PTK
Physical Therapy Korea
https://doi.org/10.12674/ptk.2023.30.2.128
pISSN: 1225-8962 eISSN: 2287-982X
Phys Ther Korea. 2023;30(2):128-135

Original Article

Effects of Aquatic Exercise on Upper Extremity Function and Postural Control During Reaching in Children With Cerebral Palsy

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Article Info
Received April 20, 2023
Revised May 1, 2023
Accepted May 1, 2023

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Key Words
Aquatic exercise
Cerebral palsy
Postural control
Upper extremity function

Background: Despite the fact that aquatic exercise is one of the most popular alternative treatment methods for children with cerebral palsy (CP), there are few research regarding its effectiveness.

Objects: The purpose of this study was to examine the effects of aquatic exercise on upper extremity function and postural control during reaching in children with CP.

Methods: Ten participants (eight males and two females; 4–10 years; Gross Motor Function Classification System levels II–IV) with spastic diplegia were recruited to this study. The aquatic exercise program consisted of four modified movements that were selected from the Halliwick 10-point program to enhance upper extremity and trunk movements. The participants attended treatment two times a week for 6 weeks, averaging 35 minutes each session. The Box and Block Test (BBT), transferring pennies in the Bruininks-Oseretsky Test (BOT), and pediatric reaching test (PRT) scores were used as clinical measures. Three-dimensional motion analysis system was used to collect and analyze kinematic data. Differences in BBT and BOT values among pre-treatment, post-treatment, and retention (after 3 weeks) were analyzed using a Friedman test. In addition, the PRT scores and variables (movement time, hand velocity, straightness ratio, and number of movement units) from the three-dimensional motion analysis were tested using a Wilcoxon signed-rank test. The significance level was established at $p < 0.05$. When the results appeared to be statistically significant, a post-hoc test for multiple comparisons was performed with the Wilcoxon signed-rank test.

Results: All clinical measures, which included BBT, transferring pennies of BOT, and PRT, were significantly increased between pre-intervention and post-intervention scores and between pre-intervention and retention scores after treatment ($p = 0.001$). Three-dimensional motion analysis mostly were significantly improved after treatment ($p = 0.001$).

Conclusion: Aquatic exercise may help to improve body function, activity, and participation in children with varying types of physical disabilities.

INTRODUCTION

Musculoskeletal problems caused by the long-term effects of cerebral palsy (CP), such as contracture, a reduced range of motion, and motion displacement, may contribute to difficulties in balance control and a reduced functional level [1]. In addition, neurological symptoms result in poor motor control, an asymmetrical movement pattern, incoordination, and sensory disorders, leading to functional impairment in CP [2].

Aquatic exercise is known to be an effective intervention to reduce spasticity, improve cardiorespiratory function, enhance the range of joint movement, and increase motivation, self-perception and self-esteem [3]. The buoyancy, resistance, and hydrostatic pressure of the aquatic environment provide the participant and therapist with a safer atmosphere for therapeutic activities intended to improve muscle strength, balance, and technical skills [4]. Such treatments in water are appropriate for children with CP because the aquatic environment reduces the negative influences of exercise on postural control and excessive joint loading [5]. Despite the fact that aquatic exercise is one of the most popular alternative treatment methods for children with CP, there are few published studies regarding its effectiveness [6,7].

Active balance control strengthens balance by two mechanisms: compensatory postural adjustment (CPA) and anticipatory postural adjustment (APA) [8]. CPA refers to reactive responses to postural perturbation, and APA refers to movement that reduces the effects of perturbation by voluntary control [9]. The control mechanism for the reaction to unexpected external postural turbulence is CPA, whereas the control mechanism for an action for predictable internal postural adjustment is APA [10]. Children with CP often have impaired postural control, and consequently have difficulties in organizing CPA and APA [11]. The causes of inadequate postural control are impaired muscle recruitment patterns, delayed onset times, and frequent co-activation of antagonist muscles [10].

Activities such as reaching and grasping are important basics of upper extremity multi-joint movement in daily life. It has been found that the quality of reaching, or postural control performance, is influenced by the pelvic position during the initiation stage, and is related to the stabilization of the head and pelvis, as well as the movability of the trunk, during the action of reaching [12,13]. Previous researchers have found that children with CP are disturbed by dysfunctional postural control during the activity of reaching [14]. It is assumed that their arms, hands and trunk are held together during reaching in an attempt to support precise hand movement [15]. The coordination of postural control and upper limb control allows the right hand to move towards a target while the balance of the body maintained [16]. However, there are only a few studies on the relationship between postural adjustment and hand movement in a sitting posture for children with diplegic CP [17,18]. The purpose of this study was to examine the effects of aquatic exercise on upper extremity function and postural control during reaching in children with CP.

MATERIALS AND METHODS

1. Participants

The participants in this single-group pre-post design study were 10 children who volunteered in 12 aquatic exercise sessions. They had been diagnosed with CP with diplegia, and were recruited from a local rehabilitation center in Seoul, Republic of Korea. The inclusion criteria were: (1) level II–IV on the Gross Motor Function Classification System (GMFCS) [19] and (2) the ability to understand the experimental process and methods. The exclusion criteria for the participants were: (1) any other congenital or neurological abnormality except for CP, (2) surgery within 6 months, (3) Botox injection within 3 months, (4) fear of water, and (6) open wound or active infection. This study was approved by the Yonsei University Mirae Campus Human Studies Committee; parental consent was obtained prior to the research. The participants' general characteristics are shown in Table 1.

2. Tests of Upper Extremity Function and Trunk Stability

Each participant was assessed before and after the 12 sessions of aquatic exercise in order to examine the effects of the intervention on postural adjustment and upper extremity function. The clinical outcome measurements were the Box and Block Test (BBT), the Bruininks-Oseretsky Test (BOT) of Motor Proficiency, and the Pediatric Reaching Test (PRT) in both the sitting and standing positions.

Table 1. General characteristics of participants

Participant	Sex	Age (y)	GMFCS	Dominant side	Primary mobility device
1	Male	9	III	Right	Walker
2	Female	8	III	Left	Walker
3	Male	6	IV	Right	Walker
4	Male	10	II	Left	None
5	Male	4	II	Right	None
6	Male	8	III	Right	Walker
7	Male	7	II	Left	None
8	Male	4	II	Left	None
9	Male	5	III	Right	Walker
10	Female	4	IV	Right	Walker

GMFCS, Gross Motor Function Classification System.

BBT was used to objectively examine the participant's hand function and upper limb agility in the common uses of everyday life [20]. We counted the number of blocks that each subject moved from one side of a wooden box to the other using his/her dominant hand for 1 minute. The test-retest reliability of this test has been reported to have a rho coefficient of 0.93 and 0.97 for the right and left hands, respectively. Inter-rater reliability was 0.99 and 1.00 for the right and left hands, respectively [21].

BOT of Motor Proficiency was designed by Bruininks-Oseretsky to measure the fine and gross motor skills of people aged 4 to 21 [22]. This test examines the agility, coordination, strength/visual motor control, upper limb speed, and dexterity in children with motor skill disorders. We selectively adopted 'Transferring pennies in a box with preferred hand' from the BOT. This test item, as part of the subtest for upper-limb speed and dexterity, provides standardized results based on gross and fine motor hand function [23]. Each participant was asked to place pennies in a box with his/her preferred hand for 15 seconds. The average number of pennies transferred was calculated from three tests per participant.

As an indirect measure of trunk stability, the PRT was conducted in this experiment. This test is known to be a reliable and valid method for testing children with CP. The PRT was developed and modified from the Functional Reach Test, which was first developed to measure adult subjects' functional reach while standing [24]. Considering that many children with CP are only able to maintain the upright position while sitting, the PRT was developed to measure the maximal reach distance of children with CP in both the sitting and standing positions. The sum of the three functional reach distances in the three reach directions (anterior, right, and left) while the subjects were sitting was used as the PRT score. Because more than half of our participants were able to stand independently, we performed the PRT test only with subjects in the seated position.

A real-time three-dimensional motion analysis system (Vicon MX T40S; Motion Systems Ltd.) was utilized to quantify the quality of upper extremity and trunk control while the participant performed reaching-forward-and-returning tasks toward targets. Fifteen cameras were used to analyze participants' motions at a sampling rate of 60 Hz. Reflective markers were attached to C7, the T10 spinous process, the humeral head, the lateral epicondyle, the dorsal metacarpophalangeal joint of the hand on the inspected arm, and the respective target. Changes in the movement time (MT), hand velocity (HV), straightness ratio (SR), and number of movement units (MUs) were analyzed. The reach phase of the MT was defined as the target arrival time from the starting position to the target. HV indicates the maximum hand resultant velocity value between the initiation and the termination. SR was measured via the route taken by the hand between its initiation and termination point. SR represents the straightness of the hand trajectory.

The participants sat on stools with their feet placed flat on the ground and their hip and knee joints kept at 90°. In the starting position, the shoulder of the dominant hand was at approximately 0° of flexion/extension and 0° of internal rotation. The elbows were to be kept at 90°, and the forearms were placed on an armrest, with the palms facing the ground. The non-dominant hand was placed around the trunk in a relaxed manner. A target was placed at eye level at a distance of 120% of arm's length in three directions: (1) anterior to the dominant hand, (2) deviated 40° laterally, and (3) deviated 40° medially from the sagittal plane of the dominant hand (Figure 1) [15]. In order to minimize the effect of possible confounding variables depending on different test administrators, the same administrator conducted the training and the test to measure the participants' results. Participants performed 10 reaching trials toward each target, and the average values of the kinematic variables were used for data analysis.

3. Intervention

All subjects participated in 12 aquatic exercise sessions (35

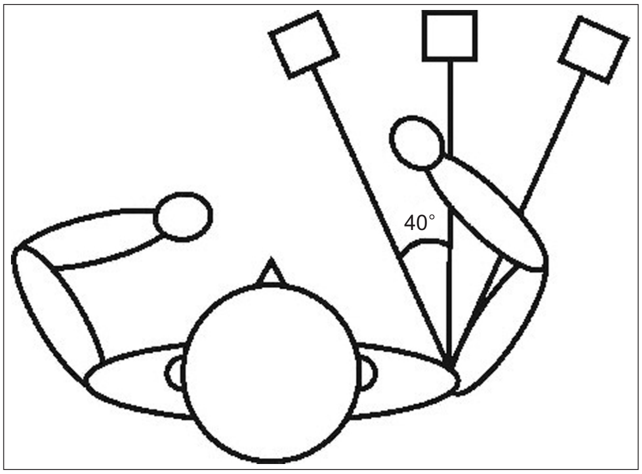

Figure 1. Experimental setup for reaching test. Placement of medial and lateral targets was deviated 40° medially and laterally from anterior target, respectively.

minutes/twice per week) according to an aquatic exercise protocol. The protocol consisted of a general preparation exercise and three specific movements focused on enhancing upper extremity and trunk movement. Each movement was selected and modified from the Halliwick 10-point program. The Halliwick method is a common aquatic exercise program for people with physical or learning disabilities [25]. The specific exercises were lateral movement of the trunk and upper limbs, anterior and posterior movement of the trunk and upper limbs, and cross movement of the trunk and upper limbs.

General preparation exercise was intended to allow participants to adapt to the characteristics of the water, such as buoyancy, water pressure, water resistance, and viscosity, before conducting the aquatic exercises. This included movement in the water to relax the participants, such as moving the arms and legs in the water, maintaining a certain posture, touching the water with the ear, and kicking the water with the legs. Taking a deep breath by mouth and blowing bubbles were conducted to accelerate respiratory control and create bonds with the therapists. These activities lasted for 5 minutes.

After the preparation, each subject performed three specific movements. At the beginning of each exercise, the therapist instructed the participant to sit on his lap so that the water came up to the participant's shoulders while the participant's body was held by each side of the pelvis to balance him/her in every direction. The therapist provided hands-on assistance whenever necessary to allow the participant to perform the given exercise in a correct and smooth way. The overall motion was slow, and each activity was repeated for 10 minutes.

1) Lateral movement of the trunk and upper limbs

The participants were asked to stretch their dominant arms with trunk side flexion as far as possible in the same direction while balancing their bodies without compensatory trunk motions. Then, they repeated the same movement in the opposite direction. Participants moved their arms on the surface of water.

2) Anterior and posterior movement

The participants slowly lowered their heads backward until their ears contacted the surface of water, and maintained this position for 5 seconds. Then, the participants attempted to sit up by moving their heads and drawing both arms forward to place their hands on the therapist's shoulders. The movement of both arms was above the surface of water. The overall motion was to occur slowly while symmetrical body balance was maintained.

3) Cross movement

The participants maintained balance while supinating both arms horizontally to maintain the positions of their bodies. They were to grab the therapist's opposite shoulder by rotating their trunk in their preferred direction while attempting to maintain balance. This was repeated in the opposite direction of lateral movement of the trunk and upper limbs.

4. Statistical Analysis

Statistical tests were done using the PASW Statistics (ver. 18.0; IBM Co.). Differences in BBT and BOT values among pre-

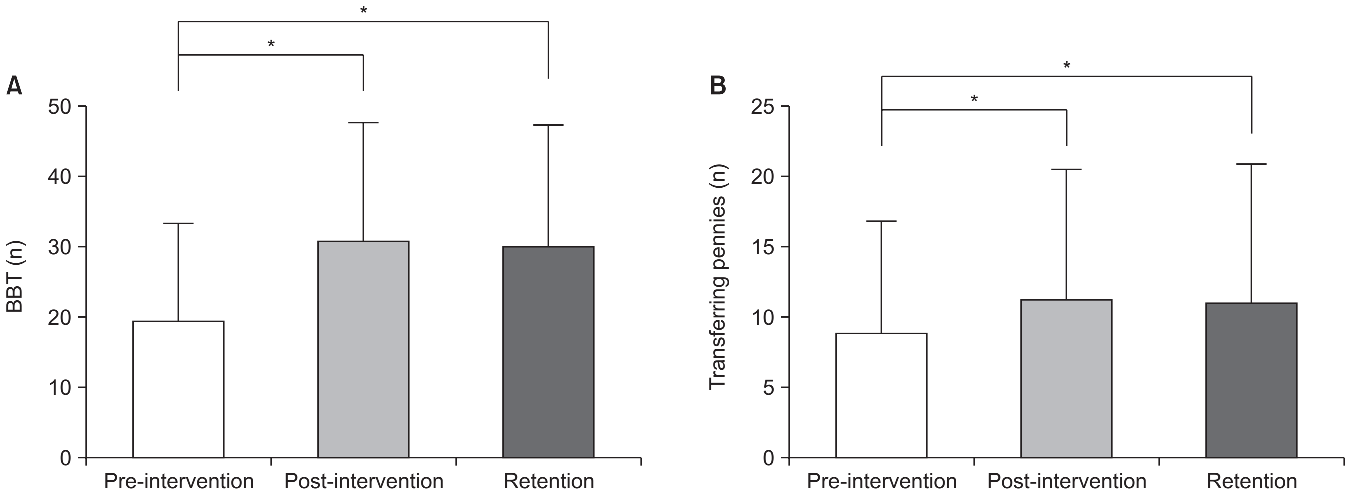

Figure 2. Changes of the upper extremity function. (A) BBT scores at the pre-intervention, post-intervention, and retention. (B) Transferring pennies scores of the BOT at the pre-intervention, post-intervention, and retention. BBT, Box and Block Test; BOT, Bruininks-Oseretsky Test. *$p < 0.05$.

treatment, post-treatment, and retention (after 3 weeks) were analyzed using a Friedman test. In addition, the PRT scores and variables (MT, HV, SR, and MUs) from the three-dimensional motion analysis were tested using a Wilcoxon signed-rank test. The significance level was established at $p < 0.05$. When the results appeared to be statistically significant, a post-hoc test for multiple comparisons was performed with the Wilcoxon signed-rank test [26].

RESULTS

1. Clinical Measurement Scores

BBT scores differed significantly among pre-intervention (mean ± standard deviation = 19.50 ± 13.91), post-intervention (mean ± standard deviation = 30.80 ± 16.78), and retention (mean ± standard deviation = 30.00 ± 17.26) ($p < 0.001$), and post-hoc analysis revealed that the post-intervention and retention scores were greater than the pre-intervention scores ($p = 0.005$). Statistically significant increases were found in the scores for transferring pennies in the BOT ($p = 0.001$), and post-hoc analysis revealed a statistically significant difference between the pre-intervention (mean ± standard deviation = 8.80 ± 8.07) and post-intervention scores (mean ± standard deviation = 11.20 ± 9.29) ($p = 0.004$) and between the pre-intervention and retention scores (mean ± standard deviation = 11.01 ± 9.87) ($p = 0.011$). However, no statistically significant difference was noted between the post-intervention and retention tests in either the BBT or the BOT (BBT: $p = 0.356$, BOT: $p = 0.595$) (Figure 2). PRT scores also increased significantly from the pre-intervention to the post-intervention analysis (Table 2).

Table 2. Dominant side PRT performance after intervention (N = 10)

Test	Pre-intervention	Post-intervention	p-value
PRT (cm)	95.80 ± 36.78	129.70 ± 50.29	0.01*

Values are presented as mean ± standard deviation. *Significant difference before and after intervention ($p < 0.05$). PRT, pediatric reaching test.

2. Kinematic Variables During the Reaching-forward-and-returning Tasks

Three-dimensional motion analysis results for performance in reaching towards targets are presented in Table 3.

MT (except return), HV, and SR appeared to be significantly different after the intervention in all directions for the reaching tasks ($p < 0.05$). MUs differed significantly in the reaching tasks toward the anterior and lateral targets, but not toward the medial target.

DISCUSSION

Aquatic exercises, including underwater aerobic exercise, swimming skills improvement training, water resistance activity, and underwater walking exercise, have been clinically applied in various ways to enhance rehabilitation interventions in children with CP [3,4]. In the current study, we examined the effect of aquatic exercise on postural control and reaching performance in children with CP. The results showed that 6-week aquatic exercise improved the upper extremity functions and the postural control of children with CP.

In the present study, the BBT and the transfer of pennies in the BOT both were conducted to measure fine motor skills. The BBT is designed to assess the skills used in moving a material across the midline, while the transfer of pennies in the BOT is designed to measure delicate hand function using both hands. The PRT was used to assess changes in postural control

Table 3. Three-dimensional motion analysis results for the reaching tasks towards the targets

Kinematic variable		Anterior target		Medial target		Lateral target		p-value		
		Pre	Post	Pre	Post	Pre	Post	Anterior	Medial	Lateral
MT (ms)	Reach[a]	0.96 ± 0.29	0.74 ± 0.19	0.99 ± 0.32	0.77 ± 0.19	1.21 ± 0.59	0.87 ± 0.25	0.04*	0.04*	0.02*
	Return[b]	0.69 ± 0.14	0.59 ± 0.89	0.78 ± 0.71	0.68 ± 0.18	0.68 ± 0.16	0.74 ± 0.19	0.17	0.31	0.39
	Total[c]	2.76 ± 0.25	1.82 ± 0.52	2.84 ± 1.96	1.90 ± 0.49	3.08 ± 1.82	2.12 ± 0.59	0.02*	0.03*	0.01*
HV (m/s)	Mean	0.32 ± 0.13	0.44 ± 0.13	0.32 ± 0.99	0.43 ± 0.09	0.37 ± 0.16	0.48 ± 0.18	0.01*	0.01*	0.01*
	Peak1[d]	0.76 ± 0.19	0.97 ± 0.19	0.73 ± 0.17	1.01 ± 0.19	0.81 ± 0.28	1.08 ± 0.29	0.01*	0.01*	0.01*
	Peak2[e]	0.89 ± 0.17	1.36 ± 0.29	0.87 ± 0.14	1.26 ± 0.33	0.94 ± 0.25	1.29 ± 0.26	0.01*	0.02*	0.01*
SR (%)		134.52 ± 17.06	117.67 ± 9.97	133.07 ± 21.13	114.23 ± 6.05	139.36 ± 18.99	119.58 ± 13.31	0.01*	0.02*	0.01*
MUs (n)		2.37 ± 1.28	1.53 ± 0.50	2.52 ± 1.12	1.92 ± 0.52	2.93 ± 1.59	1.93 ± 0.63	0.04*	0.14	0.03*

Values are presented as mean ± standard deviation. [a]target arrival time, [b]arrival time from target to starting position, [c]total movement time, [d]peak velocity from the starting position to the target, [e]peak velocity from the target to the starting position. *Significant difference before and after intervention ($p < 0.05$).

during the reaching activity. Three-dimensional motion analysis system was used to observe the effects of the treatment on movement dysfunction [27]. This type of system provides information on the movement speed, maximum joint movement angle, coordination between joints, and movement smoothness in a given space and time frame in upper extremity functional studies [28]. In this study, MT, HV, SR, and MUs were used as the kinematic parameters during reaching to assess upper extremity functional changes and postural control improvement.

First, the BBT scores and the number of pennies transferred in the BOT increased significantly from the pre-intervention to the post-intervention. Furthermore, the improvement was maintained 1 week after the intervention. Second, postural control while sitting, tested using PRT scores, also improved significantly after the intervention. Third, all the kinematic variables in the reaching tasks related to the anterior and lateral targets significantly improved after the intervention. In the reaching tasks for the medial target, all the kinematic data showed improvement after the intervention. However, the MUs and the return MT exhibited no statistical improvement. As expected, the clinical measurements of hand coordination, upper extremity dexterity, hand movement, and hand agility improved after the aquatic exercise. Postural control in the sitting position also improved. Last, during the reaching task, the speed of hand movement increased, and the MT and SR to the target decreased. The smoothness of the hand trajectory during the reaching task also improved.

Medial and lateral reaching require more challenging anticipating postural control of the trunk if stable balance is to be maintained while a person reaches for a target [29]. According to research by Ju et al. [16], with regard to motor control, trunk rotation is more difficult, as it requires the movement of the transverse plane. This causes additional problems in medial or lateral reaching tasks. Furthermore, to reach a medial target, midline crossing is necessary. Therefore, reaching for a medial target can be considered a more difficult task in terms of freedom of movement. It is proposed that the aquatic intervention-induced improvement was not sufficient to cause significant changes in the MU and return MT during the task of reaching for the medial target, a more difficult task. The aquatic exercise program used in this study consisted of trunk flexion/extension in the sagittal plane, leaning to the side in the frontal plane, and trunk rotation in the transverse plane with midline crossing. Therefore, it could be expected that a longer duration of participation in the given aquatic exercise program would improve postural control in transverse plane, especially for the midline crossing activity. In addition, adding more underwater motor tasks with rotational components would be suggested for the advanced stages of aquatic interventions for children with CP.

Our results indicate that aquatic exercises conducted in children with CP improved upper extremity function and postural control. Interestingly, aquatic exercise helped to maintain or strengthen the effect of the treatment, as the BOT and BBT indicated that the participants continued to improve even after the treatment. Getz et al. [6] concluded that there is evidence that aquatic exercise enhances respiratory function in children with CP. However, there is limited evidence to support the application of aquatic exercise in CP subjects in the activity and participation level area of the International Classification of Function (ICF). Furthermore, they stated that future clinical studies using various objective outcome measures would be required to prove the effectiveness of aquatic programs for CP. In this study, the aquatic exercise program was based on the Halliwick method. The program consisted of four modified movements which were selected from the Halliwick 10-point program to enhance upper extremity and trunk movement. The positive and objective evidence of this study supports that of previous studies that examined the effectiveness of aquatic exercise in the rehabilitation treatment of children with CP [3,6].

There were limitations of this study. First, a control group was not included in the study design, and the sample size was relatively small. Therefore, a randomized controlled trial of aquatic intervention for children with CP will be required in future studies. Furthermore, the application of the aquatic exercise program needs to be extended to children with various types of CP and various levels of severity, such as those with higher GMFCS levels. The inclusion of psychological outcome measures is recommended in future studies to evaluate the psychological effects (e.g. motivating the child and providing a stimulus in a social environment) of aquatic treatment.

CONCLUSIONS

The results of this study suggest that 12 sessions of aquatic exercise were beneficial in improving upper extremity function and postural control in children with CP. Although our results were not conclusive, there was a positive effect of aquatic exercise on upper extremity function and postural control during reaching performance. The addition of more underwater motor tasks with rotational components is suggested for the advanced stages of aquatic interventions for children with CP. In conclusion, aquatic activity has great potential for contributing to life-long exercise programs for children with CP. We have demonstrated that aquatic exercise may help to improve body function, activity, and participation in children with varying types of physical disabilities.

FUNDING

None to declare.

ACKNOWLEDGEMENTS

None.

CONFLICTS OF INTEREST

No potential conflicts of interest relevant to this article are reported.

AUTHOR CONTRIBUTION

Conceptualization: YJ, HSJ, CY, OK, HC, DO. Data curation: YJ. Formal analysis: YJ, HSJ, CY, OK, HC, DO. Investigation: YJ. Methodology: YJ, HSJ, CY, OK, HC, DO. Project administration: YJ. Resources: YJ, HSJ, CY, OK, HC, DO. Software: YJ, HSJ. Supervision: YJ, HSJ, CY, OK, HC, DO. Validation: YJ, HSJ, CY, OK, HC, DO. Visualization: YJ, HSJ, CY, OK, HC, DO. Writing - original draft: YJ, HSJ. Writing - review & editing: YJ, HSJ, CY, OK, HC, DO.

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