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RESEARCH ARTICLE

Influence of Instrument Handle Design on Ergonomic Strain and Clinical Performance in Clinicians with and without Carpal Tunnel Syndrome

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ABSTRACT

Background: Musculoskeletal disorders (MSDs) are among the leading causes of disability worldwide, and carpal tunnel syndrome (CTS) is one of the most prevalent conditions in professionals who perform repetitive, high-precision tasks with handheld tools. While adaptive instrument handle designs can reduce ergonomic strain, their specific effects in individuals with CTS vs. their healthy counterparts have not been evaluated.

Aims: To employ periodontal hand instrumentation by dental hygienists as a clinical model to investigate the effects of a novel adaptive hand instrument design on ergonomic outcomes in clinicians with and without carpal tunnel syndrome, with the objective of advancing strategies for the prevention and mitigation of repetitive strain injuries.

Methods: Forty-eight clinicians (24 healthy, 24 with physician-diagnosed CTS) each performed a separate, standardized instrumentation task using two curettes: one a rigid silicone tool and the other an adaptive silicone over stainless steel instrument. Surface electromyography mapped muscle activity in hand and forearm muscles, while ultrathin force sensors measured thumb and forefinger grip force. Visual analogue scales recorded discomfort and fatigue, grasp correctness was scored by means of a 7-point scale, and task completion was quantified using ImageJ software. All data was analyzed using a two-way mixed ANOVA followed by Bonferroni's multiple comparisons testing ($p<0.05$).

Results: Clinicians with CTS experienced more than twice the levels of discomfort (204%), fatigue (212%), and muscle workload (208%) compared with healthy clinicians ($p < 0.0001$). They also applied an approximately one-third greater grip force during instrumentation ($p < 0.0001$). The adaptive handle design significantly improved all outcomes related to strain in both experimental groups ($p<0.0001$). It significantly reduced muscle work by approximately 38% in clinicians with CTS and by 51% in healthy clinicians ($p<0.0001$). A similar but smaller trend was observed for grasp correctness ($p=0.045$). Deposit removal did not significantly differ between groups or instruments, averaging >93% task completion.

Conclusion: Individuals with CTS exhibited altered instrumentation biomechanics, including increased muscle work, grip force, discomfort, and fatigue, despite comparable task performance to healthy controls. An adaptive handle design significantly improved ergonomic outcomes in both groups, underscoring its potential to reduce musculoskeletal disorder risk and reduce strain in professions requiring repetitive, high-precision hand movements.

Introduction

According to Global Burden of Disease estimates, musculoskeletal disorders (MSDs) are among the leading causes of disability worldwide and affect approximately 1.71 billion individuals globally.[1] These disorders can result in years lived with disability and they impose significant health and economic burdens.[2] Upper extremity MSDs are particularly relevant to clinicians who perform repetitive, high-precision tasks requiring sustained grip and fine motor control.[3]

MSDs are injuries or disorders affecting muscles, tendons, nerves, joints, cartilage, and spinal discs that arise from chronic strain and cumulative trauma resulting from tasks requiring forceful, repetitive motions combined with sustained, awkward postures.[4,5] These disorders encompass a wide range of upper extremity conditions affecting both soft and hard tissues including carpal tunnel syndrome (CTS), one of the most prevalent musculoskeletal conditions in clinicians.[5]

CTS occurs when increased force within the carpal tunnel compresses the median nerve at the wrist. Clinicians, including dentists and surgeons, experience elevated risk of CTS due to sustained static, awkward positions that require precise tool handling.[6,7] Repetitive instrumentation demands continuous thumb-index finger pinch grip to achieve clinical goals and stabilize instruments during use, generating musculoskeletal overloading across the small intrinsic hand muscles and flexor tendons.[8] Such chronic exposures can produce disability, pain, and fatigue.[5]

Recent studies in individuals with CTS have examined the relationship between underlying musculoskeletal pathology and instrumentation biomechanics. For example, dental hygienists with physician-diagnosed CTS required significantly greater muscle work and evidenced altered grip force mechanics during instrumentation in comparison to healthy clinicians.[5] Surface electromyographic (sEMG) mapping in individuals with CTS revealed 1.4-1.6 times greater muscle activity in these clinicians, along with an elevated thumb:forefinger grip force ratio of 3.4:1 compared to 3:1 in healthy clinicians.[5]

Optimizing instrument handle designs may be key to reducing biomechanical load during tasks that require repetitive force and precision. Factors such as handle diameter, surface materials, weight, balance, shape and texture can influence grip force, muscle strain, and user comfort.[8] Softer, thermally insulating silicone handles reduce vibrations and provide thermal comfort, which is ergonomically favorable. However, they also dampen tactile feedback, which is essential to avoiding over-instrumentation and unnecessary exertion by the clinician or operator.[5] On the other hand, one of the primary benefits of rigid stainless-steel designs is that they provide better tactile feedback, but at the cost of increased muscle strain, discomfort and fatigue.[5]

To address these limitations, recent studies have tested adaptive handle designs which conform more closely to the anatomy of the hand. The adaptive design increases the contact area between the hand and the instrument by allowing the instrument to conform to the curvature of the hand and fingers. Moreover, it redistributes loading of the small muscles of the distal fingers by the instrument's weight and instrumentation to larger muscles and surfaces.[8]

Despite these early findings, important questions remain with regard to causation, prevention and mitigation of MSDs. We regard our work on hand instrumentation and CTS as a first step in gaining a better understanding of the pathways that contribute to the development of MSDs - not only in dental hygiene, but also in fields such as sewing, gardening, hand tools, office desk jobs, and other occupations that require repetitive hand motion.[3,9]

The goal of this study was to evaluate the effects of two periodontal curette handle designs - a rigid silicone handle and an adaptive silicone-overlaid stainless-steel handle - on ergonomic outcomes such as discomfort, fatigue, muscle work, grip force and force distribution between the thumb and forefinger, as well as grasp correctness and deposit removal. By comparing these outcomes in clinicians with and without CTS, we seek to develop a foundation for understanding which elements of hand instrument design are most relevant to improving ergonomic performance and thus may be most impactful for repetitive stress injury prevention and mitigation in healthy clinicians and those with CTS.

Study Population & Methodology

STUDY DESIGN

In this in vivo study, the ergonomic performance of a curette with a rigid silicone handle was compared with that of a curette featuring an adaptive, silicone-overlaid stainless-steel handle. Discomfort, fatigue, muscle work, grip force, thumb: forefinger grip force ratio, clinician's grasp, and completeness of deposit removal were evaluated in dental hygienists with and without CTS.

This study was performed as a self-regulated exempt study in accordance with the criteria of the University of California Irvine Institutional Review Board. Only de-identified, coded data were recorded during testing in typodont models.

CLINICIANS

Forty-eight hygienists who met study inclusion/ exclusion criteria participated in this study. They were recruited by word of mouth and received a $25 incentive after study completion. Testers were all right-handed. Female dental hygienists with small to medium clinical glove sizes and a minimum of five years of clinical experience practicing at least three days/week participated in this study. 24 participants who had no history of injuries, symptoms, or diagnoses of upper extremity MSDs within the six months prior to the study comprised the healthy group (Group 1). 24 participants with physician-diagnosed active CTS since at least one year who had not undergone surgical intervention comprised the CTS group (Group 2). Full demographics are shown in **Table 2**.

INSTRUMENTS TESTED

Two curettes were compared:

- **Curette A:** rigid silicone handle (LM ErgoSense®, LM-Dental, Parainen, Finland)
- **Curette B:** adaptive silicone-over-stainless-steel handle (ErgoFlex Elite®, DoWell Dental Products, Rancho Cucamonga, USA)

Both curettes featured stainless-steel blades, and all instruments were freshly sharpened by the same researcher prior to each test to ensure consistent conditions. All participants were shown a one minute instructional video on instrumentation with the adaptive curettes, followed by a five minute period to familiarize themselves with the instruments before testing began.

Instrument properties are summarized in **(Table 1).**

Table 1: Properties of the two test instruments used in this study.

Instrument	Trade name	Handle material	Handle length	Handle diameter (pen grip)	Weight
Curette A	LM ErgoSense	Silicone	108.8 mm	13.4 mm	17.7 g
Curette B	ErgoFlex Elite	Silicone-overlaid stainless steel	110.6 mm	11.5 mm	19.4 g

TESTING PROCEDURE

All hygienists tested both instruments in a randomized order. Individual instrument sequences were randomized using Research Randomizer (https://www.randomizer.org, accessed April 2025-March 2026). Each participant removed supragingival deposits from 12 anterior typodont teeth using traditional scaling techniques. Participants instrumented two separate typodonts- one with each curette.

Each typodont was fitted with a full set of artificial teeth and mounted in an adjustable mannequin (Acadental, Overland Park, KS, USA), which was fixed onto a clinical dental chair.

Artificial calculus (Dental Calculus Set, Kilgore International Inc., Coldwater, MI, USA) was applied to the 12 anterior teeth by the same researcher using a standardized template to ensure identical amounts and locations of deposits across all models. The calculus was applied 18 hours prior to each test arm to ensure consistency, as the hardness levels of the deposits increase over time.

Each test arm consisted of four 2-minute scaling intervals in which the facial surfaces of the lower anteriors were scaled in the "towards" direction for the first 2-minute interval, followed by a 30-second rest period. During the second interval the facial surfaces of the lower anteriors were scaled in the "away" direction, followed by a 30-second rest period. The third interval covered the lingual surfaces of the lower anteriors in the "towards" direction, followed by a 30-second rest period. The final interval consisted of scaling the lingual surfaces of the lower anteriors in the "away" direction, followed by a 30-minute break before scaling the second typodont. During "towards" scaling, clinicians sat in the 7-9 o'clock position, and during "away" scaling they sat in the 12 o'clock position. Testers could not be blinded due to the different appearance and ergonomics of the two curettes, but all data extraction and evaluation were performed by the same blinded, experienced researcher. For each tester, the entire instrumentation process was video-recorded using an i-phone, and the video was used for subsequent evaluation of grasp correctness.

This study was performed using typodont models to avoid the many confounding factors that would arise from testing in live patients, including variations in patient anatomy, deposit traits, and tissue anatomy. The researchers recognize the limitations of this method, and follow-up studies in live patients are planned.

DISCOMFORT AND FATIGUE

Immediately following each test arm, participants completed hard-copy visual analogue scale (VAS) surveys for discomfort and fatigue. Each VAS consisted of a horizontal 10 cm line, with "0" on the left representing no discomfort or fatigue, and "10" on the right representing the worst discomfort or fatigue. The VAS scoring process was calibrated and administered by the same researcher using standardized language, and new unmarked hard copy scales were provided for each scoring event to avoid visual bias.[5]

MUSCLE WORK

Real-time, continuous surface electromyography (sEMG) measurements recorded muscle activity throughout instrumentation in four major muscles that are activated during dental prophylaxis (**Figure 1**): The Abductor Pollicis Brevis (APB), First Dorsal Interosseous (FDI), Flexor Pollicis Longus (FPL), and Extensor Digitorum Communis (EDC). Surface electrodes (FREEEMG, ©BTS Engineering, Quincy, MA, USA) transmitted signals wirelessly to a laptop. Electrode placement was guided by live muscle function tests, and a 15s maximum voluntary isometric contraction (MVC) was recorded for each muscle to serve as the 100% activity threshold for normalization. Raw sEMG signals were rectified and filtered using a second-order Butterworth filter with a 10 Hz high-pass cutoff frequency, and total muscle work was calculated from the sEMG curves to represent the total area under the curve across the instrumentation period.[5]

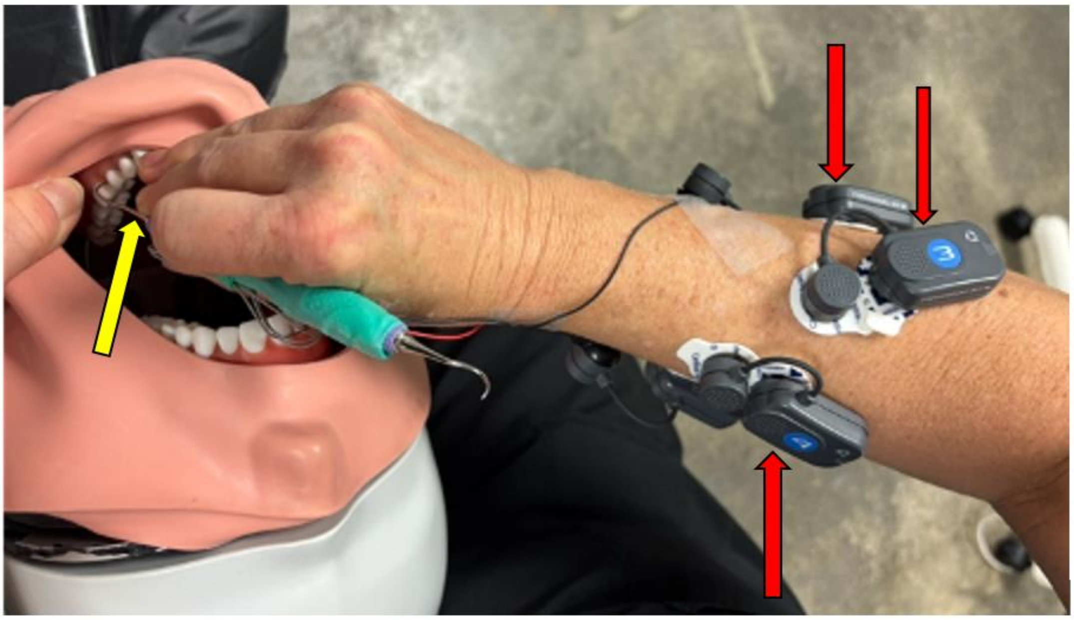

Figure 1: Mapping Muscle Activity and Pinch Force during Instrumentation.

Surface EMG electrodes (red arrow) are attached to the clinician's arm, directly transmitting information on the work occurring in each muscle to the mapping software. Ultrathin flexible pinch force sensors are mounted on the curette's thumb and forefinger grip zones using a thin green sheath. Sensors are not visible, but their location underneath the green sheath is indicated by a yellow arrow. The sensors are connected by fine wires to the microcontroller.

THUMB AND FOREFINGER GRIP FORCE

Two ultra-thin-film mini-force sensors (Rp-CMk01-1, Hilitand, Wuhan City, CN) linked to a U4 microcontroller (Arduino, Monza, IT) were mounted on each curette at the thumb and forefinger grip zones using a thin sheath (Handix, Oslo, NO) (**Figure 1**). The sensors continuously measured the force with which the thumb and forefinger gripped the curette during instrumentation. Correct sensor placement was confirmed prior to data collection, and participants verified that the equipment did not interfere with scaling. The thumb: forefinger grip force ratio was derived by dividing the thumb grip force by the forefinger grip force for each participant and curette type.[5]

CLINICIAN'S GRASP

Clinician's grasp was evaluated from video recordings of each test arm and tester using a scoring rubric established in our previous publication.[10] An experienced dental instrumentation instructor scored the grasp correctness of all participants for each curette respectively. The scoring system assigns 1 point for correctly fulfilling each of seven criteria, producing a maximum score of 7: Correct finger pad positioning of the thumb, index finger, and middle finger (1 point each); maintaining an ergonomically favorable C-shaped convex configuration of the index finger and thumb (1 point each); absence of fingertip blanching indicative of an excessively tight grasp (1 point); and approximately 70° blade to tooth adaptation (1 point).

DEPOSIT REMOVAL

Deposit removal was quantified as the percentage of surface area in which all deposits had been removed from the typodont teeth. Pre and post-instrumentation images were analyzed using ImageJ software (https://imagej.net/ij/, accessed April 2025 - March 2026).[5]

STATISTICAL ANALYSIS

A two-way mixed ANOVA was used to assess each variable (discomfort, fatigue, sEMG muscle work, thumb: forefinger force ratio, clinician's grasp score, and deposit removal), with the between-subjects factor as group (Healthy vs CTS) and within-subjects factor as curette type (A vs B). Effect sizes were reported as partial eta-squared for ANOVA. Bonferroni-adjusted pairwise comparisons were used for post hoc testing ($p<0.05$).

Results

All 48 participants completed the study in full compliance with the protocol. All were right-handed and wore a small to medium-size glove. Demographic characteristics are presented in (**Table 2**).

Table 2: Demographic characteristics of participating dental hygienists.

Variable	Group 1 (No MSDs)	Group 2 (Carpal Tunnel Syndrome)
Gender	24 female, 0 male	24 female, 0 male
Mean age (range)	34.6.7 (27.6-46.2) years	37.2.7 (28.4-46.1) years
Race/ethnicity	1 African American, 8 Asian, 1 Hawaiian/Pacific Islander, 3 Multiracial, 11 White (6 Hispanic)	1 African American, 9 Asian, 3 Multiracial, 11 White (5 Hispanic)
Mean years in practice (≥3 days/week)	6 years	11 years

Discomfort and Fatigue (Figure 2)

Clinicians with CTS reported approximately double the instrumentation-related discomfort ($p<0.0001$) and fatigue ($p<0.0001$) than healthy clinicians across both curettes. In this group, discomfort was reduced by 30% ($p<0.0001$) and fatigue by 38% ($p<0.0001$) when the adaptive curette was used vs. the conventional rigid instrument. Healthy clinicians experienced approximately half the discomfort (50% reduction) ($p<0.0001$) and less than half the fatigue (63% reduction) ($p<0.0001$) from using the adaptive tool vs. the rigid instrument.

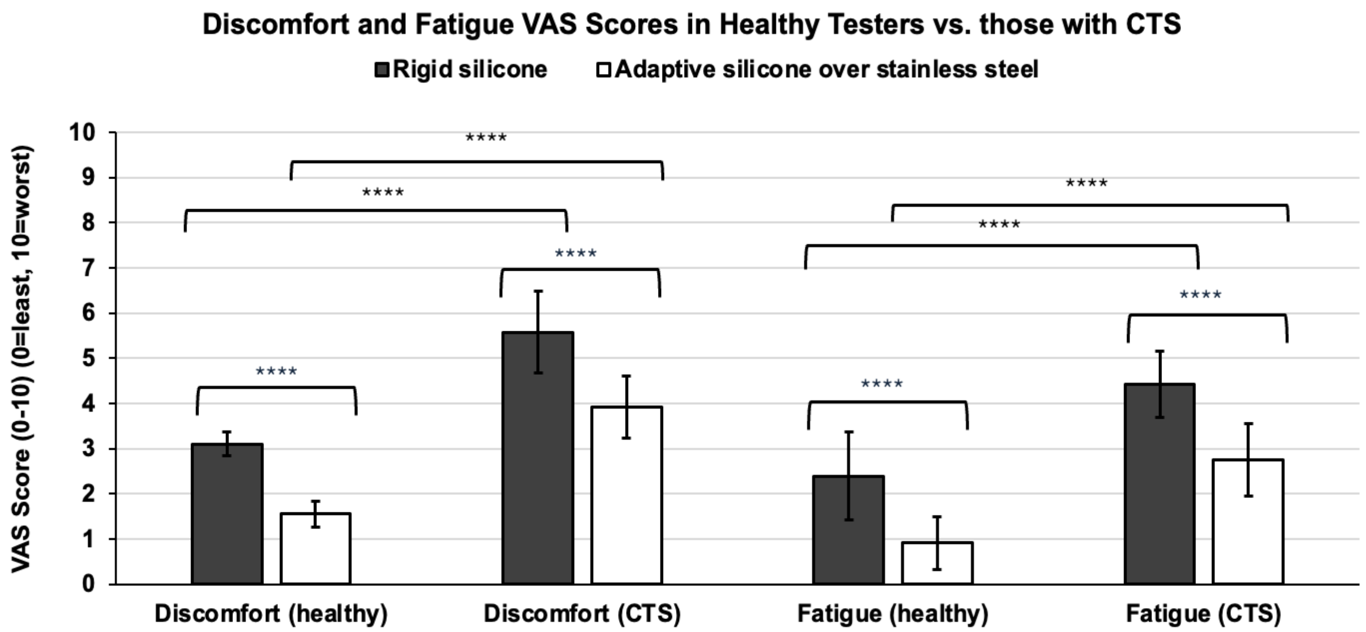

Figure 2: Discomfort and Fatigue VAS Scores in Healthy Clinicians vs. those with CTS. Brackets indicate statistically significant differences: *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001

Muscle Work (Figure 3)

Clinicians with CTS expended more than double (208%) the total muscle work than their healthy counterparts across both curettes (p<0.0001). For the rigid curette, they recorded a mean sEMG value of 240.5 ± 10.45 compared to 125.5 ± 11.84 in healthy clinicians. In clinicians with CTS, instrumenting with the adaptive curette reduced muscle work by approximately 38% (240.5 to 149.5, p<0.0001), whereas in healthy clinicians, muscle work was reduced by approximately 51% (125.5 to 61.6, p<0.0001).

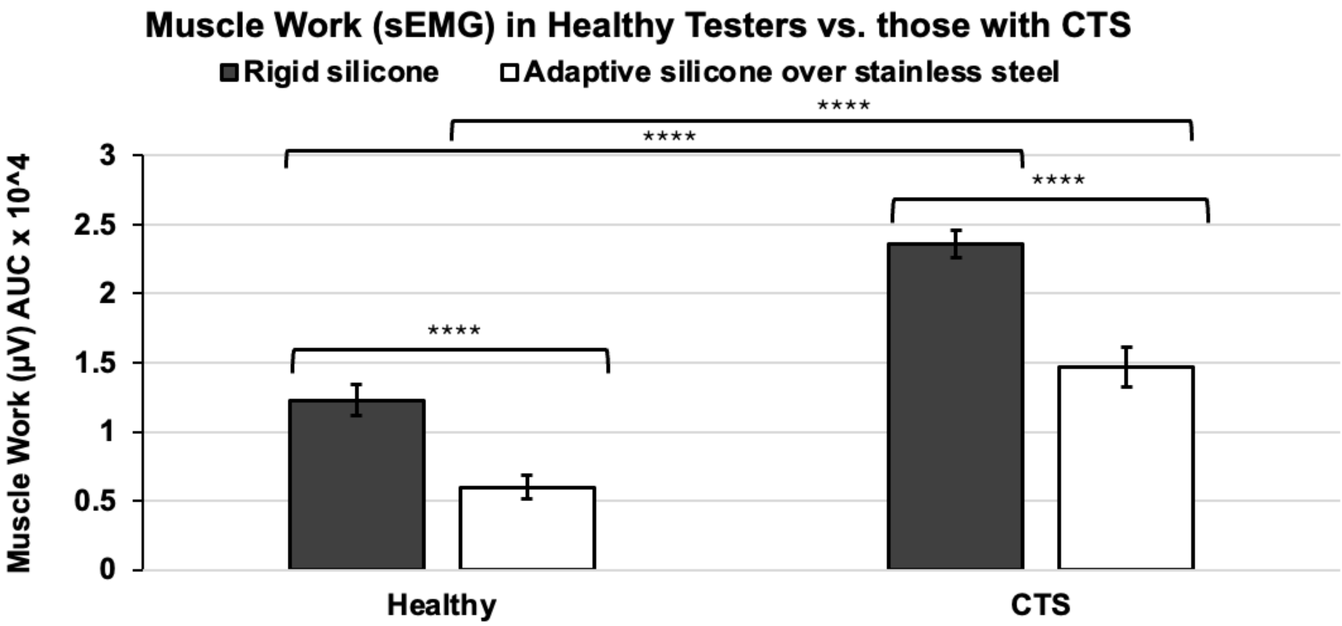

Figure 3: Muscle work (sEMG) in Healthy Clinicians vs. those with CTS. Brackets indicate statistically significant differences *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001.

Thumb and Forefinger Grip Force (Figure 4, Table 3)

Clinicians with CTS applied significantly greater thumb grip force than healthy clinicians across both instruments (p<0.0001). While using the rigid curette, they exerted a mean thumb grip force of 0.310 ± 0.022 N compared to 0.238 ± 0.014 N in healthy clinicians. Forefinger grip force while using the rigid curette was also significantly greater in clinicians with CTS (0.086 ± 0.015 N, p=0.0032) compared to healthy clinicians (0.076 ± 0.008 N, p=0.0032). The thumb:forefinger force ratio was elevated in clinicians with CTS (3.59:1 rigid, 3.44:1 adaptive) compared to healthy clinicians (3.12:1 rigid, 2.96:1 adaptive), indicating greater relative thumb loading in clinicians with CTS.

Clinicians used a significantly lower thumb grip force during instrumentation with the adaptive curette vs. the rigid instrument, with healthy clinicians employing approximately 36% less force (0.238 to 0.152 N, p<0.0001) and clinicians with CTS expending approximately 24% less force (0.310 to 0.236 N, p<0.0001). Forefinger force was reduced by approximately 32% in healthy clinicians (0.076 to 0.051 N, p<0.0001) and 21% in clinicians with CTS (0.086 to 0.068 N, p<0.0001).

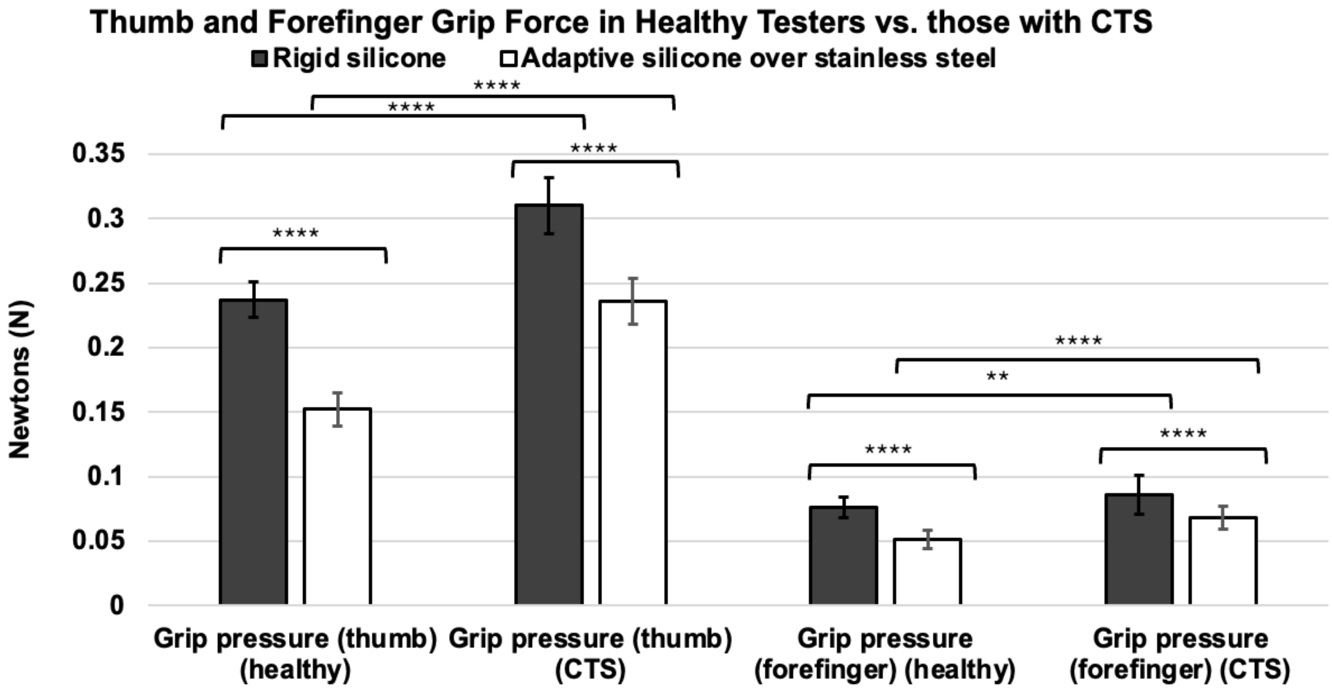

Figure 4: Thumb and Forefinger Grip Force in Healthy Clinicians vs. those with CTS. Brackets indicate statistically significant differences *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001.

Table 3: Thumb:Forefinger Grip Force Ratio in healthy clinicians and those with CTS across handle designs.

Group	Handle Design	Mean Grip Force (N) (Thumb)	Mean Grip Force (N) (Forefinger)	T:F Ratio
Healthy	Rigid silicone	0.238	0.076	3.12:1
Healthy	Adaptive silicone	0.152	0.051	2.96:1
CTS	Rigid silicone	0.310	0.086	3.59:1
CTS	Adaptive silicone	0.236	0.068	3.44:1

Clinician's Grasp (Figure 5)

All clinicians demonstrated significantly better grasp correctness during instrumentation with the adaptive curette vs. the rigid curette. When the tester groups were evaluated separately, the same trend was apparent, with a significantly higher mean correctness score in healthy testers for the adaptive curette (6.63/7, p<0.0001) vs. the rigid instrument (4.46/7, p<0.0001). In clinicians with CTS, the mean score was also significantly better for the adaptive instrument (5.08/7 vs 3.92/7, p=0.0069). When using the rigid curette, clinicians' mean grasp correctness scores did not differ significantly between healthy testers (4.46 ± 1.28, p=0.734) and those with CTS (3.92 ± 1.25, p=0.734). However, for the adaptive curette, healthy clinicians demonstrated significantly higher grasp correctness scores (6.63 ± 0.71, p=0.0002) than clinicians with CTS (5.08 ± 1.44, p=0.0002). Healthy clinicians showed a greater improvement in mean grasp score when using the adaptive curette (2.17-point) vs. clinicians with CTS (1.17-point), demonstrating a significant group x curette interaction (p=0.045).

Figure 5: Correctness of Grasp in Healthy Testers vs. those with CTS. Figure 5 compares clinician's grasp correctness (7-point scale) between participants who were healthy and those diagnosed with CTS. Brackets indicate statistically significant differences *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001.

Deposit Removal (Figure 6)

Deposit removal did not differ significantly between the two groups of clinicians and the two curettes (p>0.64). Healthy clinicians achieved 93.5% (± 2.72) deposit removal with the rigid curette, and 93.8% (± 2.60) with the adaptive curette. Clinicians with CTS achieved 92.5% (± 3.80) deposit removal with the rigid curette, and 92.6% (± 2.38) with the adaptive curette. No significant differences were observed between curette types within either groups (p>0.85). The overall mean deposit removal across all participants was 93.1%, demonstrating that all clinicians maintained comparable clinical performance regardless of curette type.

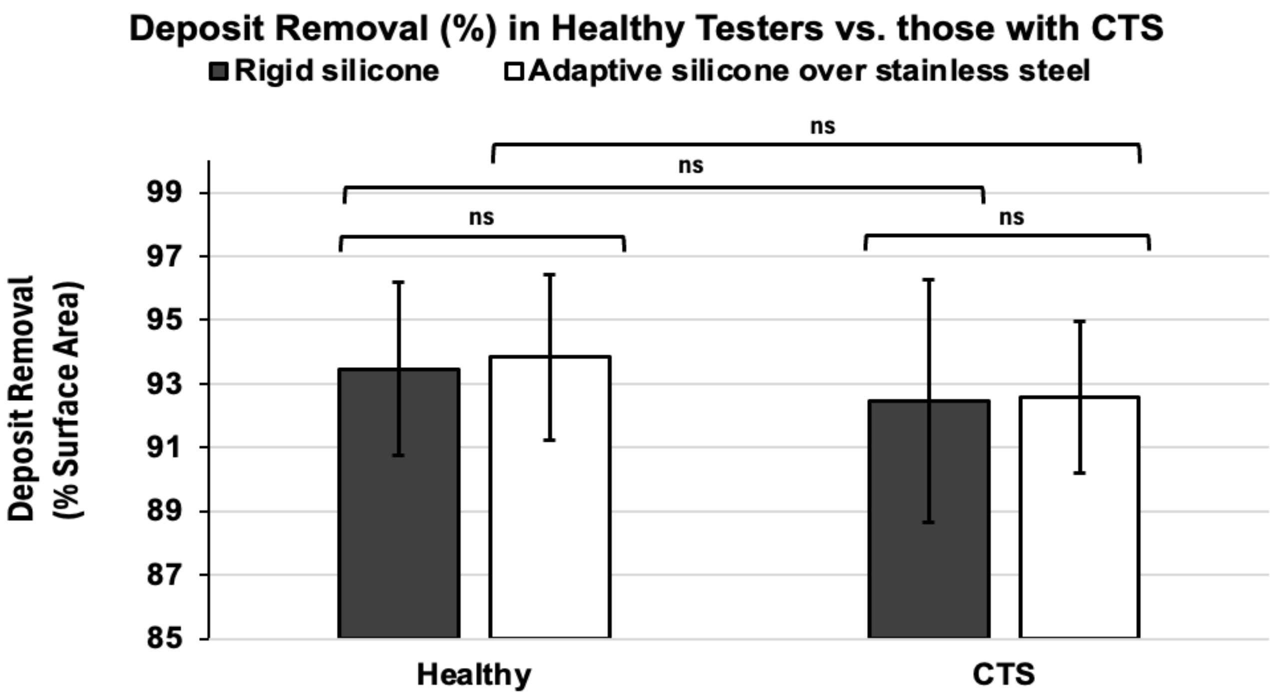

Figure 6: Deposit Removal (%) in Healthy Participants vs. those with CTS. Brackets indicate statistically significant differences *p<0.05; **p<0.01; ***p<0.001; ****p<0.0001.

Discussion

This study compared the performance of two periodontal curette designs in dental hygienists with and without carpal tunnel syndrome. The goal was to evaluate the influence of handle design on ergonomic and biomechanical outcomes during instrumentation. One instrument featured a rigid silicone handle and the other an adaptive silicone-overlaid stainless-steel handle. The outcome variables observed included discomfort, fatigue, muscle work, grip force, force distribution between the thumb and forefinger, grasp positioning, and deposit removal.

Study results confirmed that clinicians with CTS experience significantly greater ergonomic strain during instrumentation than healthy individuals across a wide range of measured variables. Testers with CTS showed higher discomfort, greater fatigue, increased muscle work, elevated grip force and lower grasp correctness scores than their healthy counterparts. Moreover, individuals with CTS consistently concentrated a disproportionately greater grip force in the thumb, despite the localization of their disability exactly in this anatomical area. These findings are consistent with previous research highlighting altered sEMG patterns, reduced neuromuscular efficiency, and modified muscle recruitment in individuals with CTS.[5,11,12] Independent studies have similarly reported that instrument handle design significantly affects forearm muscle activity during scaling[13] and that finger rest position influences hand muscle load and grip force during instrumentation.[14]

At a first glance, the elevated grip forces observed in the thumb in clinicians with CTS are surprising. Greater thumb force trends may reflect a compensatory mechanism in response to the manifestations of median nerve compression. Clinicians with thumb weakness may need to grip harder to achieve adequate lateral and vertical control as well as stabilization during the instrumentation,[5] accelerating fatigue and strain in the intrinsic muscles of the thumb.[15] Previous biomechanical analyses have established that grip forces during periodontal scaling are substantial and sustained,[16,17] and a systematic review confirmed that instrument design features directly influence the magnitude of these forces.[18] Additional research is needed to gain a better understanding of the merits and downsides of grip force redistribution - such as that provided by the adaptive handle design used in this study - in individuals with CTS as a first step towards developing better preventive and adaptive approaches.

A comparison of the outcomes for the rigid vs the adaptive instrument design highlighted significant differences in ergonomic performance. The adaptive silicone design significantly reduced discomfort, fatigue, muscle work, grip force and supported a correct ergonomic grasp. These results support findings from previous studies,[5,8,10] and are consistent with independent research demonstrating that handle diameter, surface material, weight, and shape are important determinants of ergonomic performance.[19,20] A four month RCT found that larger diameter and lighter curette handles significantly reduced arm pain in dental hygienists,[21] and an evidence-based review confirmed that softer handles are associated with more favorable ergonomic outcomes.[22] The adaptive silicone-over-steel curette overall demonstrated better ergonomic outcomes than the solid silicone curette, despite being somewhat heavier and featuring a slightly smaller diameter, indicating a need for additional, multifactorial studies on the relative and perhaps interconnected merits of these design features. Moreover, the adaptive design incorporates several unique ergonomic features that have been shown to improve force transfer by maximizing the area of contact between the tool and the hand[23,24] and distributing instrumentation forces over a larger surface area to reduce loading per unit area. This effect lowers stress on musculoskeletal surfaces.[23,25] Previous studies evaluating ergonomics of hand tools have established that both objective and subjective measures like sEMG and VAS are important for the evaluation of tool design,[26,27] and this study supports a strong consensus between both measures.

Despite differences in nearly every other ergonomic variable measured, the level of deposit removal did not differ statistically between tester groups, averaging above 93% across all participants. However, this equivalent outcome came at a considerably greater cost to clinicians with MSDs, as they exerted substantially greater energy while enduring higher levels of discomfort and fatigue to achieve comparable outcomes as those without MSDs. These findings reinforce concerns about long-term career sustainability in dental clinicians and many others. In dentistry, the consequences of work-related MSDs are documented extensively. Most hygienists are unable to work full-time after several years of clinical practice, and nearly ⅓ of dentists are forced to retire early due to musculoskeletal conditions.[3] Similarly, research in office workers has shown that CTS is associated with significant long-term loss of productivity, more time away from work, and higher functional impairment.[9]

Although this study focused on dental hygienists, the underlying biomechanical challenges of CTS are not unique to dental clinicians. Various occupations demand sustained, repetitive work with handheld tools. 41% of surgeons report their work as physically strenuous and 73% are impacted by uncomfortable or exhausting postures, with musculoskeletal strain documented across multiple areas of the body including the wrist and forearm.[28] Among hand surgeons, 60.4% report sustaining a work-related musculoskeletal injury, with CTS being the third most common diagnosis at 15.6%.[29]

Physical therapists rely on techniques with repetitive movement, high patient load, and unfavorable ergonomic positions, all of which contribute to a high prevalence of wrist and hand pain.[30] Carpenters exposed to vibrating hand tools experience adverse hand health outcomes including reduced grip strength and neurovascular symptoms that overlap with CTS pathology.[31] Sewers engaged in prolonged hand stitching tasks report a high prevalence of musculoskeletal symptoms in the hand, wrist, and forearm due to sustained repetitive gripping.[32] Farmers performing biomechanically demanding manual tasks face elevated rates of MSDs in the hand and wrist, and constructions workers are at increased risk of developing CTS requiring surgical procedures.[33,34] Thus, the adverse health consequences of repetitive, precise and forceful finger, hand, arm and shoulder movements are shared across a wide range of professions, underlining the urgency for finding better solutions to this challenge.

Several limitations of this study should be addressed. Only 1 type of MSD (CTS) was evaluated, and future studies should consider other common musculoskeletal conditions. The force sensors and sEMG electrodes were limited to specific anatomical locations, and additional sensor placements may uncover further observations with regard to biomechanical loading. The study was performed on typodont models rather than a clinical setting, which does not fully replicate the intricacy of live patient anatomy. Additionally, the two curettes had somewhat different handle diameters and weights, which may have affected results, as previous studies have shown that handle shape and weight influence grip force.[19,20] All clinicians in this study were female with small to medium glove sizes, and our findings may not translate accurately to clinicians with larger hands. Future research should include larger sample sizes, different hand sizes and genders, additional instrument or tool designs, as well as non-dental populations with various forms of MSDs.

The concept that novel adaptive handle designs may not only benefit individuals with CTS but may also reduce the risk of developing this condition through a more favorable ergonomic functionality is intriguing and has implications across many professions that require repetitive manual activity. Larger and more extensively stratified studies are needed to further elucidate the role of design-based variables in the development, prevention, mitigation of MSDs across different professions.

Conclusion

Dental hygienists with CTS exhibited significantly altered instrumentation biomechanics compared to healthy clinicians, reporting higher discomfort and fatigue and exerting greater muscle work and grip force, while achieving comparable clinical performance. The adaptive silicone-overlaid stainless-steel curette significantly improved ergonomic outcomes in both tester groups. These findings support the role of an adaptive handle design in the prevention and mitigation of musculoskeletal disorders in dental clinicians and suggest a broader application to non-dental occupations that require repetitive and precise hand movements.

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