

Thera-Band application changes muscle activity and kyphosis and scapular winging during knee push-up plus in subjects with scapular winging

The cross-sectional study

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Abstract

Scapular winging (SW) is defined as increased prominence of the whole medial border of the scapula. Many researchers recently recommended knee push-up plus (KPP) for enhancing serratus anterior (SA) activation. However, during push-up plus, thoracic kyphosis (TK) may usually occur as a compensatory movement. Thus, the purpose of this study was to investigate the effect of Thera-Band application during KPP on rectus abdominis (RA) activity, TK angle (TKA), SA activity, and amount of SW in subjects with SW.

Fifteen subjects performed KPP with Thera-Band applied to different posterior body parts (no Thera-Band, in the occiput, and in the thoracic region). Electromyography was used to record the RA and SA activities. Image J software was used to calculate the compensatory TKA during KPP, and a scapulometer was used to measure SW in the quadruped position. One-way repeated-measures analysis of variance was used to test for significance.

KPP with Thera-Band in the occiput showed significantly lower RA activity ($P = .001$) and TKA ($P < .001$) than KPP with no Thera-Band. SA activity ($P = .020$, $P = .047$) and SW ($P < .001$, $P < .001$) were significantly lower with Thera-Band applied to the occiput and thoracic regions than in KPP with no Thera-Band.

Thera-Band applied to the occiput and thorax can be beneficial as it decreases RA and SA muscle activity and reduces TKA and SW during KPP in subjects with SW.

Abbreviations: KPP = knee push-up plus, RA = rectus abdominis, SA = serratus anterior, SW = scapular winging, TK = thoracic kyphosis, TKA = thoracic kyphosis angle.

Keywords: knee push-up plus, scapular winging, Thera-Band

1. Introduction

Scapular winging (SW), a type of scapular dyskinesia, is defined as increased prominence of the whole medial border of the scapula that increases the internal rotation of the scapula.^[1] It is caused by neuromuscular, musculoskeletal, and structural disorders. In particular, weakness of the serratus anterior (SA) muscle without thoracic nerve injury is an important cause of SW.^[2] SW contributes to loss of muscle power, limitation of shoulder flexion and abduction, and shoulder pain.^[3] Additionally, muscle imbalance involving excessive upper trapezius (UT)

activation and less activation of the SA and lower trapezius (LT) during shoulder flexion could cause SW.^[4–6]

Many researchers recently recommended knee push-up plus (KPP) for enhancing SA activation.^[2,7–9] KPP was used in the early rehabilitation stage because it demanded less shoulder resistance but elicited higher SA activity.^[2,7] Ludewig et al,^[9] reported higher normalized SA activity and lower UT/SA muscle ratio during KPP than during other modified push-up plus.

The plus phase during push-up plus results in the protraction of the scapula because it provides translation of the thorax posteriorly on a fixed scapula.^[10] However, during push-up plus, thoracic kyphosis (TK) may usually occur as a compensatory movement. Hyperkyphosis causes excessive scapular protraction and downward rotation.^[11,12] Thoracic erector spinae (TES) and rectus abdominis (RA) muscle activity are affected by trunk posture^[13]; especially, a flexed trunk posture inhibits TES and shortens RA. In addition, previous studies reported that TK is positively associated with forward head posture (FHP).^[14,15] Previous studies have investigated various methods for inhibiting FHP during scapular exercises, through craniocervical flexion, craniocervicothoracic stabilization, and scapular bracing.^[16–18] In particular, Song et al,^[16] studied the effect of craniocervical flexion during KPP. Increased TK angle (TKA) may change the scapulohumeral relationship and cause weakness of the shoulder complex muscle and limitation of the glenohumeral joint range of motion. Consequently, this posture may result in shoulder impingement.^[19,20] Song et al,^[16] suggested inhibition of excessive TKA during push-up plus.

Recently, Thera-Band has been used not only to provide resistance for exercise but also to deliver isometric contraction for

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muscle preactivation or reciprocal inhibition during therapeutic exercises. Choi et al,^[21] reported higher gluteus maximus activity during isometric hip abduction with Thera-Band application. Moreover, Park et al,^[22] reported higher SA activity during isometric horizontal abduction with Thera-Band. Therefore, we decided to apply Thera-Band to the occiput and thoracic regions because the thoracic curvature could be altered by improving cranio-cervical alignment through the activation of deep cervical flexors, and Thera-Band can reciprocally inhibit the RA muscle. Additionally, Thera-Band was also applied to examine whether different SA activity and the resultant change in the SW amount can be induced during KPP.

The purpose of our study was to compare the outcomes of different Thera-Band application conditions (no Thera-Band, Thera-Band in the occiput, and Thera-Band in the thoracic region) in RA activity, TKA, SA activity, and SW during KPP in subjects with SW. The hypothesis is that RA activity, TKA, SA activity, and SW would differ in different Thera-Band application conditions.

2. Methods

2.1. Study design and setting

The study design of this study was a cross-sectional study. Subjects were recruited from a University at Wonju in South Korea. All procedures were conducted in the applied kinesiology and ergonomic technology laboratory at Yonsei University. An informed consent form was read and signed by all subjects before the study. The Yonsei University Wonju Institutional Review Board approved this study (1041849-201701-BM-073-01).

2.2. Subjects

A sample size of 6 was calculated by using G-power software (with an α level of 0.05, power of 0.80, and effect size of 0.71 (Heinrich-Heine-Universität, Düsseldorf, Germany) calculated with a partial η of 0.334 from a pilot study of 6 subjects). Finally, 15 participants with SW were recruited (age 20.7 ± 1.1 years, height 168.9 ± 6.2 cm, weight 64.2 ± 6.9 kg, body mass index 22.5 ± 2.3 kg/m², SW 31.7 ± 6.6 mm). SW was determined by using a scapulometer. If the medial border of the scapula was protruded by >2 cm from the posterior thoracic rib cage, the scapula was classified to have winging.^[23] The greater SW side was adopted if both sides were determined as showing SW. Subjects were recruited if they showed excessive compensatory TKA during KPP ($46.8 \pm 10.0^\circ$). The exclusion criteria were: SW secondary to posterior shoulder tightness^[24]; inability to perform at least 5° thoracic spine extension, because Katzman et al,^[25] reported that structural kyphosis is not corrected by various cues; upper-extremity problems such as shoulder tendinitis, instability, impingement, or pain due to difficulty of performing the exercise in this study.^[9]

2.3. Surface electromyography recording and data processing

Surface electromyography (EMG) data were collected from the RA and SA by using a Noraxon TeleMyo 2400 system (Noraxon Inc., Scottsdale, AZ). The Noraxon MyoResearch 1.06 XP software was used for data analysis. The sampling rate of EMG signals was 1000 Hz. The EMG signals were amplified, band-pass filtered from 20 to 450 Hz, and notch filtered at 60 Hz before processing in root mean square. After shaving the hair and

scrubbing the skin with alcohol, the principal investigator (PI) attached disposable Ag/AgCl surface electrodes on the subject's muscle belly. The RA electrode placement was 3 cm away laterally from the umbilicus.^[26,27] The SA electrode placement was 2 cm apart just below the axillary area, at the level of the scapular inferior tip and just anterior to the latissimus dorsi.^[28] To minimize cross-talk, 2 electrodes were placed approximately 2 cm apart in the muscle fiber direction. Maximal voluntary isometric contraction (MVIC), which was used to normalize EMG data, was measured according to the methods of previous studies.^[19,29–31] For the RA, the subject lied in the supine position and performed trunk flexion while the PI applied resistance to the subject's shoulders. For the SA, the subject sat on a chair and rotated the shoulder internally and abducted the shoulder to 125° in the scapular plane while the PI applied downward resistance to the subject's distal humerus. The subjects performed each position for 5 seconds and rested for 1 minute between trials to avoid muscle fatigue.^[30] The mean value of the middle 3 seconds among the 3 trials of 5-second contractions was taken for data analysis. The EMG signals recorded during 3 exercises were described as a percentage of MVIC (%MVIC).

2.4. TK angle and SW amount

TKA was measured during each condition by using an iPhone (Apple Inc., Cupertino) and the Image J software.^[32,33] First, reflective markers were attached on the subject's T1, T3, T11, and L1. Second, we positioned the camera at 2 m of the lateral side from the subject's trunk and took a picture during exercises. Then, we drew 2 lines to calculate the TKA by using Image J software (downloaded free from the Internet); one was connecting T1 and T3, and the other was connecting T11 and L1. Using Image J software, angle between 2 lines was measured (Fig. 1). The interclass correlation coefficient (ICC) of the TKA with Image J in this study was 0.99 (95% confidence interval [CI] 0.99–0.99, standard error of measurement [SEM] 0.54° , and minimal detectable change [MDC] 1.50°). We measured SW by using a scapulometer (Fig. 2). The scapulometer was positioned on the T5 spinous process and measured between the scapular medial border and spinous process. The ICC of the scapulometer in this study was 0.99 (95% CI 0.98–0.99, SEM 0.51 mm, and MDC 1.41 mm). TKA was measured during each condition to compare the compensatory TKA during KPP among the 3 conditions, and



Figure 1. The measurement of thoracic kyphosis angle.



Figure 2. Measurement of scapular winging by using a scapulometer.

SW was measured immediately after each condition to compare the change of SW after KPP in the 3 conditions.

2.5. Procedure

Before measurement, the PI determined the SW side of the shoulder and requested the subject to remove the upper garments. All subjects were identically educated by the PI on how to perform each exercise for approximately 10 minutes until the proper motion of each exercise was achieved. The order of exercises was randomized by using the Randomization website (<http://www.randomization.com>) to avoid learning effects. The subjects performed each exercise for 5 seconds. To minimize muscle fatigue, resting periods of 30 seconds between 3 trials and 10 minutes between exercises were allowed. The mean value of the 3 trials for each exercise was used in data analysis. TKA was measured during each condition to compare the compensatory TKA during KPP among the 3 conditions, and SW was measured immediately after each condition owing to the inability to measure SW during KPP.

2.5.1. KPP without Thera-Band (no Thera-Band condition).

KPP is a knee push-up with full protraction of the scapula (the “plus”) after full elbow extension with the palms and knees maintained at shoulder width. The KPP exercise was divided as follows: starting phase, holding phase, and ending phase. The starting phase involves scapular protraction by translating the trunk maximally posteriorly. Then, in the holding phase, the starting phase is maintained for 5 seconds. Finally, the ending phase involves returning to the starting position.^[34]

2.5.2. KPP with Thera-Band to the occiput (occiput condition). KPP with Thera-Band to the occiput was performed in the same way as KPP without Thera-Band, except that Thera-Band was placed at the occiput. For the Thera-Band application to the occiput, the head of the subject was positioned neutrally by the PI, and Thera-Band was placed around the occiput, with both ends of Thera-Band stabilized by using the palms. The tension of Thera-Band was determined according to the ability of each subject to perform >10 repetitions of standardized KPP with Thera-Band in each position.^[7,22] Each subject was instructed to maintain the assumed Thera-Band placement without actively extending the head or trunk against the resistance of the Thera-Band while performing a standardized KPP.

2.5.3. KPP with Thera-Band to the thoracic region (thoracic region condition). KPP with Thera-Band to the thoracic region was performed in the same way as in the occiput condition, except that Thera-Band was placed to the thoracic region, which is the apex of compensatory TKA during KPP. The thoracic region was determined by the PI through visual screening. Thera-Band was placed in the same manner as in the occiput condition, except Thera-Band was around the region with the most excessive TK (Fig. 3). The tension of the Thera-Band was also determined as in the occiput condition.

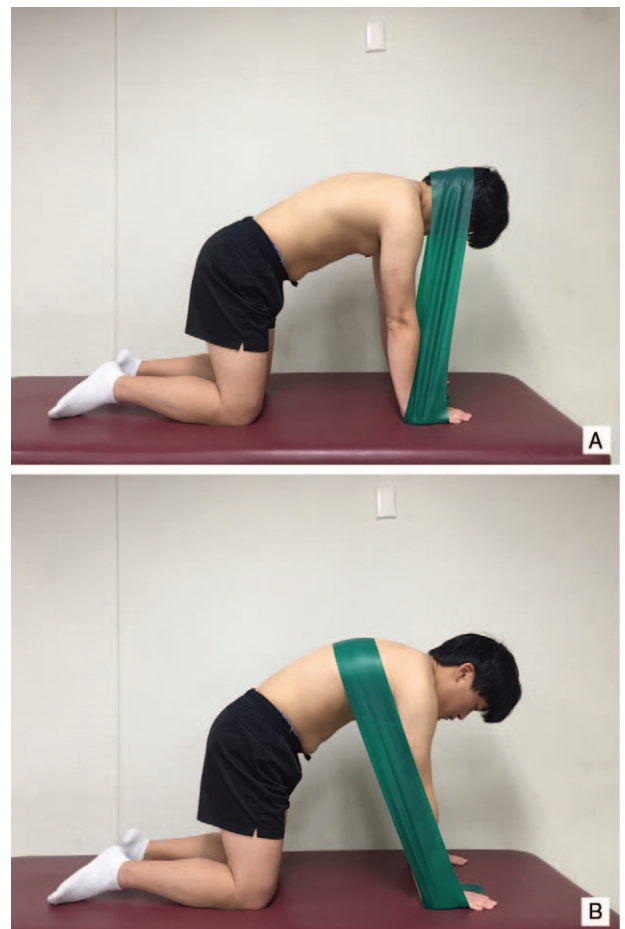


Figure 3. Thera-Band application to different posterior body parts. A: occiput, B: thoracic region (apex of the thoracic region during KPP). KPP = knee push-up plus.

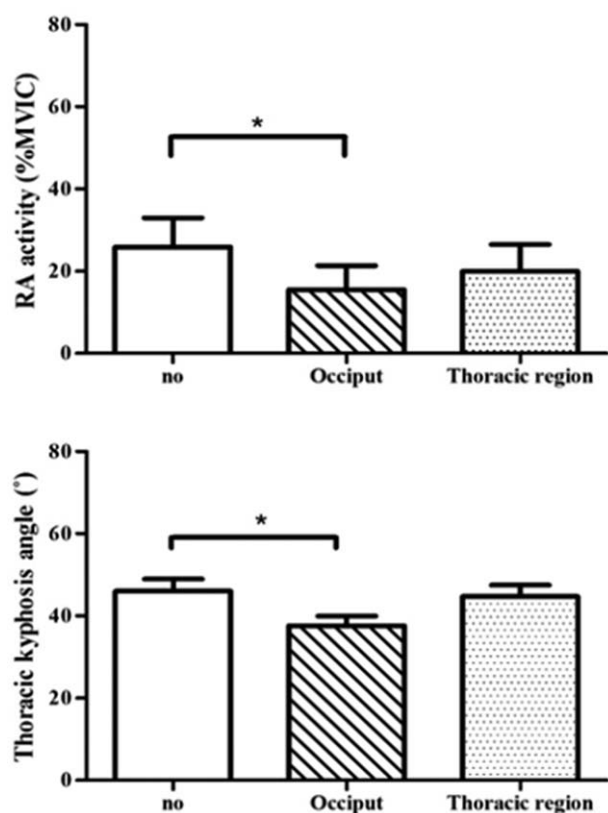


Figure 4. Outcomes of normalized electromyographic RA activities and TKA in Thera-Band application to different posterior body parts during KPP. Values are means \pm standard deviation. %MVIC=percentage of maximal voluntary isometric contraction, KPP=knee push-up plus, RA=rectus abdominis, TKA=thoracic kyphosis angle. *Significant difference with Bonferroni adjustment ($P < .017$).

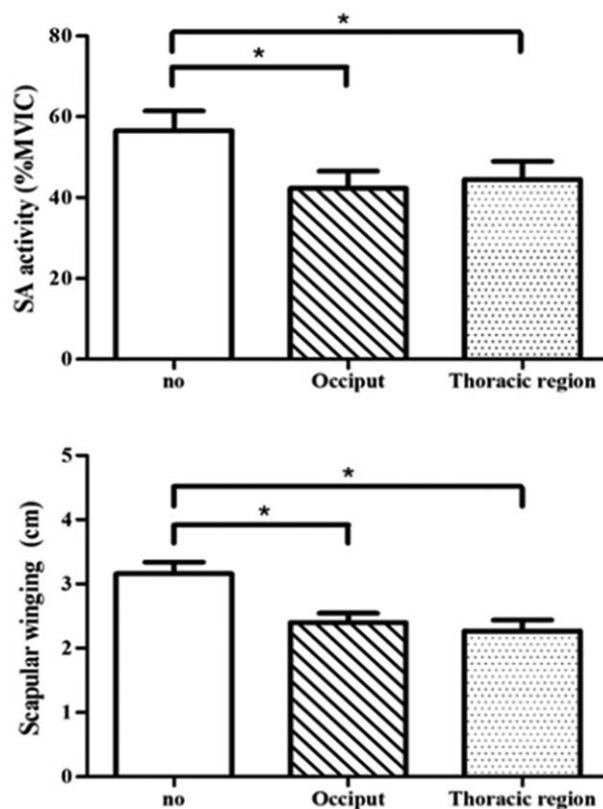


Figure 5. Outcomes of normalized electromyographic SA activities and SW in Thera-Band application to different posterior body parts during KPP. Values are means \pm standard deviation. %MVIC=percentage of maximal voluntary isometric contraction, KPP=knee push-up plus, SA=serratus anterior, SW=scapular winging. *Significant difference with Bonferroni adjustment ($P < .017$).

2.6. Statistical analysis

To confirm normal distribution, one-sample Kolmogorov-Smirnov test was used ($\alpha=0.05$). One-way repeated analysis of variance (within factors: no Thera-Band, occiput, and thoracic region) was used to assess the statistical significance of RA activity, TKA, SA activity, and SW by using PASW Statistics 23 (SPSS, Chicago, IL).^[35] The significance level was set at $\alpha=0.05$. If a significant difference was found, Bonferroni adjustment was performed (with $\alpha=0.05/3=0.017$).

3. Results

RA activity, TKA, SA activity, and SW had significant differences among the 3 conditions ($F=4.720$, $P=.017$; $F=14.327$, $P<.001$; $F=4.511$, $P=.020$; and $F=27.330$, $P<.001$, respectively). RA activity in the occiput condition was significantly lower than that in the no Thera-Band condition ($P=.001$), and TKA was significantly lower in the occiput condition than in the no Thera-Band condition ($P<.001$) (Fig. 4). SA activities in both the occiput ($P=.020$) and thoracic region ($P=.047$) conditions were significantly lower than those in the no Thera-Band condition. In addition, SW in both the occiput ($P<.001$) and thoracic region ($P<.001$) conditions was significantly lower than that in the no Thera-Band condition (Fig. 5).

4. Discussion

The aim of this study was to determine the effects of Thera-Band application to the occiput and thoracic regions on RA activity, TKA, SA activity, and SW in subjects with SW. RA activity and TKA were significantly lower when Thera-Band was applied to the occiput, and SA activity and SW were significantly lower when Thera-Band was applied to both the occiput and thoracic regions. These results supported our hypothesis that RA activity, TKA, SA activity, and SW would differ among the 3 different KPP exercises in subjects with SW. To our knowledge, this is the first study to demonstrate that Thera-Band application can influence trunk muscle activity and correct excessive TKA and SW during KPP.

RA activity decreased significantly by 43.30% and TKA was also reduced significantly by 18.24% when Thera-Band was applied to the occiput. Although we did not measure FHP, previous studies reported that reduced FHP contributed to less kyphosis.^[14,15,36] Yoon et al,^[36] demonstrated that correction of FHP with the use of a craniocervical brace decreased TKA during visual display terminal work in men with FHP. Lau et al,^[14] reported a moderate positive relationship between TKA and FHP in subjects with neck pain ($\rho=-0.62$). Quek et al,^[15] also reported that TKA and FHP had a moderate negative association ($\rho=-0.48$) in subjects aged >60 years. Because FHP was assessed by using the measured craniocervical angle, a decreased craniocervical angle indicated increased FHP. Thus, the reduced

TKA from the Thera-Band application to the occiput may be explained by the decreased FHP with Thera-Band placement to the occiput. Because the subjects were asked to maintain the tension of the Thera-Band during KPP, the deep cervical flexors were likely to be activated to maintain the neutral head posture with Thera-Band (although the activity of the deep cervical flexors and the angle of FHP were not measured in the current study). There is another possible explanation for the decreased TKA from the improved head posture. Previous studies have investigated the effect of alteration of alignment on muscle activity and kinematics.^[36–38] These studies showed altered muscle activity or kinematics because the external application method (i.e., scapular bracing or postural taping) influenced the mechanical change in alignment-altered proprioceptive input. By maintaining correct craniocervical alignment by applying Thera-Band to the occipital region in this study, the thoracic alignment was also influenced because the cervical spine and thoracic spine have a direct bony connection. Furthermore, there was a positive relationship between the RA and TK curvature. According to a previous study that reported that RA activity was greater during isometric trunk flexion than during isometric trunk extension against external resistance, increased RA activity can cause TK.^[39] That is, maintenance of excessive TK can approximate the proximal and distal attachment of the RA and consequently shorten the length of the RA.^[19] According to the theory of Kendall et al,^[19] the corrective exercise program of TK included an anterior trunk lengthening exercise. In the current study, the neutral head posture from Thera-Band placement contributed less RA activation in association with decreased TK. Thus, application of Thera-Band to the occiput is the most effective method to inhibit RA activity and compensatory TK during KPP among the 3 KPP exercises in this study.

In contrast to our hypothesis, the SA activity decreased significantly when Thera-Band was placed to both the occiput and thoracic regions (by 16.74% and 15.58%, respectively). SW also decreased significantly in both the occiput and thoracic regions (by 24.84% and 27.04%, respectively). In contrast, Cole et al,^[17] who used a different method from the corrective method of our study, reported higher SA activity in scapular bracing with a compression shirt in subjects with poor posture due to the mechanical change of joint alignment and the elicited proprioception. In the study of Lee et al,^[18] SA activity did not show a significant difference between shrug with 30° shoulder abduction in the frontal plane with craniocervicothoracic stabilization and preferred shrug with 30° shoulder abduction or shrug with 30° shoulder abduction in the frontal plane. In this study, there are possible explanations for the decreased SA activity associated with decreased SW when Thera-Band was placed in both the occiput and thoracic regions. First, improved craniocervical alignment by Thera-Band application may have positively influenced the thoracic spine (reduced compensatory TK in the current study), and proper thoracic alignment is likely to alter the scapula position. Because the scapula is positioned in the posterior rib cage, which is connected to the thoracic spine by costovertebral and costotransverse joints, improved cervicothoracic alignment may have provided a stable base for the scapula, as evidenced by the decreased amount of SW in this study. Second, the maintained tension of Thera-Band to the thoracic region might have facilitated the scapular medial stabilizers (middle trapezius [MT] and lower trapezius [LT]), although MT and LT activities were not measured because of Thera-Band application to the thoracic region. Because Thera-Band was applied to the apex of compensatory TK (mostly

between T5 and T10 in this study), to which the MT and LT were attached, it is feasible that activated MT and LT could stabilize the scapula, as indicated by the decreased amount of SW. In particular, MT and LT activation may be antagonistic to SA activation. Previous studies have demonstrated higher MT and LT activities and lower SA activity during isokinetic scapular movement in overhead athletes.^[5] Granata et al^[40] assumed that the LT was inhibited by the SA, which antagonized the LT to maintain the upward rotation and protraction of the scapula. Therefore, KPP with Thera-Band in the occiput and KPP with Thera-Band in the thoracic region are effective exercises to reduce the amount of SW in subjects with this condition.

This study has several limitations. First, we showed only the short-term effect of Thera-Band application during KPP. Second, as only subjects aged 19 to 29 years were recruited, the results could not be generalized to the general population. Third, Thera-Band stabilized by using the palms was not perpendicular to the ground because Thera-Band application during KPP was planned as a home exercise to be performed by the subjects themselves. Further studies should investigate a way to make Thera-Band vertical to the ground such that the same force is applied in all exercises. In addition, further studies should investigate Thera-Band application during KPP in a longitudinal manner.

5. Conclusion

This study investigated the effect of Thera-Band application to the occiput and thoracic regions during KPP in subjects with SW by measuring the RA activity, TKA, SA activity, and SW. The results of this study proved that Thera-Band application to the occiput reduced RA activity and TKA, as compared with the no Thera-Band condition. SA activity and SW were significantly lower in the KPP with Thera-Band in the occiput and thoracic region conditions than in the no Thera-Band condition. Therefore, Thera-Band application to the occiput and thorax may be recommended to alter RA and SA muscle activity as well as compensatory TKA and SW during KPP in subjects with SW.

Author contributions

Conceptualization: H. Cynn.

Data curation: D. Kim.

Methodology: D. Kim.

Supervision: H. Cynn.

Writing – original draft: A. Shin.

Writing – review & editing: H. Cynn, J. Lee.

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