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Original Article

Evaluation of a Novel Ergonomic Sheath for Dental Instruments: Effects on Muscle Work, Fatigue, and Operator Comfort—A Pilot Clinical Study

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ABSTRACT

Prolonged use of manual dental instruments often contributes to operator discomfort, muscle fatigue, and work-related musculoskeletal disorders (MSDs). This pilot in vivo investigation explored how an innovative ergonomic handle sheath affects muscle activity, perceived comfort, and fatigue during two common dental procedures: (a) ultrasonic scaling performed by hygienists with and without MSDs, and (b) tooth cavity preparation performed by dentists using a micromotor handpiece. Twenty dental hygienists were divided equally into two groups—those without MSDs and those previously diagnosed with such conditions. Each group carried out scaling using a piezoelectric device, both with and without the ergonomic sheath. In addition, ten healthy dentists prepared four standardized cavities using a dental micromotor under the same conditions. Electromyographic data from four target muscles, along with self-reported comfort and fatigue ratings, were collected. The dataset was analyzed using a repeated-measures ANOVA followed by Tukey's post-hoc comparisons.

Use of the ergonomic sheath led to statistically significant improvements in comfort and reductions in fatigue and muscular workload for both dental tools. Although hygienists with MSDs exhibited higher muscle activity overall and appeared to benefit slightly more from the sheath, these group differences did not reach statistical significance. The findings indicate that an ergonomic handle sheath can enhance the usability and ergonomic efficiency of both ultrasonic scalers and micromotors, suggesting its potential value in minimizing muscle strain and improving practitioner comfort during clinical practice.

Keywords: Ergonomic sheath, Dental ergonomics, Muscle activity, Ultrasonic scaler, Micromotor handpiece, Fatigue

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Introduction

The high prevalence and severity of instrumentation-related musculoskeletal disorders (MSDs) among dental professionals underscore the urgent need for innovative preventive and therapeutic strategies. Work-related MSDs and chronic inflammatory conditions are reported to affect between 54% and 93% of dentists and dental hygienists [1]. Dental hygienists, in particular, experience these injuries more frequently [2]. Such conditions are often chronic, widespread, and primarily affect regions including the spine, shoulders, wrists, hands, and fingers [1–12]. Many hygienists are forced to reduce their working hours within a few years of clinical practice due to functional limitations imposed by MSDs [10, 13, 14].

Dentists face similar challenges, with the majority reporting musculoskeletal pain linked to repetitive and high-force activities inherent to their work [12–30]. Nearly half of practicing dentists report that MSD-related pain contributes to sleep disturbances, reduced job satisfaction, and loss of income [31]. Alarmingly, over one-quarter of dentists retire prematurely due to chronic pain or physical disability [15], resulting in significant personal and economic repercussions. The financial burden is also substantial; one study estimated an annual income loss of approximately USD 131 million due to MSDs within the dental profession [20, 32].

In response, the development of advanced dental materials and ergonomically enhanced tools has accelerated. Traditionally, dental instruments have been constructed as long, narrow, and rigid metallic devices. Recent ergonomic redesigns have introduced softer, lighter, and wider non-metal handles to address the biomechanical stress imposed by conventional designs. Evidence indicates that instruments with slightly larger diameters, lighter weights, and silicone-coated or thermally insulated grips significantly reduce musculoskeletal strain in the hand, wrist, and arm [33–38]. Simultaneously, ergonomic training and modified instrumentation techniques have been investigated as complementary strategies to alleviate pain and improve clinician comfort [32].

Technological advancements, particularly in motion tracking and surface electromyography (sEMG), have enabled precise, real-time assessments of how instrument design and material properties influence operator biomechanics, posture, and muscle activity. However, ergonomic improvements have primarily focused on manual tools, while power-driven dental devices such as scalers and micromotors have seen relatively limited design innovation.

Despite the extensive body of research documenting the prevalence and consequences of MSDs in dental practitioners, little attention has been paid to how these disorders affect the muscle work required to complete specific instrumentation tasks and the related discomfort and fatigue. A recent pilot study addressing this gap found that clinicians with MSDs reported approximately 70% greater discomfort, twice the fatigue, and required over double the muscle effort compared to healthy counterparts when performing standardized scaling tasks with periodontal curettes [39]. These findings underscore the need for further investigations into ergonomic interventions that could alleviate the physical burden on dental professionals.

Accordingly, the objective of this in vivo study was to evaluate the influence of an ergonomic handle sheath on muscle workload, operator comfort, and fatigue during (a) piezoelectric scaling procedures performed by hygienists with and without MSDs, and (b) dental cavity preparation by healthy dentists using a dental micromotor.

Materials and Methods

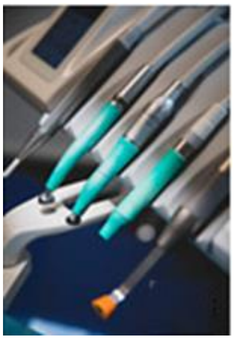
This study protocol was reviewed and granted exempt status by the Institutional Review Board (IRB) of the University of California, Irvine, as it involved only de-identified data. All participants were informed of their right to withdraw at any time and for any reason, without consequence.

Testing was performed by dental hygienists and dentists on typodont models mounted in dental manikins attached to standard dental chairs. Each participant completed the protocol twice—once using the ergonomic sheath and once without it. The order of testing was randomized in a 1:1 ratio using the online platform *randomiser.org* (accessed 23 August 2023). A 10-minute rest interval separated the two test sessions, and the return to baseline muscle activity was confirmed using sEMG at the end of the rest period. All participants wore standard nitrile examination gloves during the procedures (Dental City Stratus Nitrile Powder Free Gloves, Green Bay, WI, USA).

Ergonomic Sheath ***(Figure 1)***

The ergonomic sheath **(Figure 1)** employed in this study was fabricated from medical-grade silicone (Handix, Oslo, Norway). It was easily applied by rolling it over the handles of dental handpieces or piezoelectric scalers. The sheath, approximately 1 mm thick, was designed to provide both thermal insulation and a cushioning effect for the fingers during instrument use. The silicone's durometer was optimized to absorb vibrational energy while preserving precise tactile sensitivity, thereby enhancing both comfort and control during dental instrumentation.

a)



b)

c)

d)

Figure 1. (a) The ergonomic sheath is provided as a rolled-up ball, which is placed on the instrument end and unrolled to apply to the grip area (b). (c) Clinician with sEMG electrodes in place using scaler with ergonomic sheath (green) in place. (d) Typodont with artificial calculus and biofilm.

Ultrasonic scaling—participants

Twenty right-handed dental hygienists were enrolled in the ultrasonic scaling component of the experiment. **Group 1** included ten individuals without any recent or historical upper-limb musculoskeletal injuries. None had experienced pain or functional issues involving the fingers, hands, or wrists during the six months preceding participation, nor had they received a diagnosis of an upper-extremity musculoskeletal disorder (MSD). **Group 2**, in contrast, comprised ten hygienists who had been clinically diagnosed with chronic MSDs of the fingers, hands, arms, and/or shoulders within the three months prior to testing. Because of pain and physical limitations, these participants were unable to maintain full-time clinical workloads at the time of study involvement.

Ultrasonic scaling—experimental procedure

To ensure procedural consistency, each typodont was prepared with simulated deposits representing biofilm and calculus. Artificial plaque (Occlude Green Marking Spray, Pascal International, Bellevue, WA, USA) and artificial calculus (Dental Calculus Set, Kilgore International Inc., Coldwater, MI, USA) were carefully applied to both supra- and subgingival surfaces on 32 standardized teeth within the typodont model (Kilgore International Inc., Coldwater, MI, USA) **(Figure 1)**. These materials were allowed to set for 18 hours before instrumentation to simulate the increasing hardness of clinical deposits.

The prepared typodonts were mounted in dental manikins attached to standard clinical chairs. Hygienists worked from typical seated positions and were permitted to adjust their posture or the manikin's position as necessary to replicate realistic working conditions. A research observer was present during all procedures to record any repositioning or interruptions so that transient irregularities in the surface electromyography (sEMG) readings could later be identified and accounted for.

Each participant performed scaling using a Woodpecker piezoelectric ultrasonic scaler (Gulin, China) equipped with a rigid, non-metallic handle. The hygienists were instructed to remove all simulated plaque and calculus deposits as they would in routine clinical practice, avoiding any unnecessary abrasion of the tooth or artificial gingival structures. The procedure followed a standardized sequence involving eight regions:

1. facial surfaces of the lower anterior sextant,
2. lingual surfaces of the lower anterior sextant,
3. facial surfaces of the upper anterior sextant,
4. lingual surfaces of the upper anterior sextant,
5. buccal surfaces of the lower right sextant,
6. buccal surfaces of the lower left sextant,
7. buccal surfaces of the upper right sextant, and
8. lingual surfaces of the upper right sextant.

To prevent overexertion, especially among participants in the MSD group, full-mouth scaling was not required; the chosen regions were sufficient for comparative assessment of muscle activity and fatigue.

Cavity preparation using a dental micromotor—participants

The micromotor phase of the study involved ten right-handed dentists, each with a minimum of five years of continuous clinical practice experience. None of these participants reported any recent upper-extremity injuries or symptoms and had not been diagnosed with MSDs within the six months preceding participation.

Cavity preparation using a dental micromotor—experimental procedure

Extracted teeth were mounted in typodont models that were secured in dental manikins (Kilgore International Inc., Coldwater, MI, USA) and attached to standard dental chairs to simulate clinical conditions. Participants were seated as they would be in practice and allowed to reposition themselves or the manikin as needed for visibility and comfort. All positional adjustments were documented in real time by a researcher to facilitate accurate interpretation of the sEMG signal and identification of potential artifacts.

Each dentist was instructed to prepare four specific cavities: a Class V restoration on the upper left central incisor, a Class V restoration on the lower right canine, a Class II three-surface restoration on the upper right first molar, and a Class II three-surface restoration on the lower left second molar. All preparations were performed using a **KaVo INTRA LUX KL703 LED steel micromotor** (KaVo Dental Technologies LLC., Charlotte, NC, USA), which features a rigid metallic handpiece.

Surface electromyography (sEMG)

Muscle activity during all procedures was continuously monitored using a wireless surface electromyography system (FREEEMG, ©BTS Engineering, Quincy, MA, USA). To ensure uniform placement and minimize operator bias, all electrodes were applied by the same examiner (CW). Disposable adhesive sensors were positioned directly over four hand and forearm muscles known to contribute to grip control and precision manipulation of dental tools [2, 5, 33, 35, 36, 40–43]: the **Abductor Pollicis Brevis (APB)**, **First Dorsal Interosseous (FDI)**, **Flexor Pollicis Longus (FPL)**, and **Extensor Digitorum Communis (EDC) (Figure 1)**.

A standardized placement and calibration protocol was followed [44]. This procedure included: (1) locating and confirming the appropriate anatomical landmarks for electrode positioning [45]; (2) determining a **maximum voluntary contraction (MVC)** baseline for each muscle over a 15-second interval to enable subsequent normalization [46–49]; and (3) recording muscular effort continuously throughout each instrumentation task.

Following acquisition, the raw EMG signals were rectified and processed through a **second-order Butterworth high-pass filter (10 Hz cutoff)** using BTS EMG Analyzer™ software (version 1). The resulting data were expressed as the **integrated EMG (iEMG)**, which quantifies total muscle workload by calculating the area under the activity curve during the entire procedure.

Visual analogue scale (VAS) and qualitative responses

After completing each experimental condition, participants rated their **fatigue** and **comfort** levels using printed visual analogue scales (VAS) ranging from 0 to 10, where 0 represented no fatigue or discomfort and 10 indicated maximum fatigue or discomfort. Fatigue was assessed globally, while comfort was rated specifically for the wrist, fingers, and palm. Participants were also invited to record **open-ended remarks** describing their subjective impressions of the ergonomic sheath's handling, feel, and overall usability.

Data analysis

All data were analyzed using **IBM SPSS Statistics 19** (IBM®, Armonk, NY, USA). Differences between conditions were assessed through a **repeated-measures analysis of variance (ANOVA)**. Post-hoc comparisons were performed using **Tukey's test**, with the statistical threshold for significance defined as **$p < 0.05$**.

Results and Discussion

All subjects were right-handed and completed both test conditions successfully. Among the hygienists **without** musculoskeletal disorders, all ten were female, aged between **24 and 56 years** (mean age = 36.1 years), and had **3–30 years** of clinical experience (mean = 16 years). Hygienists **with** MSDs were also female, aged **47–68 years** (mean = 49.3 years), with **10–32 years** of professional experience (mean = 18 years). Statistical testing confirmed a significant age difference between the two hygienist groups (**$p = 0.0092$**), while the difference in years of experience approached but did not reach significance (**$p = 0.0584$**).

The dentist cohort (n = 10) consisted of six women and four men aged **31–49 years** (mean = 42.7 years) with **9–26 years** of practice experience (mean = 19 years). None had a history of upper-extremity MSDs.

*(a) sEMG outcomes—ultrasonic scaling **(Table 1)***

When scaling was performed **without** the ergonomic sheath, hygienists with MSDs demonstrated greater overall muscle activity compared to those without disorders, although the difference was not statistically significant (**$p = 0.4309$**) **(Table 1)**.

The introduction of the **ergonomic sheath** led to a measurable decline in total muscle workload across both groups. The reduction reached statistical significance for hygienists without MSDs (**$p = 0.0079$**) and for those with MSDs (**$p = 0.0028$**). While the magnitude of improvement was slightly higher among the MSD group, the between-group difference was not statistically significant **(Table 1)**.

Table 1. Mean total muscle work expended by 10 hygienists to complete scaling.

	No MSD, No Sheath, (n = 10)	No MSD, Sheath (n = 10)	MSD, No Sheath (n = 10)	MSD, Sheath (n = 10)
Mean total muscle work (mV)	0.704	0.539	0.746	0.577
Std. Deviation	0.118	0.167	0.115	0.180

(b) Surface EMG data—cavity preparation ***(Table 2)***
Dentists exhibited a significant reduction in overall muscle workload when the ergonomic sheath was applied, compared with procedures performed without it. This decrease was observed during the preparation of both anterior (**p = 0.0154**) and posterior (**p = 0.001**) cavities, indicating that the sheath effectively lessened muscular effort across intraoral sites **(Table 2)**.

Table 2. Mean total muscle work expended by 10 dentists without MSDs.

	No Sheath: Anterior Teeth (n = 10)	Sheath: Anterior Teeth (n = 10)	No Sheath: Posterior Teeth (n = 10)	Sheath: Posterior Teeth (n = 10)
Mean	0.968	0.713	1.334	1.081
Std. Deviation	0.114	0.286	0.089	0.166

(a) Comfort and fatigue—scaling ***(Table 3)***
In the absence of the ergonomic sheath, healthy participants reported significantly higher comfort levels and lower fatigue compared to those with MSDs ($p < 0.0001$). When hygienists with MSDs used the sheath, their reported comfort and fatigue improved considerably, approaching the levels observed in the healthy group. However, finger comfort ($p < 0.0001$) and overall fatigue ($p = 0.002$) remained significantly lower in the MSD group **(Table 3)**.
Among hygienists without MSDs, the use of the sheath led to a significant increase in comfort in the palm ($p = 0.0051$) and wrist ($p = 0.015$), while the improvement in finger comfort did not reach statistical significance ($p = 0.081$). Fatigue levels in this group were notably reduced with sheath use ($p = 0.0002$).
For participants with MSDs, the ergonomic sheath significantly enhanced comfort in all measured regions—the palm, wrist, and fingers (all $p < 0.0001$)—and also led to a substantial reduction in fatigue ($p < 0.0001$).
Overall, both groups demonstrated marked improvements in comfort and fatigue when using the sheath, with the only exception being finger comfort among healthy testers, which showed a non-significant change.

Table 3. Mean Comfort and Fatigue in hygienists during scaling on a scale of 0–10, where 0 is best and 10 is worst.

	No MSD, No Sheath, (n = 10)	No MSD, Sheath (n = 10)	MSD, No Sheath (n = 10)	MSD, Sheath (n = 10)
Mean Comfort Palm (S.D.)	3.2 (0.33)	2.6 (0.299)	5.7 (0.523)	3.1 (0.338)
Mean Comfort Wrist (S.D.)	2.4 (0.216)	1.9 (0.168)	4.8 (0.529)	2.7 (0.312)
Mean Comfort Fingers (S.D.)	1.7 (0.183)	1.4 (0.116)	5.3 (0.449)	2.8 (0.297)
Mean Fatigue (S.D.)	1.9 (0.238)	1.1 (0.138)	6.0 (0.555)	3.0 (0.316)

(b) Comfort and fatigue—cavity preparation ***(Table 4)***
When the ergonomic sheath was applied, mean comfort in healthy testers increased significantly across all measured regions: the palm ($p = 0.0002$), the wrist ($p = 0.0368$), and the fingers ($p = 0.0368$). Additionally, mean fatigue decreased significantly in this group with sheath use ($p = 0.015$) **(Table 4)**.

Table 4. Mean Comfort and Fatigue in dentists during cavity preparation on a scale of 0–10, where 0 is best and 10 is worst.

	No Sheath (n = 10)	Sheath (n = 10)
Mean Comfort Palm (S.D.)	1.9 (0.88)	1.1 (0.18)

Mean Comfort Wrist (S.D.)	1.9 (0.568)	1.5 (0.127)
Mean Comfort Fingers (S.D.)	1.9 (0.5676)	1.5 (0.127)
Mean Fatigue (S.D.)	1.9 (0.568)	1.4 (0.199)

Overall, participants reported higher comfort and lower fatigue when using the ergonomic sheath compared to working without it. This trend was consistent across all groups, independent of clinician type or MSD status.

In the open-ended feedback, most participants indicated a preference for using the ergonomic sheath during procedures. A summary of these comments is provided in **Table 5**.

*Tester open-ended written comments **(Table 5)***

Table 5. Testers' Comments.

Comfort	Fatigue	Overall Feel	Comments
No Sleeve	No comments	No comments	1/30 testers: Slightly improved tactile sensation
With Sleeve	30/30 testers: Felt more comfortable, as the tool seemed lightly padded, warmer, and softer	27/30 testers: Reduced need for tight gripping led to lower tiredness	26/30 testers: Gentler on fingers and hand, giving a softer feel and improved control of the instrument
	24/30 testers: Required less forceful grip with the sheath, resulting in reduced fatigue and fewer slips	21/30 testers: Hand experienced less strain following use	7/30 testers: Sleeve performed better without gloves than with them
	20/30 testers: Tool felt steadier in the hand		

This pilot study evaluated the impact of a newly designed, soft, flexible ergonomic handle sheath on clinicians' physical workload, perceived fatigue, and comfort when using power-driven dental instruments. The investigation included two standardized clinical tasks: piezoelectric scaling performed by dental hygienists and the preparation of four dental cavities using a steel micromotor by dentists. Both devices were chosen because they are commonly used in practice and generate considerable vibration, a recognized contributor to musculoskeletal disorders (MSDs) [50, 51]. To explore differences in workload and fatigue, scaling tasks were performed by both clinicians with and without pre-existing MSDs.

All participants were right-handed to reduce potential confounding from handedness, as left-handed clinicians may be more susceptible to MSDs due to instrumentation and positioning protocols designed for right-handed practitioners [52–54]. The sheath's effect on left-handed clinicians, including those with MSDs, remains under evaluation.

Among hygienists, MSD-affected participants required more muscle effort and reported higher fatigue and lower comfort than their healthy peers during standardized scaling. These results underscore the importance of understanding how existing MSDs influence clinician biomechanics and ergonomics, which is critical for designing preventive and rehabilitative strategies. MSDs are highly prevalent across the workforce, affecting 33.8–95.3% of individuals, particularly in the back, neck, and upper limbs [29].

The addition of the ergonomic sheath substantially improved subjective comfort and reduced fatigue for clinicians with MSDs, bringing their ratings closer to those of healthy hygienists. The observed benefits may stem from the sheath's soft and thermally insulating material, which likely encourages more natural hand positions and grip patterns, reducing unnecessary muscle activation and discomfort associated with awkward postures. Further research is needed to elucidate how grip mechanics and muscle recruitment are modified by the sheath and to determine whether these changes translate to long-term ergonomic benefits.

Across all hygienists, the sheath significantly decreased total muscle workload, with a slightly larger effect in those with MSDs, although intergroup differences did not reach statistical significance. Similarly, during standardized cavity preparation, dentists expended less muscular effort when using the sheath. While it is not yet clear how much of this benefit is due to vibration damping versus improved handle ergonomics, these results are consistent with prior evidence showing that softer, warmer, non-metal handles reduce musculoskeletal strain [34, 35, 39, 40, 43, 44, 55–59]. The findings suggest that ergonomic design principles for hand instruments can be extended to powered dental tools, either via removable attachments like the sheath or integrated handle designs.

Beyond handle modifications, prior studies have shown that broader ergonomic interventions—including exoskeletal supports, musculoskeletal training programs, and stress mitigation strategies—can further reduce clinician strain and enhance performance [60–63].

Notably, objective sEMG measurements aligned closely with subjective VAS scores of comfort and fatigue across all groups. Clinicians consistently reported higher comfort and lower fatigue with the sheath, while sEMG data confirmed reduced muscle activity during tasks. These findings reinforce the value of combining objective and subjective measures to evaluate ergonomic interventions, as muscle-specific physiological data complement self-reported comfort and fatigue to provide a comprehensive assessment of ergonomic performance [57, 64, 65].

Summary and limitations

This pilot study highlights that clinicians with pre-existing musculoskeletal disorders (MSDs) tend to expend more muscular effort and report greater fatigue when performing standardized dental procedures than their healthy counterparts. The findings suggest that introducing a soft, flexible ergonomic handle sheath on motor-driven dental instruments may help alleviate some of this physical strain, particularly in MSD-affected clinicians.

Several limitations should be considered. The participant pool was relatively small, which may limit the generalizability of the results. Additionally, there was an age gap between healthy hygienists and those with MSDs, reflecting the fact that MSDs typically develop with advancing age; younger hygienists rarely present with these conditions. However, both groups had similar clinical experience, which partially offsets this difference. The study also did not include dentists with MSDs, leaving an important subset of clinicians unexamined. Future research should specifically address this population.

Another factor that could influence ergonomic outcomes is the posture and positioning adopted during instrumentation. In this study, participants were allowed to use their habitual working positions to avoid introducing confounding variability from unfamiliar postures. While this approach ensured ecological validity, more controlled positioning protocols may be necessary in future studies to isolate the ergonomic effects of instrument modifications.

Future research efforts are planned to expand the sample size and study duration, and to examine additional outcomes such as procedural efficiency, tactile sensitivity, and detailed biomechanical analyses of hand, wrist, and overall body positioning. These studies will also gather more comprehensive data on the severity and duration of MSDs, allowing for a clearer understanding of how specific injuries interact with clinical tasks and ergonomic performance.

Conclusion

The findings from this study indicate that the use of a novel ergonomic handle sheath on dental motor-driven instruments can reduce muscle workload, enhance comfort, and decrease fatigue during clinical procedures. These effects appear particularly pronounced in clinicians with MSDs. Further research is ongoing to validate these results, broaden the study scope, and investigate additional clinical and ergonomic parameters.

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