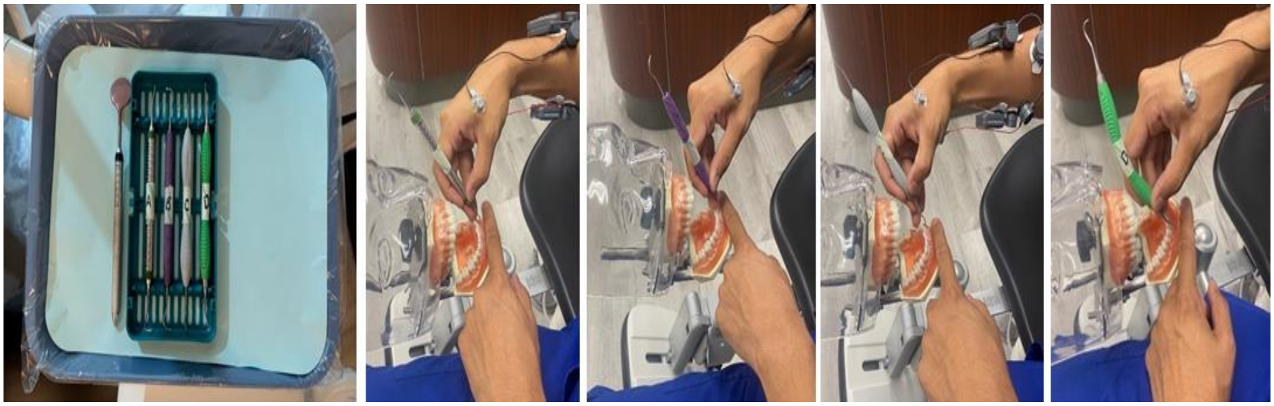

Figure 1: Four different types of scaler handles were tested in this study.

VAS Surveys and Open-Ended Comments

Standard physical visual analogue scale (VAS) surveys were used, as the information collected was of a subjective nature. The scores ranged from 1-10, and inputs were collected immediately after each instrumentation arm. Open-ended comments were also collected.

Surface Electromyography (sEMG)

Customized surface EMG (sEMG) electrodes (FREEEMG, ©BTS Engineering, Quincy, MA,USA) recorded real-time, continuous action potential signals from 4 muscles that are specifically used for gripping and manipulating dental instruments [10]: Abductor Pollicis Brevis (APB), First Dorsal Interosseous (FDI), Flexor Pollicis Longus (FPL), and Extensor Digitorum Communis (EDC). These data were transmitted wirelessly to a Dell laptop via a USB-port dongle that connected with a proprietary FREEEMG software (BTS Engineering, Quincy, MA, USA) installed on a dedicated password-protected laptop computer.

Action potential data reflecting muscle activity were collected throughout instrumentation using standard techniques. First, live muscle function tests were performed to guide and fine-tune the placement of each electrode to an optimal position on each muscle (Figure 2) [19,10] Next, a commonly used approach that permits subsequent normalization of test data was implemented by asking the testers to perform 15 s of maximum voluntary isometric contractions (MVC) for each muscle [19,20]. This trace was then considered 100% activity for that muscle. Next, testers completed the prescribed scaling regimen. SEMG signals from all 4 muscles were recorded throughout instrumentation. For purposes of data extraction, the traces were rectified and filtered according to standard techniques by means of a second-order Butterworth filter while implementing a 10 Hz high-pass cutoff frequency. From the resultant integrated action potential graph, total workload was determined by calculating the area under the curve. All data evaluation was performed by a blinded pre-standardized investigator.

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Figure 2: Placement and positioning of sEMG electrodes.

Statistical Analysis

Standard SPSS 19 statistics software (IBM®, Armonk, NY, USA) utilizing a General Linear Model (GLIM) with pairwise tests for differences between instruments was used to perform statistical analysis. A Tukey's post hoc test was also performed. Statistical significance was set at $p < 0.05$.

RESULT

All eleven testers completed the study in full compliance with the protocol. Their ages ranged from 24-40 years, with a mean age of 29 years. Five were male and 6 female, and they were all right-handed.

Fatigue

Figure 3 shows a comparison of the mean instrumentation-related fatigue for the 4 instrument designs that were tested. While a trend towards less fatigue was observed during use of both silicone scalers vs. the stainless steel and resin instruments, and the adaptive silicone scaler outperformed the rigid silicone instrument, statistical significance was only reached for the adaptive silicone vs. all instruments in the fingers, and the adaptive silicone vs. the rigid resin instrument in the thumb (Table 1).

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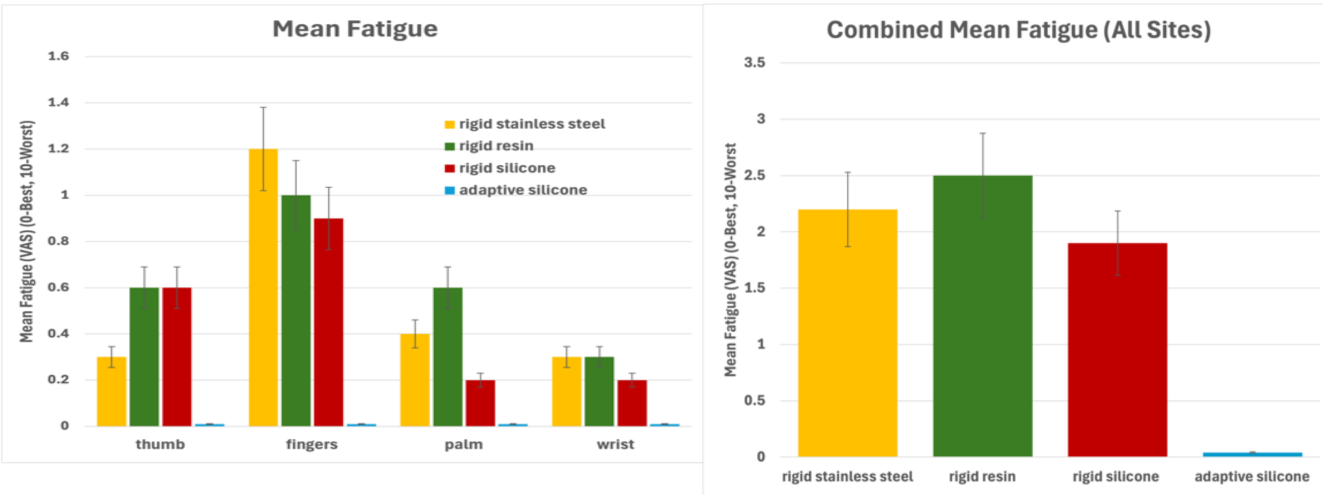

Figure 3: Mean fatigue after using each test instrument during completion of the standardized scaling task. LHS: mean VAS score at 4 anatomical sites; RHS: combined mean VAS score forall anatomical sites.

Site: Thumb	Mean Diff.	SE of diff.	95.00% CI of diff.	Adjusted P Value
Adaptive silicone vs. rigid stainless steel	-0.3	0.1528	-0.7295 to 0.1295	0.1854
Adaptive silicone vs. rigid resin	-1.1	0.2769	-1.879 to -0.3215	**0.0084**
Adaptive silicone vs. rigid silicone	-0.5	0.2236	-1.129 to 0.1287	0.1229
Site: Fingers	**Mean Diff.**	**SE of diff.**	**95.00% CI of diff.**	**Adjusted P Value**
Adaptive silicone vs. rigid stainless steel	-1	0.3333	-1.937 to -0.06276	**0.0372**
Adaptive silicone vs. rigid resin	-0.9	0.2769	-1.679 to -0.1215	**0.0251**
Adaptive silicone vs. rigid silicone	-0.9	0.4069	-2.044 to 0.2440	**0.0128**
Site: Palm	**Mean Diff.**	**SE of diff.**	**95.00% CI of diff.**	**Adjusted P Value**
Adaptive silicone vs. rigid stainless steel	-0.3	0.1528	-0.7295 to 0.1295	0.1854
Adaptive silicone vs. rigid resin	-0.6	0.2667	-1.350 to 0.1498	0.1202
Adaptive silicone vs. rigid silicone	-0.1	0.1	-0.3812 to 0.1812	0.6418
Site: Wrist	**Mean Diff.**	**SE of diff.**	**95.00% CI of diff.**	**Adjusted P Value**
Adaptive silicone vs. rigid stainless steel	-0.5	0.2236	-1.129 to 0.1287	0.1229
Adaptive silicone vs. rigid resin	-0.4	0.2211	-1.022 to 0.2217	0.2327
Adaptive silicone vs. rigid silicone	-0.3	0.2134	-0.9001 to 0.3001	0.4037

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Table 1: Statistical analysis of the data confirms significantly less fatigue in the fingers after using the adaptive silicone instrument vs. all rigid instruments, and in the thumb after using the adaptive silicone instrument vs. the rigid resin instrument.

Muscle Work

The mean muscle work used to complete the standardized scaling task varied considerably between the 4 test instruments, as shown in Figure 4. Scaling with the adaptive silicone curette required significantly less muscle work (p<0.0001) than any of the 3 rigid instruments (Table 2).

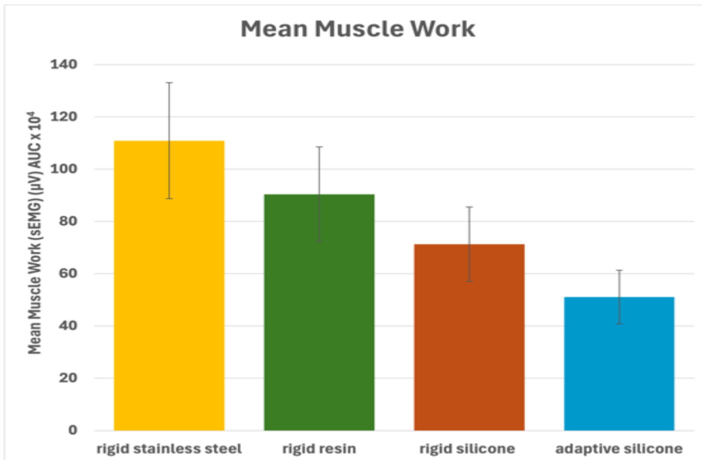

Figure 4: Mean muscle work expended using each test instrument during completion of the standardized scaling task.

	Mean Diff.	**SE of diff.**	**95.00% CI of diff.**	**Adjusted P Value**
Adaptive silicone vs. rigid stainless steel	-59.8	5.2	-74.42 to -45.18	**<0.0001**
Adaptive silicone vs. rigid resin	-39.3	4.036	-50.65 to -27.95	**<0.0001**
Adaptive silicone vs. rigid silicone	-20.2	2.611	-27.54 to -12.86	**<0.0001**

Table 2: Statistical analysis of the data confirms with a high degree of significance that less muscle work was required to complete the standard scaling task using the adaptive silicone scaler vs. the 3 rigid scalers.

Tester Comments

Overall, testers responded favorably to all test instruments. Comments are listed in Table 3.

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Rigid stainless steel	Familiar with this instrument	Current use for student issue		
Rigid Resin	Love how light it is	Would prefer softer grip		
Rigid silicone	Interesting design	Like the soft feel		
Adaptive silicone	Feels much lighter	Don’t have to grip as hard	More secure in my hand	More comfortable

Table 3: Free comments from testers participating in this study

Discussion

MSDs pose a significant challenge for dental professionals such as hygienists, whose daily tasks involve forceful repetitive motions and sustained postures that strain the musculoskeletal system. Therefore, a concerted effort is under way to identify design features and materials to address the causes of MSDs in these clinicians. The goal of this study was to assess the impact of different instrument handle designs and materials on clinician fatigue and muscle work related to a specific scaling task. Both variables are directly linked to MSDs.

While previous studies evaluating ergonomic performance of dental hand instruments have typically used longer protocols for each study arm, in order to ensure some degree of conformity with clinical practice, a very short instrumentation duration of only 1 minute per tooth surface and instrument type was implemented in this study. The impetus behind this decision was to provide a comparison of the sensitivity of a 1-10 VAS scale vs. sEMG for evaluating work and its related fatigue. Unsurprisingly, the sEMG data were considerably more sensitive to overall fatigue/work than the VAS scales, however the VAS scales were able to provide more differentiated information on effects at specific locations such as fingers, thumb, palm etc.

Therefore, both methods of data collection should ideally be used when evaluating the ergonomic performance of hand tools. These findings are in agreement with those published by other authors [21-23]. In this study the adaptive silicone handle design (Instrument D) was associated with the lowest reported levels of fatigue and muscle work, as measured by VAS and sEMG. These findings align with the results of several previous studies which indicated that more ergonomic, non-rigid silicone instrument handles which conform to the user’s hand shape and provide a softer, warmer contact surface, can reduce instrumentation-induced muscle work and fatigue while providing greater comfort and avoiding loss of pinch and grip force [11,12,24-29]. Researchers in these previous studies hypothesized that the adaptive handle, which adjusts to the curvature of the clinician's fingers and hand, may distribute instrumentation pressure and instrument weight more evenly and over a larger surface area of the fingers and the hand, reducing loading per unit of area. This is consistent with research showing that instruments designed with a focus on user adaptability - such as flexible cores or ergonomic grips - can decrease the incidence of MSDs in dental professionals [24-29].

Notable differences were observed between the different handle designs tested. While both the rigid silicone and adaptive silicone handles (Instruments B and D) showed promising results, the non-adaptive stainless steel and resin handles (Instruments A and B) were linked to higher levels of muscle activity.

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This suggests that a rigid or non-adaptive handle design increases muscle workload, contributing to fatigue and discomfort. These findings support earlier research reports suggesting that the use of more pliable or flexible materials may reduce stress on the hands and wrists [14, 24-29].

The findings from this study have direct implications for practicing hygienists and for developers of novel dental instrumentation. Adaptive handles could potentially serve as a preventive measure against the development of MSDs by reducing muscle work, fatigue and strain. By adopting ergonomic instruments, especially those with flexible or conforming handles, dental practices could mitigate the risk of long-term musculoskeletal damage in clinicians. Moreover, the results underline the importance of ongoing ergonomic education and tool design improvements in dental education. Training programs should emphasize the importance of ergonomically sound instrument use and posture, alongside the adoption of better-designed instruments. Dental schools could consider integrating the use of ergonomic instruments into their curriculum to help students build good ergonomic practices early in their careers.

While the findings are promising, this study has several limitations that should be addressed in future research. The relatively small sample size (n=11), study duration and the lack of long-term follow-up to evaluate the sustained impact of ergonomic instruments on MSDs are noteworthy.

Additionally, the sample population consisted only of dental hygiene students, which may limit the generalizability of the results to experienced professionals who may have developed their own ergonomic strategies over time. The findings from this study have direct implications for practicing hygienists and for developers of novel dental instrumentation. Adaptive handles could potentially serve as a preventive measure against the development of MSDs by reducing muscle work, fatigue and strain. By adopting ergonomic instruments, especially those with flexible or conforming handles, dental practices could mitigate the risk of long-term musculoskeletal damage in clinicians. Moreover, the results underline the importance of ongoing ergonomic education and tool design improvements in dental education. Training programs should emphasize the importance of ergonomically sound instrument use and posture, alongside the adoption of better-designed instruments. Dental schools could consider integrating the use of ergonomic instruments into their curriculum to help testers build good ergonomic practices early in their careers. The sustained impacts of ergonomic instruments on MSDs are noteworthy.

Conclusion

The results of this study indicate that adaptive silicone handles can significantly reduce muscle work and fatigue during scaling procedures while ensuring excellent tactile feedback. As the dental profession continues to confront the challenges of work-related MSDs, innovative instrument designs like those tested here hold considerable promise in enhancing clinician comfort and reducing the risk of injury. Ongoing research into instrument ergonomics, alongside education on proper posture and technique, is crucial for improving the health and well-being of dental professionals.

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