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Validating 3D indexes in the non-surgical pectus excavatum patient☆

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ABSTRACT

Background/purpose: In recent years there has been an increased interest in three-dimensional (3D) imaging for the assessment of chest wall deformities. Some studies have proven a correlation between 3D and traditional cross-sectional images but only for patients who already had an indication for a computed tomography (CT) scan prior to surgery; mainly due to their severity. Our aim is to determine the accuracy and reliability of the measures obtained by a portable 3D scanner in a cohort of pectus excavatum (PE) patients with different severity grades, as well as in controls.
Methods: We conducted a study comparing radiological and optical indexes on magnetic resonance imaging (MRI) and 3D surface images. We used a hand-held 3D scanner to obtain the optical Haller Index (3DHI) and Correction Index (3DCI) and a limited MRI scan to obtain the traditional indexes. A statistical analysis was carried out to determine the correlation between optical and radiological measures, plus a subjective severity evaluation.
Results: Twenty-eight patients and controls were enrolled in the study. In both the control and PE groups, there was a significant positive correlation between the indexes, especially for the CI. There were no differences in correlation regarding gender, age or severity. CI appears to better discriminate amongst the different severity groups and controls.
Conclusion: 3D surface imaging is feasible and appropriate to use to assess PE, regardless of the severity or characteristics of the individual patient. Even with a small hand-held device, we can obtain accurate images and measures which are especially useful for the assessment of the nonsurgical pectus patient.

Evaluating chest wall anomalies is a controversial issue. The most accurate methods employ ionizing radiation, such as X-ray images [1] or, more specifically, a CT scan. In fact, the most widely accepted indexes for PE assessment – Haller Index (HI) and Correction Index (CI) – are seen on cross-sectional CT scan images [2,3]. For most children, the risks of radiation outweigh the benefits of a CT scan [4], although there is a subset of patients who would benefit from the information it provides (such as severe, symptomatic or complex cases prior to surgery).

Approximately half of the patients with PE have mild to moderate forms of the anomaly [5]. They may be asymptomatic or may have a minor degree of deformation. Therefore they would not be candidates to surgery or they would decide to try non-operative treatments [6]. In order to evaluate this subgroup of patients, qualitative methods have been traditionally used, such as photographs or questionnaires. An assessment of the deformity has been proposed using external measures or calipers, which may at times be subjective and imprecise. However, these assessments provide valuable information. In addition, measurements can be safely repeated over time, which is important as it enables us to monitor changes in a growing, young patient or in a patient using non-operative treatments [7].

Indeed, this is where 3D surface scanning may hold extraordinary value. It is an objective, feasible, non-invasive technique that provides a surface image of the thorax, whereby we can select the best cross-section image in order to calculate the measures equivalent to the traditional ones [8,9].

Previous papers have proven the correlation between standard measures for PE on a CT scan or an MRI with the optical measures on a 3D image [9,10]. However, this correlation has been studied only in a selected group of patients who underwent a CT scan as the preoperative

Abbreviations: 3D, three-dimensional; CT, computed tomography; PE, pectus excavatum; HI, Haller Index; CI, Correction Index; 3DHI, Optical Haller Index; 3DCI, Optical Correction Index; MRI, magnetic resonance imaging.

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work-up before pectus repair. These patients are more likely to have had severe forms of the deformity. As 3D images could be more useful in the evaluation and follow up of non-surgical patients, we consider that it is important to study this correlation and the value of the optical indexes, not only in the severe cases but also in the mild to moderate deformities and in controls.

The aim of this study is to evaluate the accuracy of 3D surface imaging in order to assess a varied cohort of patients with PE of differing severity and characteristics and controls, by comparing the measures obtained with those calculated on an MRI scan and correlating them.

1. Material and methods

The present study was approved by the Ethics Review Board of our institution. We identified patients with PE from our outpatient clinic who were old enough to undergo MRI scan without sedation, and offered them the opportunity to take part in our research during 2018. All patients and caregivers agreed and signed their consent to participate. We conducted a cross-sectional study obtaining both 3D surface images and a limited MRI of the deformed area. Demographic data and chest wall deformity clinical assessments were also recorded.

The PE patients were divided in three groups according to severity, as evaluated by the three clinicians specialized in Pediatric Surgery and chest wall deformities.

As there is not a standard specific measure to differentiate the mild from the moderate cases, we decided to classify them in this subjective way. There was not any discrepancy in the assignment of each patient into the different categories by the three senior surgeons.

We used an affordable portable hand-held 3D scanner that allowed us to integrate a 3D model of the thorax to obtain the optical Haller Index (3DHI) and Correction Index (3DCI). All participants underwent a limited MRI scan to obtain the traditional HI and CI. A statistical analysis was carried out to determine the overall correlation between measures and specific correlation, according to severity, age and gender.

1.1. 3D Scanning system

We used the PocketScan 3D 1.0 scanner from Mantis Vision™ (Israel) to capture 3D images, which is a hand-held portable scanner. Its accuracy is 0.2% from the measured dimension and has a data acquisition speed of 600,000 points/s. The scanner dimensions are 120 × 60 × 30 mm, and it weighs 250 g. We connected to the computer by means of a USB 3.0 port (see Fig. 1).

The software used for the images is the Kapla Vision™ (Mantis Vision 2017). This program automatically integrates the point cloud obtained by the scan into a 3D figure.

Fig. 1. Portable 3D Scanner.

1.2. Patient positioning and data acquisition

To ensure the reproducibility of the scan, we settled a specific position for the device and requested that patients sit on a swivel chair. There was no need for external markers. We then spun the patients 360° in order to obtain the complete scan, taking images following the inspiration and expiration of each patient.

1.3. Image processing

The point cloud obtained was de-noised and integrated using the software provided with the scanner. The 3D image obtained was then exported to a second program, ECHO™ 1.2.0 (Mantis Vision 2017), where further refining was undertaken and the deformed area was selected. The selected curve underwent analysis in Matlab™ (MathWorks 2017) so as to obtain the selected measurements.

1.4. Magnetic resonance imaging

The MRI images were taken by the SIEMENS AVANTO 1.5 T RM System. We performed T2-HASTE sequences with 45 slices, using a distance factor of 0% and a slice thickness of 4 mm, with a TA of 50 s (4 apneas of 12 s) using a matrix of 186 × 256 mm.

1.5. Measurements

The measurements evaluated were the Haller Index (HI), which is the most widely used for the assessment of PE, and the recent Correction Index (CI), as described by St Peter [3].

The Haller Index is defined as the relationship between the maximum transverse diameter of the thorax from the inner side of the costal arches and the distance between the maximum depression point of the sternum and the perpendicular line that crosses anteriorly to the spine [2]. The optical HI or 3DHI, also called the Hebal-Malas Index, was defined as the relationship between the same distances (maximum transverse diameter and maximum depression point), taking as references the external points on the skin [10] (see Fig. 2).

The Correction Index calculates the percentage of deformity. Taking as reference a horizontal line drawn anterior to the spine, this measurement considers the difference between the distance to the deepest point and the maximum distance to the inner margin of the costal arches [3]. It has been proposed that CI discriminates better from amongst normal chests and different grades of severity of PE. The optical correction index 3DCI was calculated in the same way but by taking as reference a line drawn at the posterior skin surface (see Fig. 3).

1.6. Statistical analysis

We export the data to SSPS Statistics (IBM 2016) for statistical analysis.

Quantitative variables are expressed as mean and standard deviation and qualitative variables as a percentage.

The data were analyzed to check the normal distribution using the Shapiro–Wilk test. The correlation between the measurements was calculated using the Rho-Spearman test, with a 95% confidence interval. The correlation was adjusted according to the rest of the variables to analyze it globally and according to gender, age and the severity of the deformity.

2. Results

Twenty-eight children were included in the study, including 21 PE patients and 7 controls. Demographics and characteristics are summarized in Table 1.

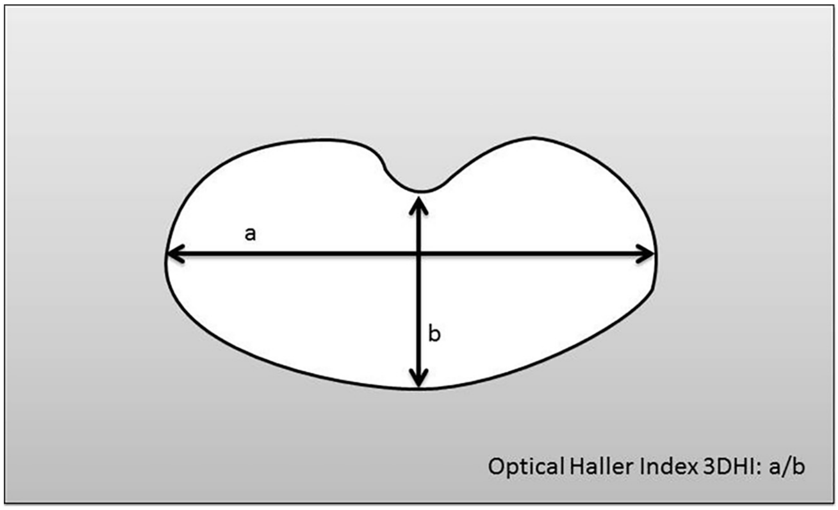

Fig. 2. Optical Haller Index.

In the control group, a statistically significant positive correlation was found between the HI on MRI and 3DHI of 0.653 with $p < 0.05$ and also between the IC on MRI and 3DCI of 0.724 with $p < 0.01$.

In the PE group, there was also a significant correlation between both indexes, which showed 0.576 for the HI on MRI and 3DHI with $p < 0.05$ and a 0.764 between the CI on MRI and 3DCI with $p < 0.01$.

Regarding the analysis of the indexes according to severity, we found that the mean value of both HI and CI on MRI were statistically different with $p < 0.001$, depending on severity. The optical 3DCI also showed a significant difference ($p < 0.001$). However, the differences amongst the 3DHI values were not statistically significant amongst the severity groups and controls.

When evaluating the indexes depending on age and gender, we found no statistically significant differences amongst the groups.

3. Discussion

Chest wall deformities are conditions of undeniable importance: they have an incidence of about 1%, they may be associated with cardio-respiratory impairment and they can cause an important psychosocial distress [11]. This is particularly true with the most severe forms of PE. The benefits, both physiological and psychological, of pectus repair have been widely studied [12].

However, there are a number of patients whose deformities are not so severe as to propose a surgical approach, or who are still too young to consider surgery, who deserve close follow up for different reasons [13]. Young teenagers with mild to moderate forms may suffer from psychological distress, anxiety or social impairment due to their deformity [14]. In addition, young children who manifest the deformity early in life may develop more severe forms of PE in the future [15].

Patients who are currently under exercise programs, vacuum therapy or simple observation are those who may benefit more from a non-invasive, non-radiating and precise measurement tool for their condition. Accurate assessment is essential to be able to evaluate any increase in the deformity during the child's growth period, the effect of exercise or the results of vacuum therapy, as well as to reinforce compliance to a treatment program [16].

Traditional methods, such as photographs or measurements taken with calipers, are useful but subjective. Although some of them have been proven to correlate with X-ray images, asymmetry and interobserver variability remain an ongoing issue in their use [17]. For this reason, 3D measures will be extremely useful for this specific subgroup of patients.

Since the 1980s, there have been a number of publications on the application of 3D imaging technology in medicine. The Moiré Fringe Projection Technique was initially used to reconstruct the topography of a surface and was applied mainly in the assessment of scoliosis, although

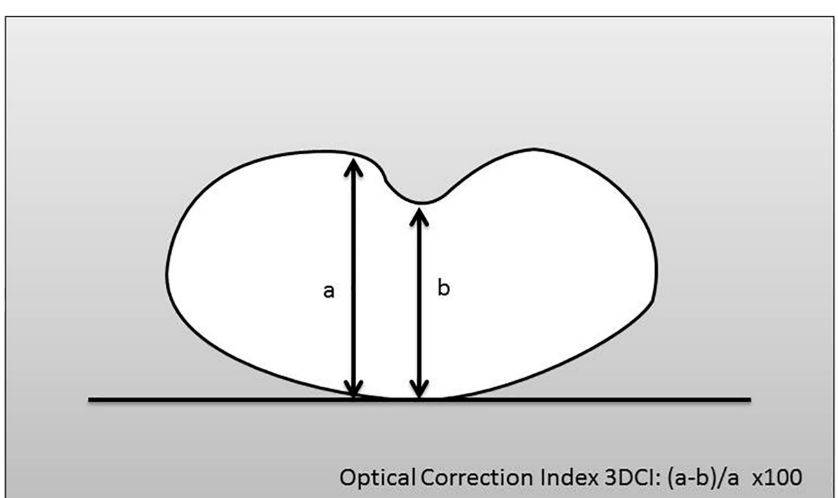

Fig. 3. Optical Correction Index.

Table 1
Main characteristics of the patients included.

		n	28
Gender	Male	18	64%
	Female	10	36%
Mean age	13.43 years (DS = 2.87)		
Grade of deformity	Control	7	25%
	Mild	8	29%
	Moderate	7	25%
	Severe	6	21%
PE patients n = 21			
Symmetry	Symmetrical	16	76%
	Asymmetrical	5	24%
Management	Observational	12	57%
	Vacuum therapy	9	43%

it gradually fell into disuse [18]. In 2007, Poncet developed an optical imaging system by which he evaluated patients with chest wall deformities [19].

The development of surface scanning technology has led to smaller and less expensive devices that can be easily used by an untrained professional. In addition, its short learning acquisition time and lack of radiation make this technology especially useful for medical purposes in children. Moreover, simplified software for the image processing allows us to automatically perform the integration of points in a three-dimensional image with greater precision, from which we can take the required measurements [20].

Our study does not focus on a specific group of patients. As we had the opportunity to perform an MRI scan, we offered every child in our outpatient clinic the opportunity to be enrolled, as long as they were old enough to undergo the MRI scan without sedation. To the best of our knowledge, this is the only study in which we have calculated the correlation in patients with mild to moderate forms of PE, as well as those with severe deformities, and controls. Although the number of patients included is limited, it has been high enough to detect statistically significant results.

According to our results, the correlation between traditional indexes and optical ones is sufficient and significant, especially for the CI, which indicates the percentage of the deformity more than the relationship between two diameters, as does the HI. Thus, the correlation between surface and radiological measures is more likely to be higher between CI and 3DCI as we can eventually eliminate the effect of soft tissue in the percentage calculated on the 3D section.

When comparing the mean values according to severity, we found that the radiological indexes discriminated significantly amongst the groups, as does the 3DCI but not the 3DHI. It was previously proven that CI discriminates better than HI the severity of the deformity on PE patients and with controls, as it is a percentage of the deformation [3]. This appears to be especially true when external landmarks are used to calculate the indexes. It is possible that with a higher number of patients we could have proven a significant difference amongst the mean 3DHI in each group. However, we consider 3DCI to be more accurate and that it should be used to evaluate PE patients with surface imaging.

We have not found any significant difference in the correlation according to gender or age group. Due to the effect of soft tissue on calculating the indexes on surface imaging, we should take into consideration the presence of breast development in girls. Only two girls in our study had already developed breasts at the time of the image acquisition, therefore we do not have enough data to ensure that the external measures for these specific cases are accurate enough. The mean values of both 3DHI and 3DCI in these two girls were close to the mean values of their severity groups.

Overall, experience with this system and the results obtained encourage the use of this technology, and we have previously reported a high rate of patient satisfaction during the data acquisition phase of our study [21]. However, it is important to note the difficulties that we encountered when dealing with the measurements tools within the software. It was necessary for us to design a specific code on a mathematic program to be able to take the measurements that we required, and we believe that more intuitive programs need to be developed in order to facilitate the future use of this technology in daily practice.

Thanks to the lack of radiation, accessibility and short scanning duration of this system, future research and applications could be aimed at the study of dynamics of the deformity during breathing, the correlation with symptoms, and so on.

4. Conclusions

New simplified and affordable surface 3D imaging technology is accurate and correlates well with traditional cross section imaging in PE patients, regardless of deformity severity.

The optical CI or 3DCI seems to be more accurate in the evaluation of PE patients than the 3DHI.

Further study should be undertaken to evaluate the effect of body mass and breast development in girls on the surface measures.

We consider that this technology is especially useful in growing children, and when using conservative management to evaluate changes over time and reinforce compliance to treatment and exercise.

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