Clinical Research

Usefulness of 3-Dimensional Body Surface Scanning in the Evaluation of Patients with Pectus Carinatum

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Background: Radiographic modalities have been commonly used to evaluate pectus carinatum (PC), and compressive orthotic bracing is the most widely accepted treatment method. The aim of this study was to determine the efficacy of 3-dimensional (3D) body surface scanning as an alternative modality for the evaluation of PC.
Methods: The medical records of 63 patients with PC who were treated with compressive orthotic bracing therapy between July 2017 and February 2019 were retrospectively analyzed. Using both 2-view chest radiography (posteroanterior and lateral view) and 3D body scanning, the height of maximal protrusion of the chest wall was measured both before and after 2 weeks of bracing therapy. The difference between the pre- and post-treatment measurements was calculated for both modalities, and these differences were compared and analyzed.
Results: Based on the comparison between the pre- and post-treatment radiographs, bracing therapy produced favorable outcomes in all patients ($p<0.001$). The measurements obtained via 3D scanning were strongly correlated with those obtained via chest radiography ($r=0.60$).
Conclusion: Based on the findings of this study, 3D body surface scanning appears to be an effective, radiation-free, and simple method for the post-treatment follow-up evaluation of PC, and thus can be considered an alternative to radiography.

Keywords: Pectus carinatum, Three-dimensional, Three-dimensional body scan, Body surface scan, Braces

Introduction

Pectus carinatum (PC), also known as pigeon chest, is a relatively common chest wall deformity that is characterized by anterior protrusion of the anterior chest wall. The prevalence of this condition has been reported to be approximately 0.7% [1,2]. As with pectus excavatum, the cause may be an imbalance of growth between the ribs and the costal cartilage of the chest wall [3,4]. Most patients with PC are asymptomatic; instead, the chief complaint is the cosmetic appearance of the chest wall associated with PC. Traditionally, surgery was the mainstay of treatment, and surgical treatment was indicated based on the degree of deformity. However, in recent years, compressive orthotic bracing has been widely used as a non-invasive method with favorable results [5,6].

Most commonly, chest X-rays and computed tomography (CT) are used to evaluate patients with PC [7,8]. Pre- and post-treatment images are obtained using these radiographic modalities to determine the efficacy of treatment. These modalities inevitably expose patients to multiple doses of harmful radiation. Recent studies have demonstrated that a 2-view chest X-ray (posteroanterior and lateral view) could replace CT in the evaluation of chest wall deformities, as the former entails less exposure to radiation [9]. At Gangnam Severance Hospital, the 2-view chest X-ray is used for the evaluation and follow-up of patients with PC. Although this technique does administer a lower radiation dose than CT, demand still exists for a new modality that eliminates any unnecessary radiation exposure.

Recently, at our institution, clinicians have begun to use 3-dimensional (3D) body surface scanning to evaluate PC

treated with a compressive orthotic brace. Using 3D body surface scanning, we can obtain images that show post-treatment results on an objective scale. In this study, measurements obtained using 3D body surface scanning were compared with those obtained using chest X-ray scans to evaluate whether 3D body surface scanning can be an effective and radiation-free alternative to evaluate the improvement of PC after compressive orthotic brace therapy.

Methods

Patients

We retrospectively analyzed the medical records of 63 patients with PC who were treated with compressive orthotic bracing between July 2017 and February 2019 at our institution. Both 3D body surface images and 2-view chest X-rays with posteroanterior and lateral views were obtained. The initial chest images were obtained at the first hospital visit, and the post-treatment images were obtained at the first follow-up visit, 2 weeks later. For both pre- and post-treatment scans, the height of maximal protrusion of the chest wall was measured on the 3D and chest X-ray images. On the lateral chest X-ray images, this height was measured as the distance between the most prominent point of the sternum and the anterior edge of the vertebral body (Fig. 1). The results were compared and analyzed. This study was approved by the institutional review board of Gangnam Severance Hospital, Yonsei University College of Medicine (IRB approval no., 3-2017-0353).

Three-dimensional body scanner

The Pectus Metric Tool 3D body scanner was used to scan the body surfaces of patients. To obtain 3D surface images, Microsoft Kinect (Microsoft Corp., Redmond, WA, USA), which uses a pattern of projected infrared dots to generate 3D images, was incorporated to capture the depth and color. The device was mounted on a curved movable platform with a 120° arc of rotation from one side to the other (Fig. 2) and connected to a personal computer. The software, which was newly developed for this purpose, could receive point cloud data using structured light scanning (Fig. 3). The real-time scanning software ReconstructMe (Profactor GmbH, Steyr-Gleink, Austria) was run on the computer, which was connected to Microsoft Kinect. Pre- and post-correction images were measured for comparison, and changes in the chest wall deformity were visualized using the developed software. With the patient in the supine position, the scan took 5 to 10 seconds to capture the necessary information. Once the initial scanning procedure was completed, the data file was saved in the standard polygon file (PLY) format for use in the software. After loading the pre- and post-correction images, the software automatically compared the point-to-point differences and generated a color map to visualize them. The color map scale indicated, in millimeters, the difference between the 2 images, which represented the improvement of the chest wall deformity.
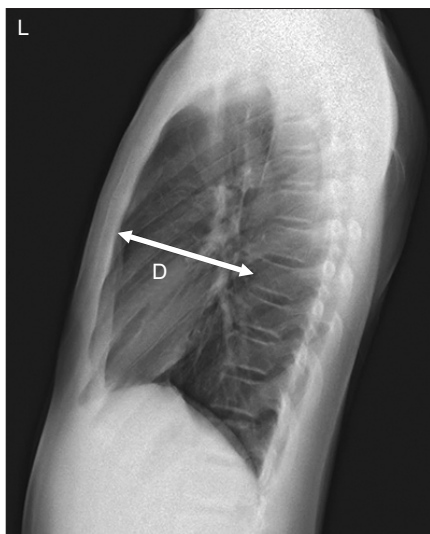

Fig. 1. Distance measurement on chest radiography (lateral view). The point of the most anterior projection of the sternum was identified, and the sternovertebral distance (labeled D) was measured.

Fig. 2. The Pectus Metric Tool 3-dimensional body scanner using Microsoft Kinect.
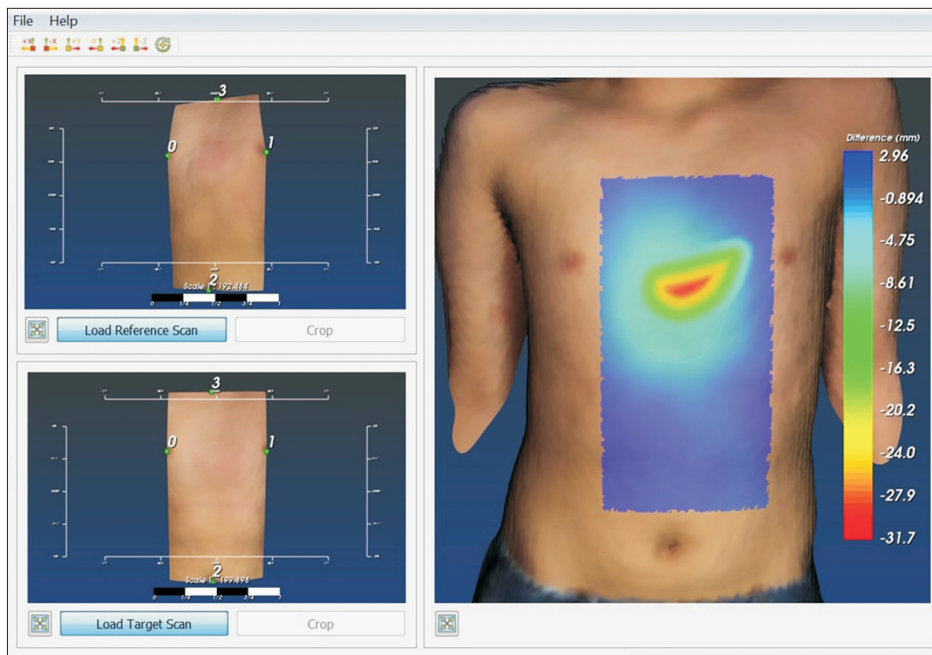
Fig. 3. Software used to compare 2 scans of the chest wall: landmark-based alignment and registration (left) and difference color map in mm (right).

Protocol for pectus carinatum bracing

The application of the brace was based on the findings of the clinical examination. Through close collaboration with a certified orthoptist, we designed a custom-fitted compression orthotic brace tailored to each patient. Patients were instructed to wear the brace over a layer of clothing to protect the skin for 20 hours per day during the compression period (2 weeks) and 10 hours per day during the maintenance period (6 months). The first follow-up visit was scheduled at the end of the compression period to evaluate patient compliance and the fit of the brace; thereafter, patients were followed up with every 3 months.

Statistical analysis

Continuous variables are expressed as means and standard deviations. Categorical variables are expressed as percentages. For the 2 modalities, the paired t-test was used for continuous variables, and Pearson correlation analysis was used to assess the correlation between the 2 variables. All statistical analyses were conducted using PASW SPSS for Windows ver. 18.0 (SPSS Inc., Chicago, IL, USA). All p-values <0.05 were considered to indicate statistical significance.

Table 1. Characteristics and measurements of patients obtained using lateral chest X-ray images

Characteristic	Value	p-value
Age (yr)	10.52±4.21	-
Male	56 (88.88)	-
Chest wall protrusion (initial, mm)	105.85±20.49	0.001
Chest wall protrusion (2 weeks after initial visit, mm)	89.84±20.00	

Values are presented as mean±standard deviation or number (%).

Results

A total of 63 patients with PC treated with compressive orthotic bracing were enrolled in the present study. All patients underwent both chest radiography and 3D body surface scanning at the initial hospital visit (pre-treatment) and at the 2-week post-treatment follow-up. The baseline characteristics are presented in Table 1. The mean age was 10.52±4.21 years, and 56 of the patients were male (88.88%). The mean chest wall protrusion height was 105.85±20.49 mm at the initial hospital visit and 89.84±20.00 mm at the 2-week follow-up visit (the post-treatment measurement). Based on the comparison between the pre- and post-treatment radiographs, compressive orthotic bracing therapy produced favorable outcomes in all patients (p<0.001).

The height difference (from pre- to post-treatment) of the point of maximal protrusion of the chest wall was measured using both 2-view chest X-rays and 3D body surface

Table 2. Pre- to post-treatment difference in the height of maximal protrusion of the chest wall as measured using 3D images and lateral chest X-ray images

Variable	Value	p-value
3D scan difference (mm)	19.44±17.46	0.057
Chest X-ray difference (mm)	16.00±9.28	-

Values are presented as mean±standard deviation.
3D, 3-dimensional.

Fig. 4. Correlations of measurements obtained from 3D scan images and lateral chest X-ray images of patients with pectus carinatum (N=63). 3D, 3-dimensional.

scanning (Table 2). The mean difference was 19.44±17.46 mm on the chest radiographs and 16.00±9.28 mm on the 3D images. As shown in Fig. 4, the measurements obtained via 3D scanning were strongly correlated with those obtained via chest radiography (r=0.60).

Discussion

PC is an anterior chest wall deformity diagnosed at birth or in early childhood that has recently been treated via non-invasive, compressive orthostatic brace therapy with favorable outcomes. To date, the most conventional and widely used methods for evaluating the outcome of treatment and/or the severity of PC have mostly been radiographic modalities, such as chest X-rays and CT. However, given the nature of the disease (which is usually diagnosed at birth or in early childhood), those receiving treatment are generally young, and the issue of radiation exposure is crucial. Parents and guardians, and in some cases the patients themselves, are generally opposed to receiving these modes of evaluation. Hence, the demand for a new modality of evaluating the treatment outcomes and/or degree of PC with minimal or no radiation has been steadily increasing.

Several studies have been conducted to attempt to reduce radiation exposure when evaluating PC severity and treatment outcomes. Khanna et al. [9] reported a statistically significant correlation between the Haller index as estimated with radiographs and the same index as estimated with CT. We found a similar trend in our data. Of the 63 patients, CT was performed in 7 patients at the initial hospital visit and post-treatment follow-up. The pre- to post-treatment difference was statistically similar between CT and chest X-ray scanning (p=0.152).

Some recent studies have indicated the possibility of alternatives to radiographic tools for the evaluation of patients with chest wall deformities [10-13]. Port et al. [12] reported the measurement and evaluation of the treat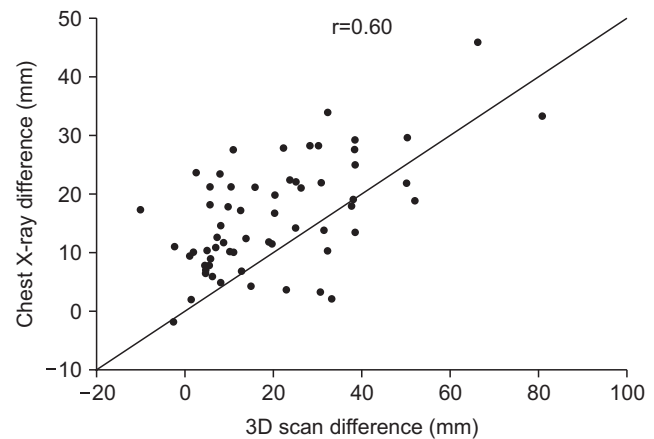ment outcome using white light scanning. Using a portable device, they obtained pre- and post-intervention images. The results they provided indicate that white light scanning may be a promising alternative to measure the severity of PC [12]. Wong et al. [13] used a 3D body scanner to evaluate the efficacy of compressive orthotic bracing. They showed that serial 3D body scan imaging can be used to measure and monitor changes over time [13]. However, their study had some limitations that cannot be overlooked; notably, their procedure required a technician to acquire and analyze the images and modify the equations to calculate the treatment efficacy. This may have led to subjective results.

In our study, the Pectus Metric Tool, which is a portable 3D body surface scanning device used to visualize the shape and contour of the thorax and to accurately assess chest wall deformity, was used to obtain 3D chest surface images in conjunction with Microsoft Kinect, an infrared laser projector. The software compared the pre- and post-treatment chest surface images to assess the change in the chest shape over the course of therapy. The system is simple to use, and technicians, who could be a source of subjectivity, are not required. In this study, we showed that 3D chest surface scanning can be used to successfully visualize and quantify the changes over the course of therapy without radiation exposure.

This study had several limitations. First, it was a preliminary study based on a relatively small cohort from a single institution. Although this study demonstrated the feasibility of the Pectus Metric Tool system in evaluating patients with PC, only a few institutions are currently using this system. To better evaluate the efficacy of this system, a larger multi-institutional study may be necessary. Second,

the 3D body surface images acquired in this study were only compared with chest X-ray images. Hence, for a more comprehensive evaluation, 3D body surface scanning should be compared with other modalities.

Nonetheless, 3D body surface scanning, at least preliminarily, appears to be an effective, radiation-free method for post-treatment follow-up evaluation of PC.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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