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ORIGINAL ARTICLE

ความสัมพันธ์ระหว่างการขยายตัวของทรวงอกและความแข็งแรงในเด็กทั่วไป

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บทคัดย่อ

ปัญหาของระบบหายใจในเด็กสามารถส่งผลต่อความสามารถในการเคลื่อนไหว การตรวจพบความผิดปกติตั้งแต่เริ่มแรกจึงมีความสำคัญ กล้องวีดิทัศน์สามารถใช้วัดการขยายตัวของทรวงอกที่เป็นตัวบ่งบอกการทำงานของระบบหายใจ อย่างไรก็ตามการวัดด้วยวีดิทัศน์นี้จะต้องมีการทดสอบความแม่นยำก่อนนำไปใช้เก็บข้อมูล นอกจากนี้ ยังไม่มีหลักฐานสนับสนุนเรื่องความสัมพันธ์ของการทำงานในระบบหายใจในส่วนของการขยายตัวของทรวงอกและความแข็งแรงของกล้ามเนื้อในเด็ก ดังนั้นงานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาความแม่นยำของกล้องวีดิทัศน์โดยใช้การวัดแบบคลื่นแม่เหล็กไฟฟ้า เป็นเกณฑ์มาตรฐานในการวัดการขยายตัวของทรวงอก และเพื่อตรวจสอบความสัมพันธ์ระหว่างการขยายตัวของทรวงอกและความแข็งแรงในเด็กทั่วไป เด็กจำนวน 47 คน (อายุเฉลี่ย 10.9 ปี, ค่าเบี่ยงเบนมาตรฐาน 1.11 ปี) ระดับชั้นประถมศึกษาได้เข้าร่วมการทดสอบ กล้องวีดิทัศน์และคลื่นแม่เหล็กไฟฟ้าถูกใช้เพื่อวัดการขยายตัวของทรวงอกในเวลาเดียวกัน โดยข้อมูลนี้จะใช้เพื่อศึกษาความแม่นยำของกล้องวีดิทัศน์ นอกจากนั้นความแข็งแรงของระยางค์ส่วนบนวัดจากแรงบีบมือโดยใช้เครื่องวัดแรงบีบมือ ในขณะที่ความแข็งแรงของร่างกายวัดด้วยแบบประเมินความแข็งแรงของ the Bruininks-Oseretsky Test of Motor Proficiency second edition (BOT-2) ค่าการขยายตัวของทรวงอกจากกล้องวีดิทัศน์และคะแนนความแข็งแรงจากการทดสอบทั้งสองแบบถูกใช้ในการหาความสัมพันธ์ ผลการวิจัยพบความสอดคล้องกันระหว่างเครื่องมือทั้งสองชนิดในระดับดีถึงดีมาก ($ICC_{2,3}$ = 0.80-0.94) แสดงว่ากล้องวีดิทัศน์มีความแม่นยำในการวัดการขยายตัวของทรวงอก นอกจากนั้นยังพบความสัมพันธ์เชิงบวกระหว่างการขยายตัวของทรวงอกและความแข็งแรง จากผลการทดสอบความแม่นยำแสดงว่า กล้องวีดิทัศน์สามารถใช้วัดการขยายตัวของทรวงอกได้ และความสัมพันธ์ระหว่างการขยายตัวของทรวงอกและความแข็งแรงบ่งชี้ว่า สามารถใช้การขยายตัวของทรวงอกประเมินความแข็งแรงเบื้องต้นในเด็กทั่วไปได้ ในทางกลับกันการประเมินความแข็งแรงสามารถใช้บ่งชี้ถึงเด็กที่อาจจะมีปัญหาด้านระบบหายใจได้

คำสำคัญ: เด็กทั่วไป, ความสัมพันธ์, ความเที่ยงตรงตามสภาพ, การขยายตัวของทรวงอก, แรงบีบมือ

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ORIGINAL ARTICLE

Correlation between chest wall expansion and strength in typically developing children

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Abstract

Respiratory problems in children could hinder motor competency. Early detection of respiratory problems is important. The simple 2D camera system (2DCS) can be used to measure chest wall expansion representing respiratory function. However, this system needs to be validated prior to data collection. Evidences also suggest chest wall expansion could be potentially used to represent muscle strength. However, the correlation between chest wall expansion and muscle strength has not been well established. Therefore, this study aimed to determine the concurrent validity of the 2DCS using the electromagnetic tracking system (EMT) as a reference standard for measuring chest wall expansion, and to investigate the correlation between chest wall expansion and strength in typically developing children. Forty-seven children (age 10.9±1.11 years) attending primary schools were recruited. The 2DCS and the EMT were used to simultaneously measure chest wall expansion. These data were used to determine concurrent validity of the 2DCS. A hand-held dynamometer was used to measure grip strength that represents upper limb strength, while strength subtest of Bruininks-Oseretsky Test of Motor Proficiency second edition (BOT-2) was used to evaluate overall strength. These strength data were further used to determine the correlation between chest wall expansion and strength. Results demonstrated good to excellent agreements between two instruments ($ICC_{2,3}$ = 0.80-0.94) indicating concurrent validity of the 2DCS. Additionally, significant positive correlations ($p < 0.05$) were found between chest wall expansion and strength. Validity result suggests that the 2DCS can be used to measure chest wall expansion. Correlation between chest wall expansion and strength indicates that we can used chest wall expansion to partially estimate the strength in typically developing children. On the other hands, strength screening could be used identify children who might have a respiratory problem.

Keywords: Typically developing children, Correlation, Concurrent validity, Chest wall expansion, Grip strength

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Introduction

In children, respiratory problems are the common illnesses that could result in hospitalization and mortality[1]. The prevalence of respiratory diseases in children is considerably increasing each year, which can impact on their quality of life[2]. Respiratory problems can also impact on their gross and fine motor functions leading to impairments in motor competence[3]. Poor motor competence can cause inactive lifestyle, and could further cause other health problems in childhood[4].

Muscle strength is an important component in physical fitness that helps children to achieve gross motor functions and relates to gross motor skills in adolescents[5]. Muscle strength could involve in other body system, such as respiratory system. One study has demonstrated the association between muscle strength and pulmonary function in typically developing children[6]. However, pulmonary function measurement in this previous study required children's understanding about procedure of spirometry and maximal breathing without coughing[7], which could be too difficult to implement in the primary school children.

Clinically, pulmonary function in healthy individuals can be indirectly measured by measuring chest wall expansion. The definition of chest wall expansion is the range of motion of the thorax which comprised of the thoracic vertebrae, sternum and ribs that involved in the respiration[8]. Greater chest wall expansion could represent better pulmonary function[8-9]. Based upon the relationship between muscle strength and pulmonary function, the relationship between muscle strength and chest wall expansion should be present as well. Measurement of chest wall expansion can be used to detect the baseline status of respiratory function and follow up the effect of intervention to enhance respiratory function[10].

Several noninvasive instruments can be used to evaluate chest wall and abdominal wall motions for estimating lung volumes[11-12]. The electromagnetic tracking device (EMT) is one of the non-invasive instruments used to precisely measure the difference of chest wall area between inspiration and expiration[12]. Nevertheless, the instrument is expensive and require highly experienced examiners to operate the instrument. Thus, it may not be suitable for using in clinical practice[13]. Although a simple tape measurement is commonly used to evaluate chest wall expansion in clinical practice, the appropriateness has been questioned in various studies[14-17]. Accordingly, the development of a simple instrument with acceptable validity and reliability is necessary.

A simple 2D camera system (2DCS) is widely used to investigate human movement in clinical research because it is portable, easy to use, inexpensive, and able to provide visual feedback and re-assessment. One study demonstrated that this system can be used to measure chest wall expansion in adults[18]. Therefore, the 2DCS could be alternately used to measure chest wall expansion in typically developing children. However, this system should be validated prior to investigate the relationship between muscle strength and chest wall expansion. Therefore, the present study aimed to 1) determine a concurrent validity of the 2DCS using the EMT as a reference standard, and 2) investigate correlation between chest wall expansion and strength by using the 2DCS. Researcher hypothesized that the concurrent validity of the 2DCS would be acceptable, and there would be an association between chest wall expansion and muscle strength.

Materials and Methods

1. Participants

Forty-seven typically developing children (25 boys, 22 girls), whose parents were willing to let their children participating in the present study, were recruited from primary schools. Based on sample size calculation, ten children were required to obtain the correlation coefficient of 0.7[20] at confidence level of 0.05 and 80% power to determine a concurrent validity, while a total sample of 47 children was needed to detect correlation coefficient of 0.4[6,19] between chest wall expansion and strength at confidence level of 0.05 and 80% power. Therefore, the total number of required sample size for this study was 47 in which a subset of 10 children was used to determine the concurrent validity. The inclusion criteria included age between 9 and 12 years, studying in age-appropriate class in typical schools, ability to understand and follow verbal instructions and participation in regular classroom activities. The exclusion criteria included metal implantation, serious medical health conditions, physical anomalies, joint contracture, severe congenital disorder, a recent surgery or fracture (within the last 12 months), hearing or visual problems that could not be fixed with external devices, a history of spinal cord or brain injury, a history of structural deformities of the spine or ribcage, and chest wall abnormalities. The children and their parents were asked to sign an informed consent form prior to data collection process. The study protocol was approved by the Ethic Committee of Mahidol University Institutional Review Board (MU-CIRB 2016/078.2405).

2. Instruments and measures

This study used the 2DCS (JVC video camera model: Everio GZ-MG645) with a custom Matlab program (MATLAB R2010a) to measure chest wall expansion. The frame rate was set at 25 frames/second and the resolution was 1080x1920 pixels. Two cameras were set at 0.85 meters height and 1.4 meters away from children in anterior and right-lateral directions. To determine concurrent validity of this system, the EMT (3D Guidance trakSTAR, Ascension Technology Corp.) with MotionMonitor software, (Innsport, Inc.) was used to simultaneously record chest wall expansion at 100 Hz. The EMT was used in this study because it is valid and reliable[12,21]. Furthermore, EMT was used to measure chest wall movement in previous study[12].

For strength assessments, upper limb strength was evaluated by using grip strength dynamometer (TKK Model 5401; Takei, Japan) in kilograms. Grip strength could be used to measure hand and forearm muscular force which indicates upper limb strength. Moreover, the functional integrity of upper extremity could be presented by grip strength measurement[22]. Strength subtest of the Bruininks-Oseretsky test of motor proficiency, second edition (BOT-2) was used to evaluate trunk, upper and lower body strength in children 4-21 years old. Previous studies used strength subtest of BOT-2 to measure muscle strength in children[23]. The intra-and inter-rater reliability of this subtest were 0.99 and 0.95, respectively.

Strength subtest consists of 5 items including 1) standing long jump, recording the distance in inches, 2) knee push-ups, 3) sit-ups counting correctly number in 30 seconds, 4) wall sit, and 5) V-up recording the highest time in 60 seconds. Scores from each item are summed up to obtain total point score. The maximum total point score is 42. Total point scores are converted to scale score for interpretation by comparing with the norm score of child at the same age. Scale score was interpreted in 5 groups 1) well-above average (25 scores or greater), 2) above average (20-24 scores), 3) average (11-19 scores), 4) below average (6-10 scores), and 5) well-below average (5 scores or less)[(24)].

3. Procedure

Children were taken to the laboratory room with private environment. Boys were asked to unclothe from the waist up, while girls were asked to wear a sport bra. Children were required to sit in a chair for body landmark identification. Body landmarks identification in each point had been assessed by an expert in pediatric physical therapy, yielding ranged from 80% to 100% accuracy. Sensors of the EMT and the 2DCS were attached on the same body landmarks in frontal and sagittal planes illustrated in Figure 1A and 1B, respectively for the first 10 children to determine concurrent validity of the 2DCS. The data from remaining children were obtained by the 2DCS alone.

Prior to data collection, a LED light was attached on the right shoulder to provide event trigger for the 2DCS. After setting up the event trigger, the researcher instructed and demonstrated the breathing method to familiarize children with testing procedure. This process aimed to minimize intra-subject variability. Children were asked to sit with their back straight on the chair, place both hands on their hips and look straight ahead for practice trials. They were given a verbal instruction to breathe in and breathe out for 2 cycles, and then after starting the third cycle, the researcher gave another verbal instruction to "breathe out maximally and breathe in maximally". Children were required to practice the breathing method until they performed it correctly.

During data collection, children were asked to perform this maximal breathing for 3 consecutive cycles. The event trigger was pressed before full expiration and released after full inspiration in each cycle in frontal and sagittal planes. Children were allowed to rest for one minute between breathing cycles. Chest wall expansion from those 3 consecutive breathing cycles were concurrently recorded using the 2DCS and the EMT. Time points from maximum expiration to maximum inspiration were identified. The difference between these two time points represents chest wall expansion. Average scores across 3 breathing cycles were used for data analysis to determine concurrent validity of the 2DCS.

After chest wall expansion measurement, grip strength dynamometer was used to evaluate both right and left hand-grip strength. Children were asked to stand up straight with arms at the side of their body and hold the dynamometer. They were given a verbal instruction to squeeze maximally and then release. Before the data collection process, children were given practice trials until they could perform it correctly. One minute for the resting period between right and left assessments was provided. Three trials from right and left hands were performed and the highest score was recorded.

Strength subtest of the BOT-2 was used to evaluate strength after completing grip strength assessment. Five items of strength subtest of BOT-2 were explained and demonstrated. Children were instructed to practice until they could perform it correctly. Children performed all five items of strength subtest with one minute rest between tests. Both grip strength and strength subtest of the BOT-2 data were further used to determine the correlation between chest wall expansion and muscle strength.

4. Data analysis

Data from the first 10 children with both the 2DCS and the EMT simultaneously recorded were used to determine concurrent validity. For data processing, coordinates x (movement in sagittal plane) and y (movement in frontal plane) from the EMT were calculated to obtain the distances between 2 sensors in centimeters (cm.). In frontal plane, UpperR and UpperL sensors presented chest wall expansion at upper level. LowerR and LowerL sensors presented chest wall expansion at lower level. Similarly in sagittal plane, Sternum and T7 sensors indicated upper level. Xiphoid process and T12 sensors indicated lower level. Linear interpolation technique was used to re-sampling. Video file (.avi) in each breathing cycle from the 2DCS was imported to a custom Matlab program for identifying sensors and calculating distance between sensors (cm.) using "Pythagorean theorem". Distance data were filtered using a 10^{th} order, FIR low pass filer with cutoff frequency at 1 Hz. This distance was used to represent chest wall expansion.

Chest wall expansion graphs from two instruments were created to detect the minimum distance and maximum distance (cm.) (**Figure 2A, 2B**). These minimum and maximum distances were obtained from full expiration and full inspiration, respectively. Averaged distance across three breathing cycles was used for further statistical analysis.

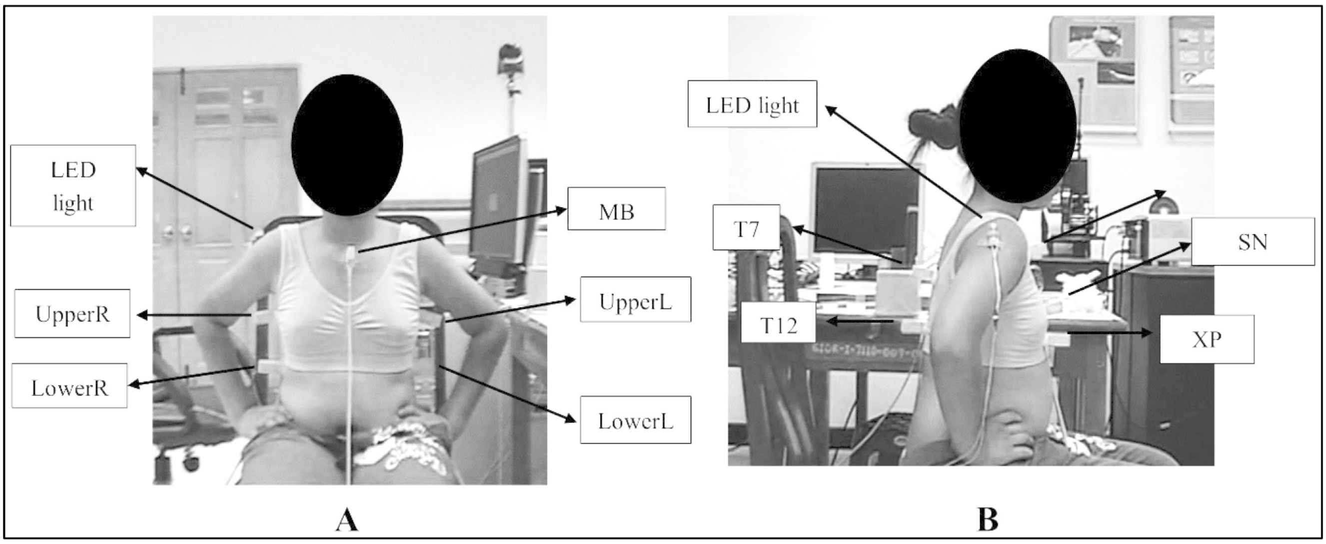

Figure 1 Body landmarks in frontal plane (A) and sagittal plane (B) as follows; the manubrium (MB), the right mid-axillary line at 4^{th} rib (UpperR), the left mid-axillary line at 4^{th} rib (UpperL), the right mid-axillary line at 9^{th} rib (LowerR), the left mid-axillary line at 9^{th} rib (LowerL), the inferior end of the sternum (SN), the spinous process of thoracic vertebrae (T7), the xiphoid process (XP), and the spinous process of thoracic vertebrae (T12).

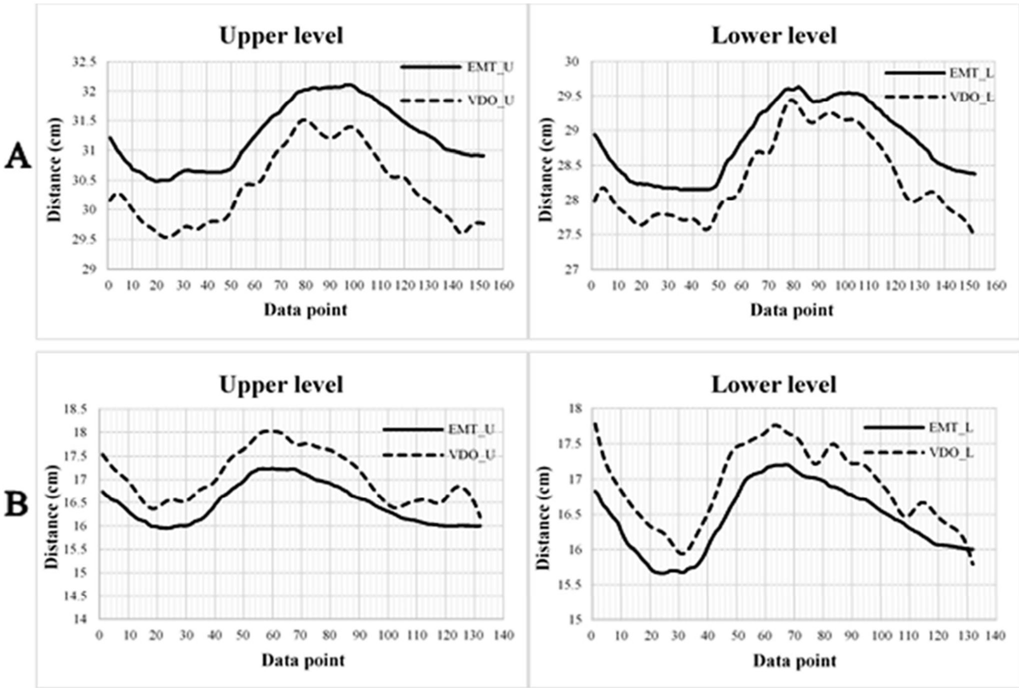

Figure 2. Chest wall expansion graph from electromagnetic tracking system (solid line) and the simple 2D camera system (dashed line) at upper and lower levels in frontal (A) and sagittal (B) planes.

To determine the concurrent validity of the 2DCS, chest wall expansion was separately analyzed in planes (frontal and sagittal planes) and levels (upper and lower levels) in centimeters. To examine correlation between chest wall expansion and strength, chest wall expansion was calculated in square centimeters (cm^2) by identifying and calculating area between sensors in the custom Matlab program to appropriately represent chest wall. UpperR ,UpperL, LowerR and LowerL sensors presented chest wall expansion area in frontal plane. Sternum, T7, Xiphoid process and T12 sensors indicated the area in sagittal plane. Chest wall expansion areas was presented as combination of two planes, frontal and sagittal planes by calculating the difference between maximum and minimum areas. Correlation between chest wall expansion and grip strength score from right and left hands was examined. Previous study reported that body surface area could vary depending on body weight[25]. Therefore, researcher also standardized chest wall expansion represented by body surface area with the weight prior to examine correlation between chest wall expansion and strength subtest of BOT-2 in statistical analysis.

5. Statistical analysis

Statistical analysis was performed using SPSS version 19 (IBM Corporation, New York, USA). Statistical *p*-value less than 0.05 would represent statistical significance. Kolmogorov-Simonov goodness of fit test was used to verify the normality of parameters of interest. Intraclass correlation coefficients ($ICC_{2,3}$) were used to determine concurrent validity of the 2DCS. Standard error of measurement (SEM) was also established. To examine correlation between chest wall expansion and strength, Pearson's correlation was used when the data were normally distributed. Otherwise, Spearman's rank correlation was used.

Results

Descriptive statistical analysis demonstrated that mean age was 10.9±1.1 years old, BMI was 20.6±6.1 kg/m^2, 53.2% were boys and 93.61% were right hand dominance. A concurrent validity study was conducted by using the first 10 participants of the 47 participants in the correlational study. Characteristics of participants are presented in **Table 1.** Concurrent validity of the 2DCS using the EMT as a reference standard for measuring chest wall expansion was presented in **Table 2.** The $ICC_{2,3}$ of the 2DCS were ranged from 0.80 to 0.94 ($p < 0.001$).

Spearman's rank correlation coefficient revealed a significant positive correlation between chest wall expansion and hand grip strength. There was a significant positive correlation between chest wall expansion score of strength subtest of BOT-2. Correlation results are shown in **Table 3 and 4.**

Table 1 Characteristics of research participants (N=47)

Demographic data	Correlation study (N=47)	Validity study (N=10)
	Mean±SD	Mean±SD
Age (years)	10.9±1.1	11±1.3
Body weight (kg)	43.6±15.9	40.2±15
Height (cm)	144.5±10.0	144.1±11.9
Body mass index (kg/m^2)	20.6±6.1	19.1±6.1
Gender (n (%))		
Boy	25(53.2%)	6(60%)
Girl	22(46.8%)	4(40%)
Dominant hand (n (%))		
Right	44(93.61%)	10(100%)
Left	3(6.39%)	-

Table 2 Concurrent validity of the simple 2D camera system using the electromagnetic tracking system as a reference standard (N=10)

Chest wall expansion (cm)		EMT		The simple 2D camera system		$ICC_{2,3}$	*p-value*
		SEM	95%CI	SEM	95%CI		
Frontal	Upper	0.46	0.45,1.06	0.68	0.83,1.42	0.80	*<0.001*
	Lower	0.49	0.77,1.41	0.60	0.92,1.67	0.93	*<0.001*
Sagittal	Upper	0.29	0.85,1.52	0.38	1.16,1.79	0.84	*<0.001*
	Lower	0.29	0.86,1.34	0.33	0.97,1.47	0.94	*<0.001*

EMT, the electromagnetic motion tracking system; SEM, standard error of measurement; 95%CI, 95% confidence interval.

Table 3 Spearman's rank correlation coefficient between chest wall expansion and hand grip strength in typically developing children aged 9-12 years (N=47)

Hand grip strength scores	Chest wall expansion (cm^2)		
	Combination of two planes	Frontal plane	Sagittal plane
Rt. Hand grip strength	0.57**	0.45**	0.57**
Lt. Hand grip strength	0.45[a]**	0.34[a]*	0.53[a]**

[a] Pearson correlation coefficient

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4 Spearman's rank correlation coefficient between chest wall expansion and scale score of strength subtest of BOT-2 in typically developing children aged 9-12 years (N=47)

Strength subtest of BOT-2	Chest wall expansion (cm^2) as normalized by body weight		
	Combination of two planes	Frontal plane	Sagittal plane
Scale score	0.32*	0.31*	0.34*

*. Correlation is significant at the 0.05 level (2-tailed).

Discussions

Forty-seven typically developing children (25 boys and 22 girls) were included in present study. The age range result represents children attending primary schools. Result also demonstrates the distribution of children's BMI which were ranged from underweight to obesity.

Concurrent validity of the 2DCS using the EMT as a reference standard for measuring chest wall expansion in frontal and sagittal planes demonstrates good to excellent agreements as research hypothesized. The results suggest that the 2DCS with a custom Matlab program can appropriately replace the EMT to measure chest wall expansion in children with typical development. It is more practical to administer comparing with the lab-based equipment, such as the EMT. Chest wall expansion as measured by the 2DCS is an indirect method which could represent to lung volume. Although Kinect camera can also be used to measure estimated lung volume(26), its clinical utility was still limited. One study has attempted to validate Kinect camera to estimate lung volume with the spirometer(26). Although they have found excellent agreement (ICC=0.96) between the Kinect camera and the spirometer, the Kinect seems to have limitation to estimate volume when participants wear too tight or loose shirt(26). In this case, estimated volume from the Kinect camera may not appropriately represent lung volume. However, present study directly attached sensors on the skin. Therefore, the data from 2DCS is more accurate to represent chest wall expansion.

Correlation between chest wall expansion and hand grip strength were ranged from fair to moderate. This result supports research hypothesis. Research evidences suggest that chest wall expansion can represent pulmonary function, and this pulmonary function (forced vital capacity (FVC) and forced expiratory volume in one second (FEV1)) is associated with hand grip strength(6,8-9). Previous study reported high correlation between hand grip strength, pulmonary function and respiratory muscle strength(27). Thus, positive correlation between chest wall expansion and hand grip strength was confirmed. Moreover, stability of shoulder joint related with chest wall movement during respiration and respiratory accessory muscle activation(28). Thus, shoulder joint stability could affect to chest wall expansion. A study reported correlation between shoulder joint stability and grip strength that improvement of shoulder joint stability by shoulder girdle exercise leaded to increase hand grip strength(29), which represented to upper limb strength. Based on result of present study it could imply that children with typical development can enhance pulmonary function, measured by chest wall expansion, through upper limb strengthening exercise.

The fair correlation between chest wall expansion and scale score in strength subtest of BOT-2 also supports hypothesis of study. Strength instruments which used in present study (grip strength and strength subtest of BOT-2) could be appropriately used to measure strength because they are portable, easy to use and less time-consuming. Since decreasing of skeletal muscle strength of both upper and lower extremities could represent respiratory problems in children(30). From these correlations might imply that strength assessments could be used to estimate respiratory problem. Moreover, this correlational study suggested that upper limb strengthening exercise and body strengthening exercise could be used to enhance respiratory function in typically developing children.

There are three limitations in present study. First, measuring in two planes of movement by using the 2DCS to derive the chest wall area may not fully present lung volume. However, present study demonstrates that video camera is sufficient to investigate the correlation and more practical for using in clinical practice in terms of cost, simplicity and portability. Second, attaching sensors on sport bra for girls to measure chest wall expansion may not be practical for female adults in clinical practice. Third, correlation from present study could not generalize in the children with pathological conditions because only healthy children were examined. Nevertheless, the results from current study can be used as the basic information for further investigation. Using the 2DCS to measure and analyze chest wall expansion in children with developmental problems, and examine the correlation between chest wall expansion and strength in children at different of age groups and body mass index groups are suggested for future study.

Conclusions

Present study demonstrates that the 2DCS is valid for measuring chest wall expansion in clinical practice. Thus, physical therapists can confidently use this simple, inexpensive and accurate instrument to measure chest wall expansion. The correlational results between chest wall expansion and strength can be used as a foundation to design cause and effect study in the future to identify efficient treatment or exercise for improving respiratory function and reducing respiratory problems in children.

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