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Bracing of pectus carinatum: A quantitative analysis

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ABSTRACT

Background/Purpose: Primary treatment of pectus carinatum (PC) is performed with an external brace that compresses the protrusion. Patients are 'prescribed' a brace tightening force. However, no visual guides exist to display this force magnitude. The purpose of this study was to determine the repeatability of patients in applying their prescribed force over time and to determine whether the protrusion stiffness influences the patient-applied forces and the protrusion correction rate.
Methods: Twenty-one male participants (12–17 years) with chondrogladiolar PC were recruited at the time of brace fitting. Participants were evaluated on three visits: fitting, one month postfitting, and two months postfitting. Differences between prescribed force and patient-applied force were evaluated. Relationships of patient-applied force and correction rate with protrusion stiffness were assessed.
Results: Majority of individuals followed for two months (75%) had a significantly different patient-applied force ($p < 0.05$) from their prescribed force. Protrusion stiffness had a positive relationship with patient-applied force, but no relationship with correction rate.
Conclusion: Patients did not follow their prescribed force. Magnitudes of these differences require further investigation to determine clinical significance. Patient-applied forces were influenced by protrusion stiffness, but correction rate was not. Other factors may influence these variables, such as patient compliance.
Level of Evidence: Treatment Study – Level IV.

Pectus carinatum (PC) presents as an idiopathic overgrowth of the costal cartilages that results in a protrusion of the sternum [1]. The cause of PC is unknown but it is the second most common chest wall deformity occurring in approximately 1 in 500 to 1500 children [2]. Previously, the primary course of action to reduce or remove the protrusion was invasive surgery, most commonly the Ravitch procedure [3]. Long-term effects of this surgery have been inconsistent, with some surgeries resulting in worsened cosmetic appearance and decreased chest wall plasticity [4]. As a result, the treatment of PC has evolved to a noninvasive, compressive bracing alternative that has been shown to be effective for most patients [1,5–11]. These braces were created to provide an alternative procedure to correct the PC deformity that has now become the primary course of treatment [7]. These braces are designed to provide a force to the underlying protrusion through a pad (example in Fig. 1). The objective is to provide sufficient force to remodel the protrusion. The force applied by the brace in this study is manually adjusted by the patient over the course of treatment. The patient is asked to reproduce a force that is consistent with the clinically prescribed guidelines, otherwise known as the clinically prescribed force (CF). The CF is determined by the clinician by applying a force that restricts deep inspiration. From anecdotal observation, if these guidelines are not followed, there may be either insufficient or excessive forces applied to the protrusion, leading to lengthened treatment time or injury, respectively. This situation exists because there are no visual cues on the brace to notify the patient of the magnitude of force.

Additionally, the CF magnitude is unknown to the clinician and presumably differs between patients. The clinician does not attempt to establish a consistent CF across all patients. Instead, each individual patient receives a CF that results in the same outcome — being able to obtain a breath that is "just short" of maximal inhalation. Therefore, physiological properties of the protrusion, such as the stiffness (i.e. the ability for the protrusion to resist remodeling), may influence the amount of force required to each that outcome [11].

No research has been reported on the direct forces applied by the brace and how its ability to provide a corrective force to the protrusion is influenced by the stiffness. Harrison et al. (2016) indicated that objective data are still required to further improve current assessment protocols, as well as the design and function of the brace itself [12]. Beginning

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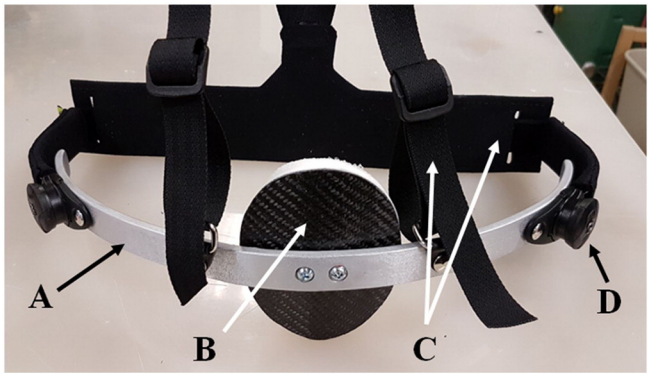

Fig. 1. The pectus carinatum brace (Braceworks, Calgary, Alberta) and its major components: A) Aluminum bar, B) Pad, C) Straps (right arrow = back strap, left arrow = shoulder strap), and D) Boa closures containing dials to adjust the brace force.

treatment at a later age has been shown to coincide with a larger pressure [11]. This relationship has been attributed to the stiffness increasing with age [13]. Therefore, one could contemplate that the patient-applied pressure would also be larger for those with a greater stiffness, which would subsequently relate to a larger patient-applied force (PF). Additionally, the same researchers determined that individuals in the older age groups had a lower correction rate [11]. These lower correction rates at older age groups may also be related to the higher protrusion stiffness. To our knowledge, quantitative data relating the brace force and stiffness have not been reported. In order to fully understand this condition as well as to advance treatment protocols, these relationships must be quantified. By developing these relationships clinicians may have the ability to personalize treatment plans.

We hypothesized that there would be a difference between PF and CF at the initial fitting of the brace (H1). Additionally, we hypothesized that these differences would remain after one month and two months from the fitting (H1a and H1b). Regarding the relationship of protrusion stiffness with the PF and correction rate, we hypothesized that a positive relationship would exist between PF and stiffness (H2). Conversely, we expected to find a negative relationship between the correction rate and stiffness (H3).

1. Material and methods

1.1. Study participants

Twenty one male participants were recruited by Braceworks Custom Orthotics (Calgary, Alberta, Canada) for the study. Ethics approval was obtained for the institution to perform this research. Demographics of the participants were obtained (Table 1). Informed consent was provided by all the participants to participate in the ethically approved study. Participants aged 10 to 18 years diagnosed with PC were considered the inclusion criteria for the study. These ages were recruited as they are most likely to respond to the brace protocol. Inclusion criteria also required the PC protrusion to be located approximately central to the body of the sternum (i.e. chondrogladiolar), as the brace is unable to correct the deformity if it is located at the manubrium of the sternum.

Exclusion criteria included children with PC protrusions not located centrally on the chest (e.g. manubrium), females (requiring modified version of brace), Marfan's Syndrome, Ehlers–Danlos Syndrome or other major disorders that affect the mechanics of the thoracic region.

Table 1
Mean and standard deviation of participant demographics.

	Range	Mean	SD
Age (yrs)	12–17	14	1
Height (cm)	150–196	172	11
Weight (kg)	42–89	51	3

1.2. Protocol

Data collection occurred at three time points: 1) the fitting appointment of the brace, 2) a one month follow-up appointment, and 3) a two month follow-up appointment. Two participants were not included in the two month time point analysis owing to drop out. Additionally, one participant was not included in the one month time point analysis owing to lack of availability. This resulted in a total of 60 data collection periods (21 at the fitting, 20 at the 1 month follow-up, and 19 at the two month follow-up), with gaps in the data for some individuals. Clinically prescribed force (CF) was collected only during the fitting appointment to determine the baseline force that was to be followed. Patient-applied force (PF), protrusion displacement (to calculate stiffness), and anterior–posterior (AP) depth measurement of the torso (to calculate the correction rate) were collected at every time point.

1.2.1. Data collection

On a testing day, the participant's regular fitting/follow-up appointment with the clinician was performed first. During the appointment, any adjustments and repairs to the brace were completed to ensure that the brace fit and maintained proper function. Following the clinician appointment, the AP depth of the participant's torso was measured five times using calipers (Model 220,335, Fillauer©, Chattanooga, Tennessee). Based on the standard clinical technique, the calipers were aligned with the apex of the protrusion. Following the AP depth measurements, the original pad of the brace was substituted with a calibrated force measurement system custom made to insert into the brace. Briefly, the force measurement system contained four load cells (TE Connectivity Ltd.® FX1901, 0–25 lb) embedded between two three dimensionally (3D) printed surfaces (Fig. 2). The four load cells were placed at the corners of the surfaces to ensure any forces acting on the peripheral of the pad were accounted for. A white, plastic surface was attached to the front of the brace (anterior to the aluminum bar) to act as a reflective surface for an LED sensor that allowed displacement measurements of the protrusion to be obtained while tightening the brace (Fig. 2). The participant was positioned standing against a wall in a neutral position (heels and back touching the wall with arms to the side). This positioning ensured minimal movement of the torso when tightening the brace. A tripod holding the LED sensor was placed approximately 6 cm away from the pad, ensuring it was in line with the

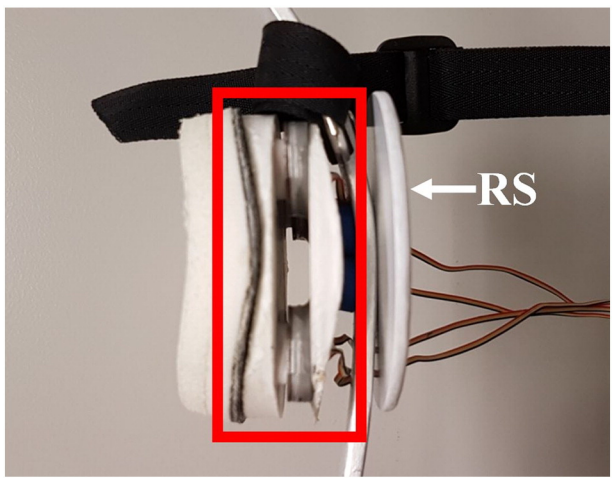

Fig. 2. The force measurement system (red box) and a white, reflective surface for the LED sensor (RS) implemented into the brace between the pad and aluminum bars.