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ORIGINAL ARTICLE

Effects of occlusal conditions on masseter and temporalis muscle activity: An electromyographic evaluation

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KEYWORDS

Electromyography;
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Abstract *Introduction:* Dental occlusion contributes to the development of temporomandibular disorder.

Objective: This case control study examined the influence of different occlusal conditions on the surface electromyography (sEMG) of the superficial part of the masseter muscle (MM) and anterior part of the temporalis muscle (TA) during clenching in the maximum intercuspal position (MIP).

Materials and methods: Twelve healthy subjects had their anterior, right posterior, or left posterior teeth added by composite resin to generate the bilateral posterior, unilateral left, or unilateral right posterior tooth losses, respectively. Muscle activity in the resting stage, MM's and TA's maximum voluntary clenching (MVC; µV) in MIP, each muscle activity's symmetry (%), and ipsilateral MM and TA synergy (%) were measured by sEMG. All parameters were analyzed by SPSS version 23.0, and the significance level was set at $p < 0.05$.

Results: The MM's and TA's sEMG activity at the resting stage significantly differed from those at the other occlusal conditions ($p < 0.05$). Both muscles' MVC were highest at the MIP during clenching but lowest during anterior clenching. During unilateral posterior clenching, such MVC was higher at the occluding than at the non-occluding sides. The TA's symmetry during clenching at the anterior and unilateral posterior teeth was lower than that at the MIP during clenching. No significant difference was seen in the ipsilateral MM and TA synergy.

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Conclusion: Different occlusal conditions influenced the MM's and TA's sEMG activity. Each masticatory muscle responded differently to the same occlusal conditions.

1. Introduction

Dental occlusion and an unbalanced masticatory system contribute to developing temporomandibular disorders (TMDs) (Manfredini et al., 2017; de Kanter et al., 2018; Al-Ani, 2020). Patients who had lost posterior teeth showed an increased prevalence towards TMDs (Wang et al., 2009). When many posterior teeth are missing, the condyles are more displaced, while the occlusal force is decreased (Kozawa et al., 2003; Seedorf et al., 2004; Kirihara et al., 2005). When the masticatory system is unbalanced, the pressure on the TMJ is affected (Jurt et al., 2020; Sagl et al., 2021). The subjects that chewed unilaterally demonstrated more signs and symptoms of TMDs when compared to the control subjects (Reinhardt et al., 2006).

Surface electromyography (sEMG) is widely used to evaluate muscle functions. This is because using a needle EMG may be invasive and cause complications such as bleeding, pain, or infections (Woźniak et al., 2013; Rubin, 2012). sEMG can monitor masticatory muscle functions such as maximum voluntary clenching (MVC), muscle activity's symmetry, and ipsilateral of the superficial fiber of masseter muscle (MM) and the anterior fiber of temporalis muscle (TA) synergy (Kulchutisin et al., 2022).

MVC is the highest muscle activity when the subject clenches their teeth in the maximum intercuspal position (MIP). The subjects with greater occlusal contact had significantly higher MVC than the ones with less occlusal contact (Ferrario et al., 2002; Pativetpinyo et al., 2018). Healthy subjects had a higher MVC of the masticatory muscles compared to patients with TMDs (Ginszt and Zieliński, 2021).

sEMG activity between the muscles on the left and right sides indicated their equilibrium. Both MM and TA showed asymmetry during chewing and submaximal clenching (McCarroll et al., 1989). Differences were found in the symmetry index of both MM and TA between the TMDs patients and the healthy subjects (Ginszt and Zieliński, 2021).

The occlusal conditions that influenced both MM and TA activities were documented by Wang et al. (2009, 2010). The MM's and TA's sEMG activity decreased when the subjects clenched on the premolar area, compared to the molar area (Wang et al., 2009). The sEMG activity of MM and TA on the laterotrusive side was significantly higher than those on the mediotrusive side (McCarroll et al., 1989; Wang et al., 2010; Pativetpinyo et al., 2018). Prior studies used cotton rolls to modify the occlusal conditions because it is the most convenient method. This study will mimic natural occlusal contact, which will represent real situations for patients who had lost their bilateral posterior, unilateral left, or unilateral right posterior teeth support, by modifying the occlusal contact using composite resin.

This study aimed to examine the influence of different dental occlusal conditions on the MM's and TA's sEMG activity while clenching in MIP. The null hypothesis was no relationship between dental occlusions and MM's or TA's sEMG activity. The alternative hypothesis was that alterations in dental occlusions would affect muscle function.

2. Materials and methods

Forty-seven dental students were randomly recruited from the Faculty of Dentistry, Naresuan University, Phitsanulok, Thailand. All of them received a clinical examination by an occlusion and orofacial pain specialist at the occlusion clinic, Dental Hospital of Naresuan University, and twelve were selected to participate in this study. The sample size calculator for comparing paired differences was used to calculate the study participants (Dhand and Khatkar, 2014). The expected difference means and standard deviation (SD) of TA and MM were 62 ± 65.7 and 137 ± 63.3 μV, respectively (Wang et al., 2010). All subjects signed informed consent and ethical approval forms provided by the Naresuan University Ethical Committee (IRB Number P10105/63).

All subjects had symmetrical dental arches with at least 28 permanent teeth, Angle's classification I, a positive value of overjet and overbite, with a lower midline shift of less than 5 mm (Saifuddin et al., 2003), and a body mass index (BMI) of less than 22.9 kg m^{-2} (Deurenberg and Yap, 1999). No subjects had signs or symptoms of TMDs, periodontal disease, a posterior crossbite, ongoing orthodontic treatment, or previous use of botulinum toxin treatment in the masticatory muscles. None of the subjects used muscle relaxants or had diseases that could affect muscle function (myasthenia gravis, dystonia, muscular dystrophy, multiple sclerosis, and neuromuscular disorders).

sEMG (BioEMGIII and BioPAK Measurement System; BioResearch Associates, Inc., Milwaukee, WI, USA) was used for measuring MM's and TA's sEMG activity. The area around the MM, TA, and the 7^{th} cervical vertebra was cleaned with 70% ethanol before attaching the surface electrode (3M Red dotTM; 3M Health care, Canada) parallel to muscle fibers with a fixed inter-electrodes distance (Fig. 1). The sensor placement was following with the guidelines of the Surface Electromyography for Non-invasive Assessment of Muscles (SENIAM) standards (Hermens et al., 2000). Using palpation, MM is located at the angle of the mandible and extends upward in an oblique and anteriorly direction to the zygomatic arch. TA is located above the ear and is attached vertically and posteriorly to the zygomatic bone.

Interference and noise tests were carried out using the BioPAK software before each measurement was taken. The muscle activity was measured in the rest position and at maximum clenching for 3-4 s (Yoshimi et al., 2009). The activity of both muscles in the resting stage and tooth clenching were measured when the subjects were sat in a dental unit with headrest support and their eyes open. All subjects had to clench their teeth in four different occlusal conditions: MIP, anterior, unilateral left, and unilateral right posterior clenching. A light-cured composite resin (Estelite®; Tokuyama Dental, Tokyo, Japan) was used to modify the teeth to simulate each occlusal condition. All subjects generated the new occlusion by having their overbite measured in the MIP to the baseline (Red line in Fig. 2A). After that, the blue line was plotted 1 mm above the red line to indicate the thickness of composite resin when simulating each occlusal condition (Fig. 2A). The palatal surface of the anterior maxillary teeth was filled with composite resin, after which shim stock was applied before the subjects were asked to bite down until the incisal edge of anterior maxillary teeth reached the blue line (Fig. 2B). The composite resin was cured in this position. Shim stock was used to confirm the anterior teeth contact, which simulated the lack of contact of the bilateral posterior teeth. After the sEMG activity of the anterior clenching was measured, the composite resin was removed from the teeth. This was followed by the right or left mandibular posterior teeth being filled with the composite resin similarly. This simulated the lack of contact between the unilateral left and unilateral right posterior teeth, respectively (Fig. 2C).

The muscle activity of each occlusal condition was recorded three times with 1-min intervals between repetitions, while the intervals between the different occlusal conditions were 5-min apart to avoid muscle fatigue. MVC was analyzed using the second clenching time to determine the average muscle activity (μV). MM and TA activity's symmetry (%) and ipsilateral MM and TA synergy were analyzed using a BioPAK program (Fig. 3).

2.1. Statistical analysis

The data were analyzed using the SPSS version 23.0 (IBM SPSS Statistics for Windows; IBM Corp, NY, USA), while the data normality was analyzed by the Shapiro-Wilk test was used to confirm the normality of the data. The means and SD of each parameter were used for descriptive statistics. Most of the data was assessed using the Kruskal-Wallis H test, except MM activity's symmetry was assessed by the One-Way Analysis of Variance (ANOVA), followed by the post hoc test. While the left and right sides of MM's and TA's sEMG activity were analyzed by the Mann-Whitney U Test. The significance level was set at $p < 0.05$.

3. Results

Table 1 shows the subject characteristics. Muscle activity in the resting stage, the MVC of both MM and TA, each muscle's activity symmetry, and the synergy of the ipsilateral of both MM and TA are shown in Table 2.

The MM's and TA's sEMG activity were lowest during the resting stage. Significant differences were detected in MM's and TA's sEMG activity between the resting stage and each occlusal condition. Although both sides of MM's and TA's sEMG activity during the anterior clenching was lower than MIP clenching, there was shown to be no significantly different.

When the subjects clenched their teeth in a unilateral position (left or right unilateral posterior clenching), both MM's and TA's sEMG activity were higher on the occluding side than the non-occluding side. However, there were no significant differences observed during this experiment.

For MM activity's symmetry, the highest value was seen in anterior clenching (75.33–92.67%), and this occlusal status was significantly different from the left posterior clenching ($p = 0.015$).

For TA activity's symmetry, the highest value was seen in MIP clenching (60–97.33%), and this occlusal condition was significantly different from the resting stage ($p = 0.009$).

Under all occlusal conditions, the synergy of ipsilateral MM and TA showed no significant difference.

4. Discussion

This study indicated that occlusal conditions influenced the MM's and TA's sEMG activity differently. Thus, the null hypothesis was rejected.

It was found that the sEMG activity of MM was higher than TA at the resting stage, which corresponds with

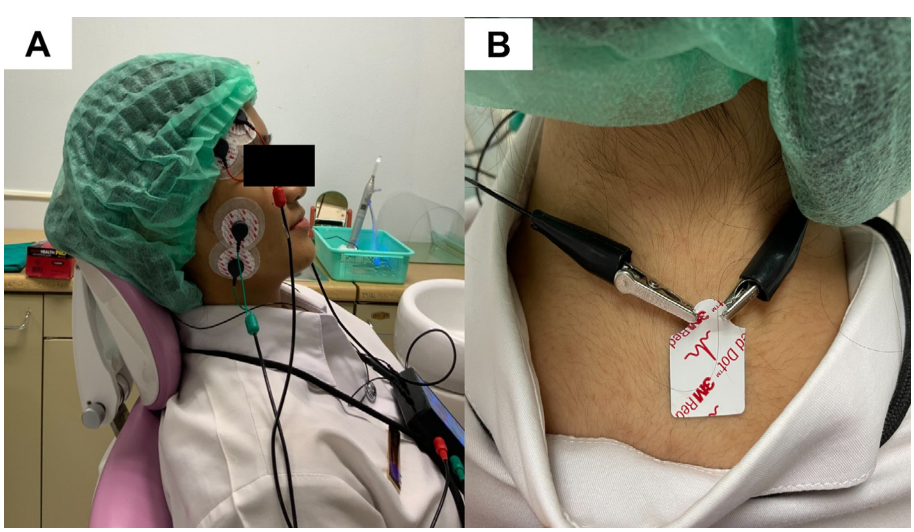

Fig. 1 Surface electromyography attached to the superficial part of the masseter muscle and the anterior part of the temporalis muscle (A). A ground electrode is attached to the posterior tubercle of the 7th cervical vertebra (B).

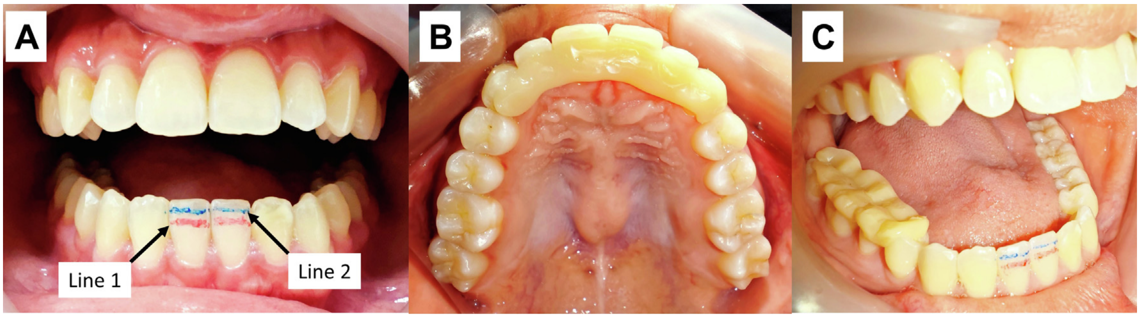

Fig. 2 The red line (line 1) indicates the overbite of the subject, while the blue line (line 2) is drawn 1 mm above the red line to mark the thickness of composite resin when biting (A). Composite resin was used to simulate the anterior clenching (B) and the unilateral posterior clenching (C).

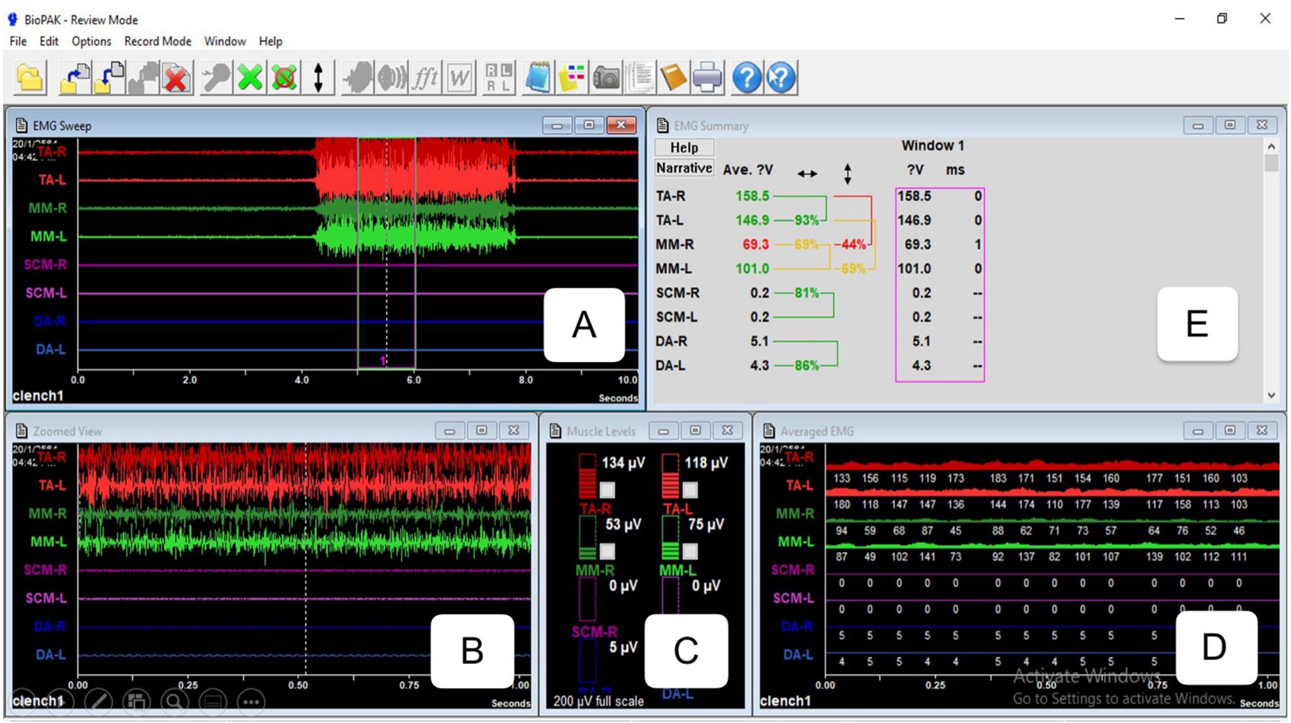

Fig. 3 BioPAK program is shown the anterior part of the temporalis muscle (TA, red line) and the superficial part of the masseter muscle (MM, green line) activity during maximum voluntary clenching at each occlusal condition (A). Zoomed view of muscle activity (B), each muscle activity levels (C) and averaged electromyography (EMG) (D) are shown in lower diagrams. The percentage of muscle activity's symmetry analyzed by BioPAK software. The ↔ column indicates the balance between the left (L) and right (R) side of each muscle activity, while ↕ indicates the balance between unilateral MM and TA activity (E). The time recording(s) is shown on the x-axis of each figure. µV; microvoltage, Ave. µV; averaged µV, SCM; sternocleidomastoid muscle, DA; digastric muscle.

previously reported investigations (Wang et al., 2009; Wang et al., 2010). The temporalis, masseter, and medial pterygoid muscles influence controlling the freeway space. However, MM is the strongest because its fibers align vertically to the angle of the mandible, which enables a more powerful contraction during its function. Due to anatomical limitations, the muscle activity of TA was measured only at the anterior part. This may explain why TA's sEMG activity at the resting stage was less than the MM (Yabushita et al., 2005; Widmer et al., 2013).

Both muscles exhibited the highest sEMG values during MIP clenching, while the lowest values were when the anterior teeth were clenched due to the patients having lost their bilateral posterior teeth. Our results agreed with a previous study that found the anterior clenching caused a reduction in the MM's and TA's sEMG activity (Wang et al., 2009). The periodontal mechanoreceptors (PMRs), abundant in the anterior teeth region, play a crucial role in the jaw-opening reflex. When the PMRs are activated, the afferent impulse will activate the muscles to control jaw opening and inhibit the

Table 1 Subject characteristics (mean ± SD).

Gender	Age (years)	Body weight (kg.)	Height (cm.)	Body Mass Index (kg m-2)
Male (n = 2)	23.00 ± 1.41	59.50 ± 3.54	167.00 ± 0.00	21.34 ± 1.27
Female (n = 10)	22.90 ± 0.88	52.80 ± 6.97	160.10 ± 7.09	20.57 ± 2.13
Total (n = 12)	22.92 ± 0.90	53.92 ± 6.91	161.25 ± 6.96	20.70 ± 1.99

Abbreviations: SD, standard deviation.

Table 2 Muscle activity, symmetry of the muscle, and synergy of the temporalis and the masseter muscle in different occlusal conditions.

	Occlusal conditions					
	Resting	**MIP**	**Anterior**	**Left**	**Right**	**p-value**
Muscle activity in MVC (μV; mean ± SD)						
Masseter muscle						
Left	11.83 ± 1.74	123.05 ± 20.89[a]	88.76 ± 8.47[a]	113.74 ± 18.37[a]	103.18 ± 16.90[a]	p < 0.05
Right	17.24 ± 2.39	106.80 ± 13.32[a]	91.27 ± 9.60[a]	82.78 ± 19.95[a]	121.64 ± 19.38[a]	p < 0.05
p-value	p = 0.119	p = 0.525	p = 0.773	p = 0.05	p = 0.299	
Temporalis muscle						
Left	8.10 ± 1.12	135.43 ± 16.00[a]	74.03 ± 10.41[a]	119.42 ± 13.01[a]	104.61 ± 13.86[a]	p < 0.05
Right	11.48 ± 1.92	138.31 ± 16.46[a]	93.01 ± 11.67[a]	98.78 ± 15.08[a]	132.17 ± 15.74[a]	p < 0.05
p-value	p = 0.248	p = 0.954	p = 0.273	p = 0.225	p = 0.083	
Symmetry of muscle activity in MVC (%; mean ± SD)						
Masseter muscle						
Left-Right	66.90 ± 5.64	76.33 ± 2.73	85.19 ± 1.51[b]	61.47 ± 5.80[b]	79.25 ± 4.82	p < 0.05
Temporalis muscle						
Left-Right	64.81 ± 4.67	86.50 ± 2.84[a]	70.36 ± 4.64	68.53 ± 5.66	77.10 ± 3.46	p < 0.05
Synergy between ipsilateral of temporalis and masseter muscle in MVC (%; mean ± SD)						
Left	64.99 ± 22.03	68.92 ± 11.95	72.77 ± 19.73	72.36 ± 13.94	71.39 ± 15.79	p > 0.05
Right	61.14 ± 18.38	74.22 ± 17.91	71.86 ± 17.91	68.19 ± 18.22	74.56 ± 16.16	p > 0.05

Note: a; indicate the significant differences compared to the resting stage at $p < 0.05$.
Other similar superscript letters represent intrarow significant differences at $p < 0.05$.
Abbreviations, MVC, maximum voluntary clenching, SD, standard deviation.

contraction of muscles to control jaw closing (Türker, 2002; Vaahtoniemi, 2020). This principle was used to generate the Nociceptive Trigeminal Inhibition-Tension Suppression System (NTI-TSS), which caused a reduction of sEMG activity of the jaw-closing muscles (Baad-Hansen et al., 2007; Lukic et al., 2021). In this study, the lowest sEMG values of both MM and TA during anterior clenching were caused by the activation of the PMRs.

The posterior teeth have more occlusal contact area than the anterior teeth, which results in an increase in occlusal force (Chutchalermpan et al., 2019). The amount of occlusal force also depends on the distance of the teeth from the TMJ and jaw-closing muscles. The closer the teeth are to the TMJ, the greater the occlusal force becomes (Okeson, 2019). This demonstrates why most anterior clenching has less sEMG activity than unilateral posterior or MIP clenching.

The difference in MM's and TA's sEMG activity on each side was detected during unilateral posterior clenching. Although there was no significant difference on either side, the MM's and TA's sEMG activity had greater at the occluding than at the non-occluding sides. These results are consistent with previous studies that found muscle activity was always lower on the mediotrusive side than on the laterotrusive side (Wang et al., 2009; Wang et al., 2010; Pativetpinyo et al., 2018).

The percentage of MM's equilibrium on both sides was highest during anterior clenching, while TA was highest during MIP clenching. Submaximal clenching influences muscle balance; the lower the force bites, the more unbalanced the muscles will be (McCarroll et al., 1989; Naeije et al., 1989). Therefore, when unilateral posterior clenching, MM's and TA's symmetry were decreased when compared to MIP clenching (except for the right posterior clenching of MM). This reduced functionality causes the muscles to lose their work balance. However, during the anterior clenching, the functional balance of MM was greater than MIP clenching, which is different from the TA. TA is more sensitive to sensory impulses than MM, particularly short-duration activation (Adhikari et al., 2011). Thus, a balance of the masticatory system may be maintained between MM and TA functions. When TA loses equilibrium, MM acts as a balancing agent. However, this assumption should be established further.

The unilateral chewing caused an imbalance in the compressive force of TMJ and altered the masticatory muscle functions (Smith et al., 1986; Okeson, 2019; Jurt et al., 2020). This situation can cause more signs and symptoms of TMDs than those who can chew on both sides (Yalcin Yeler et al., 2017; Santana-Mora et al., 2021).

The masticatory system cannot be viewed as discrete. Therefore, this study examined the ipsilateral MM and TA synergy to represent the systematic function of the masticatory system. However, the synergy of MM and TA under each occlusal condition presented no significant difference. These results imply that the masticatory system tries as hard as possible to maintain its functional balance.

4.1. Limitations

Due to some anatomical limitations, sEMG could not be placed on the whole MM or TA. Therefore, it should be kept in mind that the results of this experiment may differ from the actual function of these muscles.

In this study, the alteration of the occlusal condition by composite resin is temporary. In patients who chew food with their anterior or unilateral posterior teeth for a long time, the function of both muscles may be more pronounced.

5. Conclusions

In healthy subjects, the occlusal conditions influence the sEMG activity of the masticatory muscles. MM's and TA's sEMG activity were lowest during the resting stage and showed an increase during anterior clenching, unilateral posterior clenching, and MIP clenching, respectively. Unilateral posterior clenching will cause an imbalance in MM and TA activity.

CRediT authorship contribution statement

Jittima Pumklin: Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration. **Thanaporn Sowithayasakul:** Conceptualization, Methodology, Software, Investigation. **Chonlada Thaweemonkongsap:** Methodology, Investigation, Data curation. **Pattrapohn Saptasevee:** Methodology, Investigation, Data curation. **Pichamon Sangprasert:** Methodology, Investigation, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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