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The consistency of an optical body surface scanning method compared with computed tomography: a validation study☆

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ABSTRACT

Objective: The ideal noninvasive method for evaluation of pectus excavatum remains to be defined. We sought to verify the accuracy of an optical body surface scanning method compared with conventional CT scan.

Materials and methods: A PrimeSense 3D sensor was used to obtain data from patients undergoing surgical or noninvasive treatment for pectus excavatum. The Haller index, external Haller index, and depth ratio were then calculated from both body scan and computed tomography scan data for the same patients. Statistical analyses were carried out to find if there is consistency between data from body scanning and computed tomography.

Results: Data acquisition was complete. In total, 40 patients (median age: 5.03 years, 11 female) with pectus excavatum undergoing nonoperative ($n = 13$) or surgical Nuss treatment ($n = 27$) were included. The Haller index was lower in vacuum bell patients, which also had a higher female proportion. Pearson correlation coefficient between external Haller indices from body scanning and from computed tomography and between the depth ratios from body scanning and from computed tomography were 0.63 and 0.84, respectively. By intraclass correlation coefficient method, the correlation coefficient was 0.56 between external Haller indices from body scanning and from computed tomography and 0.80 between depth ratios from body scanning and from computed tomography.

Conclusion: The optical body surface scanning is a reliable approach to the measurement of PE severity and could be routinely used in the monitoring of PE development of treatment, especially in the pediatric population.

Study type: Diagnostic test.

Level of evidence: Level II.

Pectus excavatum (PE) or funnel chest, defined as posterior concave of the breastbone, is one of the most common congenital chest wall defects. Pathophysiologically, this lesion may result in impaired cardiac and pulmonary function, especially in severe cases [1]. Otherwise, the primary indication considered for treatment is aesthetic concerns and social and psychological stress it produces [2].

Since the management strategy largely depends on the severity of the depression [3], it is ideal to have an easy, reproducible, noninvasive method for measurement. Traditionally, noninvasive evaluation of chest wall deformities usually include imaging modalities such as chest radiograph, computed tomography (CT) and, less commonly, magnetic resonance imaging (MRI) [4]. Haller index (HI) [5], an index to quantify the severity of chest depression is routinely calculated on cross sectional images obtained from CT or MRI. However, in view of ionized radiation exposure from radiograph and CT, particularly in pediatric patients, efforts should be made to limit their use. Alternatively, other approaches have been developed to quantify the defect, especially after the introduction of nonoperative treatments for pectus deformities, namely vacuum bell or suction cup. These alternatives include photography, Likert-type satisfaction scoring scales, and scaled rod tools to evaluate the deepest point in cases with PE and the highest point with pectus carinatum [6–8]. As a novel and promising method, optical imaging techniques have been reported in previous studies [9–11]. However, this type of methods has not been thoroughly verified in terms of their accuracy and consistency when compared with CT or MRI. The objective of this study is to describe the validation of a body surface three-dimensional (3D) scanning device with which data were obtained and compared with that from CT to test its reliability.

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1. Materials and methods

1.1. Body surface data acquisition

A PrimeSense 3D sensor Carmine 1.09 system (Fig. 1) (PrimeSense, Israel, acquired in 2015 by Apple, USA) was used to acquire body surface data. The systems comprised a handheld camera set including infrared, depth and visible light cameras which were connected via a Universal Serial Bus cable to a laptop with Skanect 1.9 (Occipital, Inc., San Francisco, CA) installed. The data acquired with the camera set was transferred to Skanect and 3D reconstruction was performed in real time.

When acquiring data, patients were required to stand on a turntable with their arms abducting to the level of the shoulders during body surface scanning. The sensor/camera set was placed about 0.5 m in front of them. For patients receiving vacuum bell therapy in outpatient clinic, only the front chest was scanned while in dorsal decubitus position. The procedure took around 1–2 min for one complete lap on the turntable. The procedure was performed twice for each and every patient and the better image reconstructed was chosen for later analysis. With Skanect, the data acquired with the sensor was synthesized and output as a .stl file.

1.2. Patients

After approval of the institutional review board at our hospital, a prospective study was conducted from April 2018 to March 2019. All patients with pectus excavatum considered for surgical correction at our center were approached and enrolled after consent was obtained. Additionally, in outpatient clinic the patients deemed by the surgeons suitable for nonsurgical vacuum bell therapy were body-scanned using the sensor above mentioned to acquire data for personalized vacuum bell production and follow-up. Among these vacuum bell patients, those who had undergone CT scan at our hospital were also enrolled in this study.

Fig. 1. The camera set of the PrimeSense 3D system.

1.3. Data processing

The body scan data were imported to Materialise 3-matic 11.0(Materialise, Leuven, Belgium) to generate cross-sectional images as is done with CT images. A cross-sectional image through the deepest depression was obtained and measured for two calculated indices: external Haller index (EHI) and depth ratio (DR). The EHI is the lateral external chest wall distance divided by the distance between the external deepest point in the front chest and the posterior body surface projection of the spinous process (Fig. 2). Depth ratio is defined as the shortest vertical distance between the external deepest point and the line segment connecting the highest point on each side of the front chest divided by the same line segment. CT measurements were carried out on institutional picture archiving and communications system (PACs), including: Haller index (HI) (Fig. 2), EHI and DR for each patient by the same personnel. For every patient, each parameter was measured twice at two difference time points and a mean value was calculated for statistical analysis. If there was a significant difference between the two measurements, a third measurement would be taken to reduce human error. Patient receiving vacuum bell therapy were only scanned for the front chest at a supine position, so there were only depth ratios that could be acquired for them.

1.4. Statistics

Statistical analysis was performed using Stata 15.0 (STATA corp, College Station, TX, USA). Data obtained were examined for normality distribution. Categorical data were presented as frequencies and compared using Fisher's exact test while continuous data which did not follow normal distribution were presented as median and interquartile range and compared using Wilcoxon rank sum test. Pearson correlation was used for correlation analysis between EHI obtained from body scan (scanEHI) and HI obtained from CT(CTHI), EHI obtained from CT (CTEHI), DR obtained from CT(CTDR) and between DR obtained from body scan (scanDR) and CTHI, CTEHI, CTDR. The intraclass correlation coefficient was used to determine the consistency between scanEHI and CTEHI, scanDR and CTDR. Furthermore, scatter plot and linear regression were used to visualize their correlation. A $p < 0.05$ was deemed statistically significant.

2. Results

In total, 40 patients (median age: 5.03 years, 11 female) with PE undergoing nonoperative ($n = 13$) or surgical Nuss treatment ($n = 27$) were included in the study. The age, HI and gender ratio were presented and compared between the two groups in Table 1. There was no difference in age. However, the HI was lower in vacuum bell patients, indicating chest depression was less prominent in this group. There also was a higher female proportion in vacuum bell group.

The correlation coefficients by Pearson correlation were shown in Table 2. The figures between scanEHI and CTEHI and between the scanDR and CTDR were 0.63 and 0.84, respectively, suggesting a high correlation. By intraclass correlation coefficient method as shown in Table 3, the correlation coefficients were 0.56 between scanEHI and CTEHI and 0.80 between scanDR and CTDR, respectively. The scatter plots and linear regressions for EHI and DR were shown in Figs. 3 and 4. The results suggested a high correlation between data acquired with CT scan and body surface scanning, especially between scanDR and CTDR.

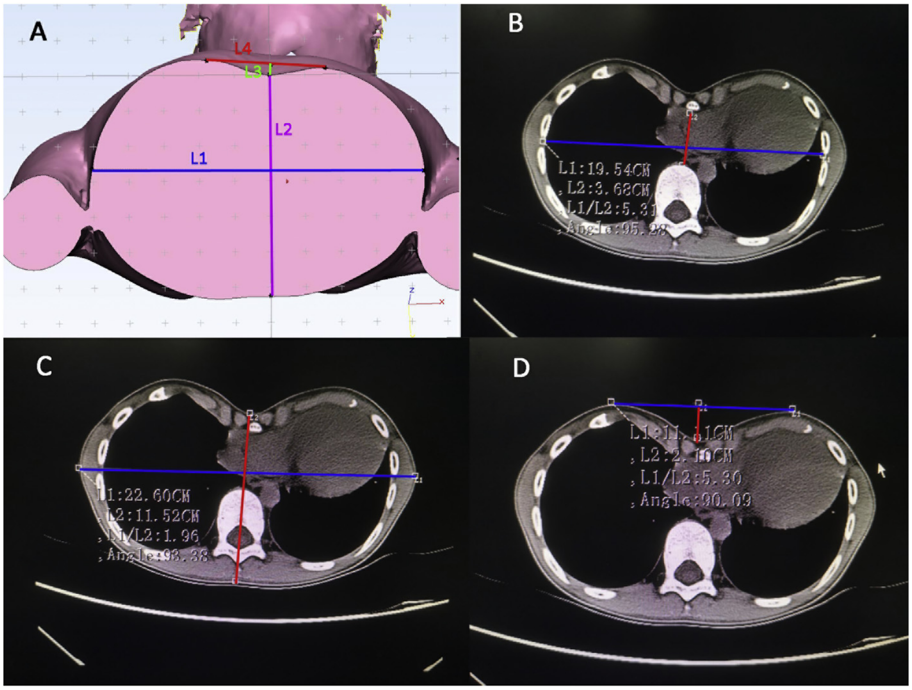

Fig. 2. Measurements in Materialise 3-Matic and institutional PACS system with images obtained from body surface scanning and CT, respectively. Images shown are cross sectional ones through the deepest depression. A: L1: the lateral external distance of the chest; L2: the distance between the external deepest point in the front chest and the external spinous process; L4: the distance between the highest points on each side of the front chest; L3: the shortest vertical distance between external deepest point and L4. B: L1:the internal lateral chest wall distance; L2: the distance between the internal deepest point in the front chest and the anterior surface of the vertebrae; C: L1:the external lateral chest wall distance; L2: the distance between the external deepest point in the front chest and the posterior body surface projection of spinous process; D: L1: the distance between the highest points on each side of the front chest; L2: the distance between the external deepest point in the front chest and L1.

3. Discussion

The quantification of the severity of pectus excavatum is routinely realized by measurement of Haller index on CT or MRI in a clinical setting [12]. However, they have their own shortcomings such as ionized radiation for CT and long workup duration and sedation requirement for MRI, which are even more so in pediatric population. In view of these, a variety of alternative methods have been developed, including physical rod and scale [13] and 3D body surface scanning [13]. As one of the optical body surface scanning solutions, PrimeSense Carmine 1.09 system was used in our study. The reason why we used this system was two-fold. First, it is open-sourced and economical, radiation-free and efficient, making it an ideal alternative to CT or MRI. And the data acquired can be exported to Skanect directly for further processing. Second, at our institution PE patients who opt for vacuum bell therapy need a front chest surface scan to obtain data for personalized vacuum bell production. The vacuum bell we currently use is bespoke according to each patient's chest configuration and all patients in vacuum bell therapy are followed up with regular body surface scanning.

Though vacuum bell therapy has now become an established a method other than surgery [14] [15], 3D body surface scanning is not much used for treatment surveillance and follow-up and has never been reported for personalized manufacture of a vacuum bell. Additionally, 3D body surface scanning was not always reported to be used as a quantitative, but sometimes as a qualitative or semiquantitative method [13]. With all the advantages mentioned above, the accuracy of body scan remains to be confirmed. Previously, one study [9] investigated the consistency of data between surface scan and CT and found good consistency between them even for different parameters (EHI from scanning vs. HI from CT). Although not as good as their findings, the results of our study suggest data acquired from body scan were reasonably correlated with those from CT, especially when comparing the same parameter (scanEHI vs. CTEHI, scanDR vs. CTDR) between the two methods and could be used for follow-up during vacuum bell therapy.

The following may explain the heterogeneity in studies. The subjects in the study by Lain, et al. [9] were older, with 360° scan for all, while in our younger patients noncompliance seemed a major issue. Patients could not always keep standing still when the turntable was rotating or lying still on table for front chest-only scan. And there also was no additional apparatus to make sure all the subjects stood in the same position and gesture. For example, some patients were found standing with their back slightly bent while the others stood up straight. Young patients were often unwilling to cooperate or inclined to cry during scanning, making the front chest move up and down more significantly than at rest. As a result, we chose to acquire data twice for each subject and used the better one for analysis and the acquisition process only lasted 1–2 min for a complete chest and back scan and 3–5 s for a front-

Table 1
Patients' demographics and comparison between the Nuss and vacuum bell groups.

	Total ($n = 40$)	Nuss ($n = 27$)	Vacuum bell ($n = 13$)	p
Age(years), median, IQR	5.03, 3.52–7.83	4.54, 3.53–10.32	5.07, 2.86–7.11	0.48
CTHI, median, IQR	4.06, 3.50–4.85	4.26, 3.86–5.07	3.52, 3.42–3.84	0.003
Gender, female	11	4	7	0.02

CTHI: Haller index obtained from computed tomography; IQR: interquartile range.

Table 2
Pearson correlation of parameters calculated.

	scanEHI	scanDR
CTHI	0.37	0.46
CTEHI	0.63	0.58
CTDR	−0.32	0.84

CTHI: Haller index obtained from computed tomography; CTEHI: external Haller index obtained from computed tomography; CTDR: depth ratio obtained from computed tomography; scanEHI: external Haller index obtained from body surface scan; scanDR: depth ratio obtained from body surface scan.

chest only scan, though artifacts remained an inevitable issue. Moreover, though the sensor we used was similar to that in one study [9], different software was utilized in ours. A further export–import step was also included in ours. These software related issues may also have brought variances.

Besides interstudy variability, we should also notice that the two methods compared in the study were carried out in different body positions. The complete chest-back scan was performed while standing and CT scan were all done in dorsal decubitus position. This may also have been an important interfering factor as evidenced by higher consistency between scanDR and CTDR since for scanDR measurement; data of the 17 patients were also obtained when they were lying on the back.

As with previous studies published, we did encounter some girl patients who had breast developing. Actually, this was part of the reasons why we chose to use a customized vacuum bell. A round-shaped vacuum bell, in contrast to a bespoke one that fits the configuration of the chest better, is obviously not suitable for a girl with breasts developing or developed. There may be concerns that breast development may affect the accuracy of body scan especially when there is asymmetrical depression. However, none of them in our series seemed to be asymmetrical ones as evidenced by the appearance and CT scan images. Since our use of vacuum bell is currently limited to patients with younger age and less severe depression, we do not think we have chance to body scan an adolescent female with severe asymmetrical excavatum. Nonetheless, this indeed raises a question if this approach is going to be extended to older girls with more severe depression.

Though our main objective was not to compare Nuss procedure with vacuum bell therapy, our findings have also shown female patients tend to have vacuum bell therapy, probably because of avoidance of a surgical scar and hence better cosmetic effect, which were considered more worthwhile by a girl' parents than a boy's. The HI in vacuum bell group was also smaller. And this was possibly owing to a collaborative result of surgeon's recommendation and the parents' view on this relatively novel approach to PE.

The present study was a pilot, small sample sized study with a couple of factors impacting the results. There were only 40 cases and only patients who had had CT performed were included. As we previously mentioned, body scanning was not always performed under ideal conditions. Deep breathing, crying and body movement had produced artifacts. Though all the image processing and measurement were performed by the same personnel, deviations were to be expected. The software we used was not specifically designed for PE indices measurement and some data processing steps were not standardized. The measurement was performed manually, not automatically. All of these may have brought errors. Further improvement should be considered to make the scanning process faster, the data processing and measuring easier and more standardized. As more patients undergoing vacuum bell therapy were followed-up with this technique, more data are expected to be acquired to confirm the conclusion.

Table 3
Intraclass correlation of parameters calculated.

	scanEHI	scanDR
CTEHI	0.56	
CTDR		0.80

CTEHI: external Haller index obtained from computed tomography; CTDR: depth ratio obtained from computed tomography; scanEHI: external Haller index obtained from body surface scan; scanDR: depth ratio obtained from body surface scan.

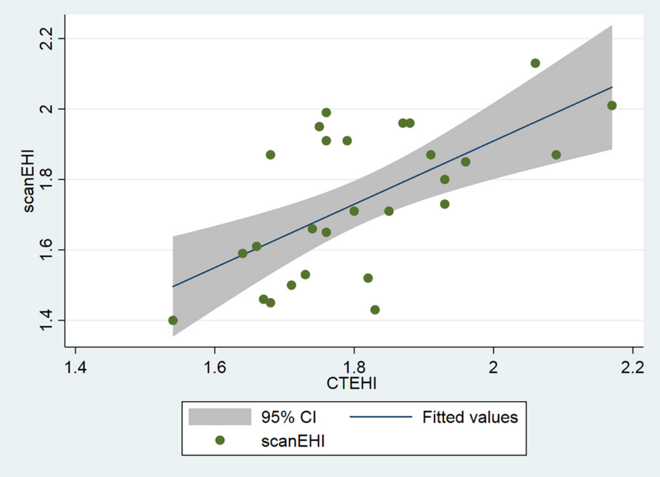

Fig. 3. Scatter plot and fitted line showing correlation between CTEHI and scanEHI. CTEHI: external Haller index obtained from computed tomography; scanEHI: external Haller index obtained from body surface scan.

4. Conclusions

The optical body surface scanning is a reliable approach to measurement of PE severity and could be routinely used in monitoring of PE development of treatment, especially in pediatric population. Some improvements are needed to make the method faster and more accurate.

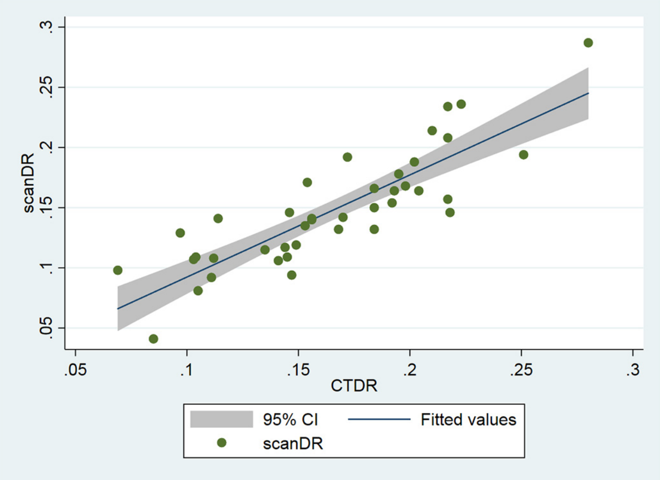

Fig. 4. Scatter plot and fitted line showing correlation between CTDR and scanDR. CTDR: depth ratio obtained from computed tomography; scanDR: depth ratio obtained from body surface scan.

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