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Effect of loupe and microscope on dentists' neck and shoulder muscle workload during crown preparation

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Although there is consensus among dentists that visual aids not only improve vision but also help improve posture, evidence is scarce. This study aimed to evaluate the effect of visual aids (loupe and microscope) on the muscle workload of dentists during crown preparation on dentiform first molars in each quadrant of a phantom head, considering dentists' muscles, patients' tooth positions and surfaces. Six right-handed dentists from a single tertiary hospital participated. Surface electromyography device recorded the muscle workload of the bilateral upper trapezius, sternocleidomastoid, cervical erector spinae, and anterior deltoid during crown preparation. The results showed significantly lower workload in all examined muscles when using a microscope compared to the naked eye ($p < 0.05$), whereas the loupe showed reduced workload in some specific muscles. The muscle with the highest workload for all visual aids was the cervical erector spinae, followed by the upper trapezius. When analyzed by tooth surface, while the loupe did not significantly reduce overall workload compared to the naked eye for each surface, the microscope significantly reduced workload for most surfaces ($p < 0.05$). Therefore, during crown preparation, the workload of the studied muscles can successfully be reduced with the use of a loupe or microscope.

In order to gain precise vision inside small and dark working field, the patient's mouth, it is unavoidable for dentists to work in a forward head posture, with the neck tilted forward and shoulders drooping forward in a rounded position[1]. This unbalanced posture leads to a high prevalence of musculoskeletal disorders among dentists[2]. Over 60% of dentists suffer from various musculoskeletal disorders throughout their work life, mostly in the neck, shoulder, and back[3]. Many studies show that this disorder is prevalent since dental pre-clinical training periods. According to a study, approximately 85% of dental students reported experiencing a musculoskeletal disorder in at least one body region, with the neck being the most commonly affected area[4]. Therefore, several past studies emphasize the importance of implementing preventive strategies against musculoskeletal disorders in dentists. These strategies include alternating between standing and sitting[5], increasing physical activity[6], engaging in stretching exercises[7], taking regular rest breaks[8], and utilizing visual aid[9]. As for the use of visual aids, there is more focus on improving the success rate of dental treatments through enhanced vision[10] than its benefits regarding enhanced posture. Although visual aids have also been highly recommended during dental treatment in order to enhance working posture and thus reduce muscle workload, there is a noticeable lack of substantial evidence supporting their ergonomic effectiveness.

In order to evaluate dentists' working posture, multiple outcome measures are applicable, such as postural assessment[11], pain scales[12], and muscle activity monitoring[13,14]. Surface electromyography (sEMG) is a non-invasive technique that quantitively acquires electrical activities from surface muscles related to muscle contraction. It is utilized for measuring muscle workload, detecting muscle fatigue, and assessing the timing of muscular contractions[15]. Currently, it is employed in various fields such as research, rehabilitation, sports, and ergonomic industry[16]. To date, several studies have examined the effect of visual aids on ergonomics in dentistry using sEMG, with a particular focus on loupes. These studies have weighted their emphasis particularly on investigating the impact of different magnification levels (2.5×, 3.0×, and 3.5×) of Galilean loupes on working posture[17], and also

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on the impact of using an ergonomic stool with or without loupes[18]. So far, no previous study has investigated the effect of dental microscope on working posture during dental treatment.

The aim of this study was to assess the impact of visual aids (loupe and dental microscope) on muscle workload during crown preparation. This evaluation is conducted according to various factors: muscle (bilateral upper trapezius, sternocleidomastoid (SCM), cervical erector spinae, and anterior deltoid), tooth position (#16, #26, #36, and #46), and tooth surface (occlusal, buccal, lingual/palatal, and proximal).

Results

A total of 288 mean %MVIC data points were obtained from the four surfaces of four teeth (#16, #26, #36, and #46) for the three types of visual aids (naked eye, loupe, and microscope) from six participants. The mean age of the participants was 32.3 ± 9.6 years. The normality tests indicated that the majority of values conformed to normal distribution.

Influence of visual aid according to muscle for all four first molars

As shown in Table 1, the muscle workload of all muscles differed significantly among the three types of visual aid ($p < 0.05$). During crown preparation without the help of any visual aids, the order of mean %MVIC in descending order was cervical erector spinae > upper trapezius > SCM > anterior deltoid. Overall, compared to working with the naked eye, the workload of every muscle reduced when using a loupe but the difference was significant only for Lt. trapezius and bilateral SCM ($p < 0.05$). Meanwhile, the use of a microscope resulted in reduced %MVIC with statistical differences for each of the other method for virtually every muscle ($p < 0.05$).

Influence of visual aid according to muscle for #16

Tables 2, 3, 4 and 5 show the mean %MVIC of each muscle for each tooth position according to different visual aids. Regarding #16, as shown in Table 2, most of the muscles showed significant differences according to visual aids ($p < 0.05$). The order of muscle workload was Lt. erector spinae > Rt. erector spinae > Rt. upper trapezius > Lt. SCM without the use of any visual aid, where Lt. erector spinae was the significantly highest ($p < 0.05$). The mean %MVIC of these muscles were all reduced with the help of a microscope although the reduction was not statistically significant for Rt. erector spinae. Even with the use of a microscope, Lt. erector spinae remained to be the muscle with highest mean %MVIC followed by Rt. erector spinae but without significant difference between them. Meanwhile, working with a loupe did not have a significant impact on muscle workload of all muscles ($p > 0.05$).

Influence of visual aid according to muscle for #26

The mean %MVIC of each muscle during crown preparation of #26 according to different visual aids is compared in Table 3. Except for Rt. anterior deltoid, there were significant differences in mean %MVIC according to visual aid ($p < 0.05$), particularly between naked eye and microscope. Considering the mean %MVIC of all the muscles, statistical differences was noted between naked eye and loupe ($p = 0.027$), even though post hoc analysis revealed no significant difference according to a specific muscle. Similar to #16, although in slightly different order, the muscle with the highest workload during crown preparation with the naked eye was Lt. erector spinae followed by Rt. upper trapezius and Rt. erector spinae.

Influence of visual aid according to muscle for #36

Significant differences were observed between working with naked eye and microscope for Lt. upper trapezius, Rt SCM. And Rt erector spinae for #36 ($p < 0.005$, Table 4). Moreover, significant differences were noted between the use of a loupe and naked eye for Lt. upper trapezius and Rt. SCM ($p < 0.02$). Without the use of magnification,

Muscle	Mean % MVIC				Overall p-value	Post-hoc		
	Total	Naked eye (N)	Loupe (L)	Microscope (M)		N vs. L	N vs. M	L vs. M
Rt. Upper trapezius	17.47 ± 14.31	22.47 ± 14.43^{a}	19.91 ± 15.98^{I}	10.03 ± 8.27$^{\alpha}$	< 0.0001	0.5476	< 0.0001	< 0.0001
Lt. Upper trapezius	12.74 ± 11.32	17.48 ± 14.02^{a,b}	12.26 ± 9.94^{II}	8.47 ± 7.07$^{\alpha,\beta}$	< 0.0001	0.0025	< 0.0001	0.045
Rt. SCM	8.67 ± 7.20	11.75 ± 9.45^{c}	8.37 ± 6.37^{II}	5.91 ± 3.07$^{\beta}$	< 0.0001	0.002	< 0.0001	0.0386
Lt. SCM	10.02 ± 7.70	13.60 ± 10.19^{b,c}	9.33 ± 6.52^{II}	7.15 ± 3.34$^{\alpha,\beta}$	< 0.0001	0.0002	< 0.0001	0.1136
Rt. Erector spinae	21.75 ± 11.79	25.74 ± 11.81^{a}	23.90 ± 11.83^{I}	15.61 ± 9.04$^{\gamma}$	< 0.0001	0.7363	< 0.0001	< 0.0001
Lt. Erector spinae	21.53 ± 13.23	24.82 ± 13.41^{a}	23.07 ± 9.67^{I}	16.71 ± 14.79$^{\gamma}$	< 0.0001	> 0.9999	< 0.0001	0.002
Rt. Ant. deltoid	8.34 ± 8.12	9.65 ± 8.54^{c}	8.68 ± 8.53^{II}	6.68 ± 7.00$^{\alpha,\beta}$	0.0349	> 0.9999	0.0333	0.2605
Lt. Ant. deltoid	3.16 ± 2.74	3.57 ± 3.50^{d}	3.55 ± 2.81^{III}	2.36 ± 1.24$^{\delta}$	0.002	> 0.9999	0.006	0.0072

Table 1. Mean %MVIC during crown preparation of all four first molars according to visual aids. Values are mean ± SD. The data is collected from the four surfaces of 4 teeth (#16, #26, #36, and #46) from six participants. Different alphabets indicate significant differences in mean %MVIC during crown preparation with the naked eye. Different Roman numbers indicate significant differences in mean %MVIC during crown preparation using a loupe. Different Greek alphabets indicate significant difference in mean %MVIC during crown preparation using a microscope. SCM, sternocleidomastoid; MVIC, maximum voluntary isometric contractions.

Muscle	Mean %MVIC				Overall *p*-value	post-hoc		
	Total	Naked eye (N)	Loupe (L)	Microscope (M)		N vs. L	N vs. M	L vs. M
Rt. Upper trapezius	16.70 ± 15.84	19.93 ± 13.61^{b}	21.89 ± 20.86^{I}	$8.28 \pm 6.37^{\alpha}$	0.0043	> 0.9999	0.0247	0.0067
Lt. Upper trapezius	8.56 ± 6.62	$10.67 \pm 7.21^{c,d}$	7.78 ± 6.19^{II}	$7.25 \pm 6.16^{\alpha}$	0.1579	0.3925	0.2244	>0.9999
Rt. SCM	7.99 ± 5.47	$10.08 \pm 6.10^{c,d}$	8.10 ± 5.90^{II}	$5.78 \pm 3.26^{\alpha}$	0.0217	0.5804	0.0176	0.3915
Lt. SCM	11.33 ± 8.92	$16.36 \pm 11.95^{b,d}$	11.13 ± 6.55^{II}	$6.50 \pm 3.00^{\alpha}$	0.0003	0.0825	0.0002	0.1507
Rt. Erector spinae	19.46 ± 9.94	20.99 ± 7.44^{b}	22.51 ± 12.19^{I}	$14.88 \pm 8.18^{\beta}$	0.0169	>0.9999	0.0875	0.021
Lt. Erector spinae	24.13 ± 13.86	30.27 ± 17.10^{a}	25.75 ± 7.92^{I}	$16.37 \pm 11.55^{\beta}$	0.0012	0.6726	0.001	0.0396
Rt. Ant. deltoid	6.04 ± 6.07	6.19 ± 6.09^{c}	5.82 ± 7.12^{II}	$6.10 \pm 5.11^{\alpha}$	0.9769	>0.9999	>0.9999	>0.9999
Lt. Ant. deltoid	4.02 ± 3.36	4.83 ± 4.38^{c}	4.58 ± 3.30^{II}	$2.64 \pm 1.33^{\alpha}$	0.0445	>0.9999	0.0684	0.1267

Table 2. Mean %MVIC during crown preparation of #16 according to visual aids. Values are mean ± SD. The data is collected from the four surfaces of tooth #16 from six participants. Different alphabets indicate significant differences in mean %MVIC during crown preparation with the naked eye. Different Roman numbers indicate significant differences in mean %MVIC during crown preparation using a loupe. Different Greek alphabets indicate significant difference in mean %MVIC during crown preparation using a microscope. SCM, sternocleidomastoid; MVIC, maximum voluntary isometric contractions.

Muscle	Mean %MVIC				Overall *p*-value	Post-hoc		
	Total	Naked eye (N)	Loupe (L)	Microscope (M)		N vs. L	N vs. M	L vs. M
Rt. Upper trapezius	17.38 ± 14.00	$24.81 \pm 16.98^{a,b}$	$18.22 \pm 9.80^{I,II}$	$9.10 \pm 9.54^{\alpha,\gamma}$	0.0002	0.2216	0.0002	0.0434
Lt. Upper trapezius	11.66 ± 10.44	$16.66 \pm 12.61^{b,c}$	$12.39 \pm 9.64^{II,III}$	$5.92 \pm 4.85^{\alpha,\beta}$	0.001	0.3824	0.0007	0.0663
Rt. SCM	8.12 ± 6.04	$11.11 \pm 7.49^{c,d}$	$8.08 \pm 5.34^{III,IV}$	$5.16 \pm 3.10^{\alpha,\beta}$	0.0021	0.1963	0.0014	0.226
Lt. SCM	11.87 ± 9.53	$16.72 \pm 11.99^{b,c}$	$11.86 \pm 8.59^{II,III}$	$7.04 \pm 3.73^{\alpha,\beta}$	0.0013	0.1771	0.0009	0.1846
Rt. Erector spinae	20.61 ± 10.54	$23.84 \pm 9.26^{a,b}$	23.75 ± 11.83^{I}	$14.23 \pm 7.34^{\gamma,\delta}$	0.0008	>0.9999	0.0029	0.0032
Lt. Erector spinae	23.22 ± 12.15	28.38 ± 12.08^{a}	25.00 ± 7.82^{I}	$16.29 \pm 12.93^{\delta}$	0.0011	0.893	0.0011	0.026
Rt. Ant. deltoid	6.26 ± 6.78	$7.22 \pm 8.46^{c,d}$	$6.31 \pm 6.94^{III,IV}$	$5.26 \pm 4.46^{\alpha,\beta}$	0.6107	>0.9999	0.9683	>0.9999
Lt. Ant. deltoid	3.90 ± 3.43	4.89 ± 4.72^{d}	4.39 ± 3.15^{IV}	$2.42 \pm 0.77^{\beta}$	0.0284	>0.9999	0.0349	0.1291

Table 3. Mean %MVIC during crown preparation of #26 according to visual aids. Values are mean ± SD. The data is collected from the four surfaces of tooth #26 from six participants. Different alphabets indicate significant differences in mean %MVIC during crown preparation with the naked eye. Different Roman numbers indicate significant differences in mean %MVIC during crown preparation using a loupe. Different Greek alphabets indicate significant difference in mean %MVIC during crown preparation using a microscope. SCM, sternocleidomastoid; MVIC, maximum voluntary isometric contractions.

Muscle	Mean %MVIC				Overall *p*-value	Post-hoc		
	Total	Naked Eye (N)	Loupe (L)	Microscope (M)		N vs. L	N vs. M	L vs. M
Rt. Upper trapezius	18.52 ± 14.37	$20.87 \pm 12.07^{a,b,c}$	$21.99 \pm 19.71^{I,II}$	$12.69 \pm 7.04^{\alpha,\beta,\gamma}$	0.048	>0.9999	0.1385	0.072
Lt. Upper trapezius	16.73 ± 15.06	$25.34 \pm 20.24^{a,b}$	$14.15 \pm 9.95^{II,III}$	$10.69 \pm 8.31^{\alpha,\beta,\gamma}$	0.0013	0.0202	0.0015	>0.9999
Rt. SCM	9.93 ± 9.52	$15.28 \pm 13.82^{b,c}$	$7.76 \pm 5.83^{III,IV}$	$6.74 \pm 3.07^{\gamma,\delta}$	0.0022	0.013	0.004	>0..9999
Lt. SCM	8.51 ± 5.98	$10.82 \pm 7.69^{c,d}$	$7.42 \pm 5.41^{III,IV}$	$7.29 \pm 3.70^{\gamma,\delta}$	0.0658	0.1421	0.1183	>0.9999
Rt. Erector spinae	23.05 ± 12.48	28.31 ± 13.51^{a}	23.75 ± 11.43^{I}	$17.10 \pm 10.05^{\alpha}$	0.006	0.5513	0.0046	0.1621
Lt. Erector spinae	18.27 ± 10.84	$20.55 \pm 10.75^{a,b,c}$	$19.79 \pm 9.03^{I,II}$	$14.48 \pm 11.94^{\alpha,\beta}$	0.1058	> 0.9999	0.1563	0.264
Rt. Ant. deltoid	9.33 ± 8.62	$10.62 \pm 8.46^{c,d}$	$9.41 \pm 8.23^{III,IV}$	$7.94 \pm 9.28^{\beta,\gamma,\delta}$	0.5655	>0.9999	0.8644	>0.9999
Lt. Ant. deltoid	2.36 ± 1.52	2.41 ± 1.14^{d}	2.67 ± 2.25^{IV}	$2.00 \pm 0.72^{\delta}$	0.3101	>0.9999	>0.9999	0.3909

Table 4. Mean %MVIC during crown preparation of #36 according to visual aids. Values are mean ± SD. The data is collected from the four surfaces of tooth #36 from six participants. Different alphabets indicate significant differences in mean %MVIC during crown preparation with the naked eye. Different Roman numbers indicate significant differences in mean %MVIC during crown preparation using a loupe. Different Greek alphabets indicate significant difference in mean %MVIC during crown preparation using a microscope. SCM, sternocleidomastoid; MVIC, maximum voluntary isometric contractions.

Muscle	Mean %MVIC				Overall p-value	Post-hoc		
	Total	Naked eye (N)	Loupe (L)	Microscope (M)		N vs. L	N vs. M	L vs. M
Rt. Upper trapezius	17.28 ± 13.15	24.28 ± 14.90^{a,b}	17.52 ± 10.81^{I,II,III}	10.05 ± 9.47$^{\alpha,\beta}$	0.0005	0.163	0.0003	0.1007
Lt. Upper trapezius	13.99 ± 10.07	17.27 ± 8.82^{b,c,d}	14.70 ± 12.13^{II,III,IV}	10.00 ± 7.74$^{\alpha,\beta}$	0.0379	> 0.9999	0.0357	0.2976
Rt. SCM	8.67 ± 7.10	10.53 ± 8.19^{d,e}	9.54 ± 8.27^{III,IV,V}	5.94 ± 2.81$^{\beta}$	0.0605	> 0.9999	0.0741	0.2272
Lt. SCM	8.39 ± 4.85	10.49 ± 6.86^{d,e}	6.90 ± 3.14^{IV,V}	7.76 ± 2.91$^{\alpha,\beta}$	0.0258	0.0291	0.141	> 0.9999
Rt. Erector spinae	23.87 ± 13.53	29.82 ± 14.16^{a}	25.58 ± 12.38^{I}	16.22 ± 10.51$^{\alpha,\gamma}$	0.0011	0.7261	0.001	0.0337
Lt. Erector spinae	20.50 ± 15.13	20.10 ± 10.11^{b,c}	21.72 ± 12.50^{I,II}	19.68 ± 21.10$^{\gamma}$	0.8883	> 0.9999	> 0.9999	> 0.9999
Rt. Ant. deltoid	11.72 ± 9.35	14.58 ± 8.73^{c,d}	13.17 ± 9.88^{II,III,IV}	7.42 ± 8.12$^{\alpha,\beta}$	0.0171	> 0.9999	0.0214	0.0872
Lt. Ant. deltoid	2.37 ± 1.54	2.15 ± 0.96^{e}	2.56 ± 1.74^{V}	2.38 ± 1.81$^{\beta}$	0.6629	> 0.9999	> 0.9999	> 0.9999

Table 5. Mean %MVIC during crown preparation of #46 according to visual aids. Values are mean ± SD. The data is collected from the four surfaces of tooth #46 from six participants. Different alphabets indicate significant differences in mean %MVIC during crown preparation with the naked eye. Different Roman numbers indicate significant differences in mean %MVIC during crown preparation using a loupe. Different Greek alphabets indicate significant difference in mean %MVIC during crown preparation using a microscope. SCM, sternocleidomastoid; MVIC, maximum voluntary isometric contractions.

the %MVIC according to muscle in descending order was Rt. erector spinae > Lt. upper trapezius > Rt. upper trapezius ≈ Lt. erector spinae. The muscle workload of Rt. erector spinae, which was the highest, showed significant difference only with the use of a microscope ($p < 0.05$). The workload of Lt. upper trapezius during crown preparation without visual aid was statistically different compared to that of loupe and microscope, presenting higher mean %MVIC ($p < 0.02$). No significant differences according to muscle was observed between loupe and microscope ($p > 0.05$).

Influence of visual aid according to muscle for #46

Considering crown preparation of #46 with the naked eye, mean %MVIC was highest for Rt. erector spinae, followed by Rt. upper trapezius and Lt. erector spinae (Table 5). Significant differences were found between Rt. erector spinae and Lt. erector spinae ($p < 0.05$). Using a loupe, the order changed to Rt. erector spinae > Lt. erector spinae > Rt. upper trapezius, but without significant difference. Workload of bilateral upper trapezius, Rt. erector spinae, and Rt. anterior deltoid showed significant difference only with the use of a microscope ($p < 0.03$).

Summary of the influence of visual aid according to muscle and tooth position

As seen in Table 6, the majority of significant differences was observed between the naked eye and microscope, and this finding was dominant during crown preparation of #26 ($p < 0.05$). Meanwhile statistical difference between naked eye and loupe was observed in the mandibular first molars (#36 and #46) while statistical differences in muscle workload between loupe and microscope was observed in the maxillary first molars (#16 and #26). As for muscle, the muscles that were the least affected according to visual aid were bilateral anterior deltoids, and the most frequently affected was Rt. erector spinae.

Muscle	#16	#26	#36	#46
Rt. Upper trapezius	**N vs. M** **L vs. M**	**N vs. M** **L vs. M**		**N vs. M**
Lt. Upper trapezius		**N vs. M**	**N vs. L** **N vs. M**	**N vs. M**
Rt. SCM	**N vs. M**	**N vs. M**	**N vs. L** **N vs. M**	
Lt. SCM	**N vs. M**	**N vs. M**		**N vs. L**
Rt. Erector spinae	**L vs. M**	**N vs. M** **L vs. M**	**N vs. M**	**N vs. M** **L vs. M**
Lt. Erector spinae	**N vs. M** **L vs. M**	**N vs. M** **L vs. M**		
Rt. Ant. deltoid				**N vs. M**
Lt. Ant. deltoid		**N vs. M**		

Table 6. Summary of the significant differences of visual aid according to tooth position. The significant differences of mean %MVIC according to visual aids from Tables 3, 4, 5 and 6 are summarized. The bold depict significant differences of muscle workload and the detailed type of visual aid with significant difference of %MVIC for post-hoc analysis is written inside. N, naked eye; L, loupe; and M, microscope.

Comparison of muscle workload according to tooth position

When evaluated according to tooth position (#16, #26, #36, and #46), no significant differences in mean %MVIC of each muscle were detected (Supplementary Table S1). Although not significant ($p = 0.051$), substantial difference was noted for Lt. upper trapezius between #16 and #36, with higher muscle workload during crown preparation of tooth #36.

Influence of visual aid according to tooth surface

Figure 1 illustrates the mean %MVIC of the studied muscles according tooth surface of each tooth. Detailed values corresponding to Fig. 1 are shown in Supplementary Table S2. When evaluated according to tooth surface, significant differences are observed mostly between the naked eye and microscope ($p < 0.05$), with lower %MVIC with the use of a microscope. These findings were observed especially for maxillary first molars (#16 and #26). Furthermore, regardless of tooth position, muscle workload during crown preparation of the proximal surface was significantly reduced with the help of a microscope compared to working with the naked eye ($p < 0.05$).

Discussion

Previous studies that evaluate the effect of magnification have focused on the effect of loupes on muscle workload of dentists during class I cavity preparations[19], periodontal probing[20], and tooth drilling, filling and polishing for composite resin restorations[18,21]. No study that has assessed the use of microscope during crown preparation was noted. Therefore, this study aimed to assess the effect of not only loupe but also microscope on muscle workload during crown preparation.

In this study, compared to working with the naked eye, the muscle workload of most muscles was reduced with the use of a loupe (Tables 1, 2, 3, 4, 5 and 6). This finding is in accordance with a recent study that found that the use of a Galilean loupe resulted in lower muscle activity in the neck and back regions (trapezius and SCM) as well as less angular deviations of the neck and trunk during Class I cavity preparations[22]. The assumed ergonomic benefits of loupes can be attributed to the fixed working distance due to magnification and the declination angles[20,23]. These two characteristics render the operator free to move yet forced to stay relatively in a less forward-flexion neck position and thereby reduce the workload for neck and back muscles. The positive impact of declination angle on posture is stressed in previous articles. Loupes that allow a steeper declination angle allow

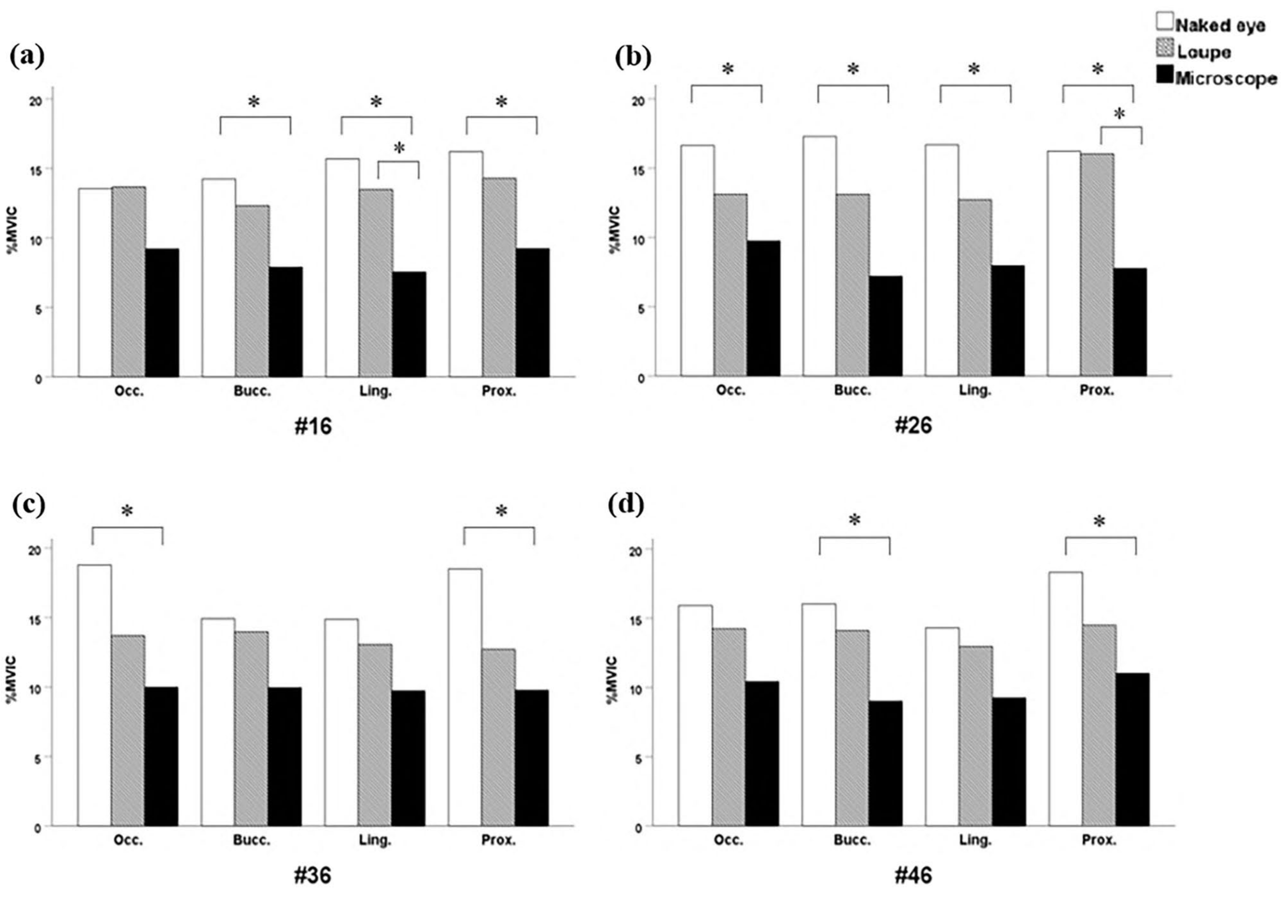

Figure 1. Mean %MVIC of the eight muscles using different visual aid according to tooth surface in each tooth. (**a**) #16, (**b**) #26, (**c**) #36, and (**d**) #46. Occ., Occlusal; Bucc., buccal; Ling., Lingual; Prox., Proximal. *Significant differences between visual aids with $p < 0.05$.

the operator to work in a more neutral position[25]. However, in this study there were some exceptions where the use of a loupe instead resulted in higher muscle workload compared to working with the naked eye, although the difference was not significant. This may be because two participants of this study do not routinely use loupe in clinic, and thus were unfamiliar with its use. Since only six participants were involved in this study, it can be assumed that their outranging values had a considerable effect on the results.

Most of the significant differences in mean %MVIC were dominantly observed between naked eye and microscope according to muscle (Tables 1, 2, 3, 4, 5 and 6). Compared to loupes, microscopes allow higher magnification levels and further constrains flexion and rotation of the operator's neck. One major difference from loupes is that it is not worn and almost every component of the microscope is adjustable in order to allow the operator to work at the most erect posture with minimal range of movement. For example, most have extendable binoculars and left/right swivel of the main body enables the operator to tilt the microscope in a vertical angulation without altering the horizontal level of the eyepieces. These characteristics allow the operator to work in a more erect position, especially of the neck.

Significant differences in muscle workload between the naked eye and loupe was only observed for mandibular first molars (Tables 5 and 6), whereas significant differences between loupe and microscope was only seen for maxillary molars (Tables 2 and 3). A possible explanation for this could be that since mandibular molars are further from the eyes, it is likely that the operator will lean more forwards for better vision during treatment without visual aid resulting in the greater enhancement of posture with the use of a loupe. On the other hand, during crown preparation of maxillary molars, dentists should tilt their heads to the right and rotate them to the left side while adopting a forward-head posture. In this situation, using a microscope may be more effective in reducing muscle workload compared to using a loupe.

Evaluating according to muscle, the results of this study showed that the mean %MVIC of cervical erector spinae, upper trapezius, and SCM differed significantly among the three types of visual aid. During crown preparation with the naked eye, the muscles with the highest workload was cervical erector spinae and upper trapezius regardless of tooth type. This is an anticipated result as dental treatments require the operator to be in a forward-head posture, forward flexion and rotation of the cervical spine, as well as slight elevation of the scapula in order to gain vision and access to the patient's teeth which is located lower, in front of the operator.

Although statistical differences for the cervical erector spinae muscle was observed according to visual aids, it remained to be the muscle with the highest workload irrespective of visual aid and tooth type. According to a systematic review, although dental loupes enhance working posture and relieves shoulder and arm pain, their effect on neck pain is scarce[26]. The neck muscles observed in this study were the cervical erector spinae and SCM. The role of the erector spinae may account for its greater muscle activity. A major function of the cervical erector spinae is to support the head when it deviates forward or to the side, away from the body's center of gravity. Even though the use of visual aids can reduce the amount of neck flexion, absolute neutral position is virtually impossible, even with the help of a microscope. The approximate degree of the axis of cervical spine during crown preparation can be estimated to be 60° without the use of any visual aid, 45° when using a loupe, and 15° when using a microscope. Assuming the head is approximately 5 kg at neutral position, these positions exert forces of 27.2 kg, 22.2 kg, and 12.2 kg to the cervical spine, respectively[24]. Therefore, to prevent neck pain, implementing additional strategies like stretching and scheduling regular breaks may be beneficial.

When treating the maxillary first molars (#16 and #26) the muscle workload of the left erector spinae was higher than the right side (Tables 2 and 3), and vice versa when treating the mandibular first molars (#36 and #46) (Tables 4 and 5). This may be due to the fact that because right-handed dentists usually work on the right side of the patient, gaining vision to the maxillary teeth requires more rotation of the head to the left side which requires more workload for the left erector spinae, than the right. Meanwhile, during the preparation of mandibular molars, the cervical spine is required to be flexed laterally to the left while maintaining a forward-flexed posture. Consequently, to prevent the head from dropping, the right erector spinae must be activated, in order to help align the head closer to the body's center of gravity. However, this explanation cannot be generalized as the preferred position during dental treatment varies greatly among dentists and depends on whether a direct view or a mirror view is used.

As demonstrated in Table 6, the muscle that was the least influenced by visual aid was anterior deltoid. However, the fact that the anterior deltoid muscle did not show significant difference according to visual aid may be attributed to its relatively low mean %MVIC. Since the function of anterior deltoid is flexion as well as internal rotation of the arm, this muscle may not be routinely used during crown preparation. Moreover, given that the distance between the patient and dentist doesn't vary greatly, there is minimal likelihood of needing to significantly flex the shoulders throughout the procedure. This finding is consistent with results from a previous study that found significant improvements in the positions of the head and neck but not in the arms, when using loupes as compared to those working with unaided eyes[23].

No significant difference in muscle workload was found according to tooth position (Supplementary Table S1). However, this finding needs to be interpreted with caution because the average of the mean %MVIC of all types of visual aids was used for analysis. Therefore, the low muscle activities during crown preparation using a microscope might have masked the differences according to tooth type.

Evaluating from tooth surface factor (Fig. 1), significant differences in overall muscle workload was noted between the naked eye and microscope during crown preparation of the proximal surface of every tooth position ($p < 0.05$). This implies that with the help of a microscope, muscle workload can be reduced substantially regardless of tooth type when performing crown preparation of the proximal surface. Taking into account that the proximal surface is often considered as the most strenuous surface to work on, this finding could potentially reduce the physical strain for dentists.

This study has several limitations. Firstly, since the crown preparations were conducted on a phantom, they do not accurately replicate clinical conditions, such as the presence of the patient's tongue and cheek, which could lead to an underestimation of the results. Secondly, given the relatively small field of view offered by microscopes, frequent adjustments might be required during actual crown preparations in patients, which may potentially result in a higher muscle workload than what was observed in this study. Furthermore, as this study did not assess the quality of the crown preparations, a comparison of preparation quality based on the type of visual aid used is also required. Lastly, considering that posture during crown preparation can vary significantly among operators, studies involving a larger number of participants appear to be necessary.

As a conclusion, the muscle workload of bilateral upper trapezius, cervical erector spinae, and sternocleidomastoid differed significantly according to type of visual aid. Within the limitation of this study, although significant differences in the muscle workload of cervical erector spinae was observed, it remained to be the muscle with the highest workload. Moreover, implementing a microscope for crown preparation may be helpful in reducing muscle workload by enabling the dentist to work in a more upright posture.

Methods

Participants

Six dentists from a Department of Conservative Dentistry in a single tertiary hospital participated in this pilot study. The inclusion criterion was right-handed dentists without any self-reported musculoskeletal pain. After a thorough explanation of the purpose and the procedures of this study, written informed consent was obtained. The study protocol was approved by the relevant institutional review board (3-2022-0272) and complied with the principles of Good Clinical Practice and the Declaration of the World Medical Association.

Gold crown preparation procedures

Gold crown preparations were performed on artificial first molars in each quadrant, including the maxillary right first molar, maxillary left first molar, mandibular right first molar, and mandibular left first molar. A 3-min break was given between each crown preparation. All participants performed four crown preparations without any visual aids (naked eye), using a Galilean loupe of their own with 2.5× magnification (*EyeMag® Smart,* Carl Zeiss, Jena, Germany or *SurgeLoup®*, Crystal Optic, Incheon, South Korea), and using a dental microscope under 4.0× magnification (OPMI® pico, Carl Zeiss, Jena, Germany).

The procedures were performed on a phantom (Mannequin trunk type, Nissin, Kyoto, Japan) that was placed on a dental chair (Intego, Dentsply Sirona, Bensheim, Germany) in order to simulate treatment in a clinical setting. A new 102R diamond bur (Shofu inc., Kyoto, Japan) was given to each participant. The participants were allowed to adopt their usual treatment posture and adjust the position of the phantom. All treatment was performed with direct view and the dental mirror was used for retraction when needed.

Muscle workload measurement

Surface electromyographic signals were recorded with FreeEMG 1000 8ch (BTS Bioengineering, Milano, Italy) and the wireless, Bluetooth-based electrodes were placed with an inter-electrode distance fixed at 2 cm, parallel to the muscle fibers, at the locations described in Table 7. The skin was prepped by cleansing the electrode placement area with an alcohol swab. For each tooth, the sEMG data was collected separately, according to tooth surface; occlusal, buccal, lingual/palatal, and proximal. The sEMG signal was recorded for 90 s for each tooth surface, followed by a rest time of 90 s in order to prevent fatigue. The initial and final 30 s of the obtained EMG signal was discarded and the middle 30 s was used for analysis.

Before crown preparation, in order to normalize the data obtained, each participant performed three trials of resisted maximum voluntary isometric contractions (MVICs) for 3 s with 20 s of recovery break between each trial for each measured muscle. For upper trapezius, the participants elevated their shoulders with maximum strength while manual pressure in the opposite direction strong enough to maintain isometric contraction was applied by the examiner. Lateral flexion of the neck for SCM, extension of the neck cervical erector spinae, and abduction of the arm for anterior deltoid was performed in the same way. The mean MVIC of the three trials was used for analysis. The participants rested for 10 min before commencing the experimental procedure.

Muscle workload data for each muscle obtained from the electrodes were analyzed using EMG Analyzer (BTS Bioengineering, Milano, Italy). The sampling rate was 1,000 Hz and the raw EMG data were processed using the root mean square (RMS) with 50 ms and 20–500 Hz filter. The EMG measurements converted to the percentage of MVIC (% MVIC) was used for comparison in this study, as shown in Eq. (1).

$$\%\mathrm{MVIC} = \frac{mean\ task - oriented\ RMS}{mean\ MVIC\ RMS} \times 100 \quad (1)$$

Muscle	Electrode placement
Upper trapezius	20% medial to half the length between lateral part of acromion and C7[27]
Sternocleidomastoid	Half the length between origin sternal notch and insertion mastoid process[28]
Erector spinae	1 cm away from the 4th cervical spinous process[15,29,30]
Anterior deltoid	Midpoint between electrodes at 2 cm anterior to midpoint between acromion and deltoid tuberosity[31]

Table 7. Placement of electrodes on selected muscles.

Statistical analysis

SAS version 9.4 (SAS Institute, Cary, NC, USA) was used for the statistical analysis. Shapiro–Wilk test and Kolmogorov–Smirnov test was used to test for the normality of data distribution. ANOVA was used to determine the differences of %MVIC among different types of visual aids (naked eye, loupe, microscope) and muscle (bilateral upper trapezius, sternocleidomastoid, cervical erector spinae, and anterior deltoid) according to tooth position (#16, #26, #36, and #46). Significant differences in muscle workload according to tooth position and the effect of visual aid according to tooth surface (occlusal, buccal, lingual/ palatal, and proximal) was also examined. Bonferroni correction was applied for the p-value of post-hoc analysis ($p < 0.05$).

Ethical approval

The study was approved by the Ethics Committee of the Gangnam Severance Hospital (IRB No.: 3-2022-0272).

Data availability

Data for the results of this study are available from the corresponding author upon reasonable request.

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Conception and design of the study: S. Hong, J.W. Park, J. Park; Acquisition and analysis of data: S. Hong, J.W. Park, J. Park; Drafting the manuscript or figures: S. Hong, J.W. Park, S.J. Shin, M.J. Jeon, J. Park, J.H. Park. S. Hong and J. Park contributed equally to this work as co-first authors.

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The authors declare no competing interests.

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