

Pectus Carinatum: An Orthotic Approach

By Gina M. Retallack, CO; David M. Notrica, MD; and Dawn E. Jaroszewski, MD

Pectus carinatum (PC) is an anterior chest wall deformity associated with abnormal growth and development of the costal rib cartilages and sternum. The cartilaginous overgrowth is observed as an outward protrusion, tilt, or convexity on the anterior chest wall and often includes the sternum and associated ribs. The True ribs prominence may be asymmetrical or symmetrical. Classification is determined by the appearance of the anterior chest wall and the location of prominent and depressed areas. Accurately identifying the type of PC deformity is a crucial step in predicting orthotic outcomes.

Classification

Several PC classification methods have been developed and published in the literature over the last 20 years.^{3,7,10,15} Each classification system is based on the location of the apical, or highest point, of the prominence. Currently recognized PC classification systems fall into two categories, which are differentiated by the location of the involved deformity:³

- 1. Chondrogladiolar (CG)
- 2. Chondromanubrial (CM)

CG PC affects the mid to lower portion of the anterior chest wall and is the more common of the two. The prominence may include the inferior costal cartilages and portions of the gladiolus (Figure 1). An asymmetrical version of CG often occurs with both an excavatum and carinatum component and is characterized by a unilateral protrusion with contralateral depression.¹⁶

CM PC affects the upper portion of the rib cage and is more likely to be symmetrical. It is substantially less common than CG, representing only 5 percent of PC cases.⁵ It typically involves the superior costal cartilages, ribs one through three, and the manubrium. The upper section of the sternum protrudes anteriorly, and the body of the sternum deviates posteriorly (Figure 2).



Figure 1: Chondrogladiolar

Figure 2: Chondromanubrial



Figure 3: Rib cage anatomy. The white section of ribs is the costal cartilage. The superior costal cartilages are shorter and the inferior cartilages are longer.

In the CG PC category, the deformity is significantly more flexible due to its inferior location on the anterior rib cage. The longer ribs and accompanying cartilage in the lower sections of the rib cage result in a more flexible deformity because of the mechanical advantage of distance from the sternoclavicular attachments (Figure 3). CG PC can be effectively treated orthotically until full stature is achieved, and even later. The correction potential for this type of PC is greater than it is for CM PC due to the flexibility of the cartilage and the associated mechanical advantage that persists even after full growth.

Orthotic treatment of CG PC has been shown to have superior results in children due to the inherent flexibility and compliant nature of the deformity.^{3,7,10}

In the CM PC category, the deformity is more rigid because of its superior location on the rib cage. The upper portion of the rib cage is composed of shorter, less flexible ribs, which reduces the overall flexibility of the deformity (Figure 3). Because the superior rib cage is more rigid, orthotic outcomes are less optimal for patients with CM deformities. To increase the chance of success, orthotic treatment should be initiated as early as possible, preferably during childhood or at the beginning of adolescence when the residual cartilage in this area is more abundant.

Epidemiology

The incidence of PC is 1:1000 teenagers and is predominantly observed in males.² At this time, no definitive etiology of PC has been determined; however, medical professionals have observed that family history increases a child's chance of having PC by 25 percent, suggesting a genetic link.⁸ There is a 21 percent chance that PC will occur in association with scoliosis and other inherited connected tissue disorders such as Marfan's syndrome, Ehlers-Danlos syndrome, Noonan syndrome, and Poland's syndrome.¹

PC may also be categorized by etiology:

- 1. **Post-surgical:** After a sternotomy or chest trauma, the sternum does not heal in the proper position, resulting in a prominence on the anterior chest wall. This type of PC is uncommon, and the deformity does not progress or change with time.
- 2. Congenital: Premature fusion of segments of the sternum can occur in newborns, presenting with a rounded, prominent chest. This deformity has the potential to progress in later years.
- 3. Idiopathic: The idiopathic PC deformity will typically present during active growth stages between 11 and 15 years of age. The deformity tends to increase concurrently with adolescent growth spurts. Orthotic treatment appears to be most effective in halting progression and achieving skeletal correction of the deformity during this period of active growth. This is the most common type of PC and is the primary focus of this article.

PC is often asymptomatic in nature; however, some patients complain of significant pain at the costochondrial junction.⁹ In some moderate to severe PC cases, decreased stamina and rapid fatigue during strenuous activity has been reported.⁶ Decreased exercise tolerance could potentially be related to the increased diameter and rigid expansion of the chest wall, which makes it difficult for the thorax to use normal chest muscles for breathing.^{3,6} As a result, accessory muscles are recruited, causing respiration inefficiencies.

The psychological issues of the deformity usually trump all physical symptoms for a young adult. Many male PC patients complain of significant body-image and confidence issues and often avoid showing their chest in public. Bulking up the pectoral muscles balances the prominence and helps conceal the deformity, so some male patients initiate body-building to mask the deformity. The psychological and social challenges of the deformity are usually the primary reasons patients seek medical attention. The resulting eagerness to initiate orthotic treatment is often helpful in ensuring compliance.

Treatment

For the past 50 years, the primary treatment for PC has been surgery. Accepted surgical techniques include excision of the deformed cartilage with sternal osteotomy and internal fixation. Complications reported from surgery include poor long-term outcomes, lengthy recovery times, and potential for recurrence.¹⁶ Restricted growth in the thoracic cavity has been noted due to the scarring and rigidity caused by the operation.¹⁴ Consequently, surgical resection has been reserved for the most severe and complicated cases. These surgical complications prompted a search for more conservative treatment methods, ultimately leading to the development of a "compressive chest brace."¹¹

Plaster casts were the first nonsurgical methods used to treat PC. The casts applied pressure on the prominence to prevent further progression and promote correction. Vidal et al. were the first to initiate nonsurgical methods to treat PC in 1977 with limited success.¹⁸ In 1979, Sydney A. Haje, MD (1952-2012), and J.L.P. Raymundo, MD, from Brazil introduced the dynamic chest compressor (DCC) brace.11 They were the first team to develop a custom-fitted orthosis to treat PC and document and publish its success. In 2000, J. Craig Egan, MD, described radiographic-proven success in treating PC with an orthosis.3 Egan's work was followed by the publication of the first series of successful cases demonstrating that compression bracing was safe and effective.⁷ These cases were published by surgeons at Cincinnati Children's Hospital Medical Center, Ohio. Numerous other studies have been published in the last 20 years illustrating different methodologies, outcome measures, and results.^{3,7,10,12,14,15} Overall, orthotic treatment is now widely accepted as an effective conservative treatment method for PC.

Orthotic Treatment

PC orthosis design is based on Wolff's Law: when healthy bone and cartilage are loaded with a constant and increasing force, they will adapt, strengthen, and gradually remodel under pressure. A PC orthosis has two opposing forces, one directly over the apex of the prominence and one on the thoracic spine. Over time, this continuous force arrests further anterior cartilaginous growth and gradually remodels the rib cage into a more normal, flattened shape. The PC orthosis is worn until skeletal maturity is reached. These biomechanical principles have been validated in the design of two different PC orthoses used at Hanger Clinic in Lafayette, Colorado: a prefabricated PC orthosis and a custom PC orthosis.

Prefabricated PC Orthosis

When indicated, we use Trulife's prefabricated Pectus Carinatum Orthosis on patients with PC. It features a low-profile design with an anterior panel ($3\frac{1}{2}$ in. x $4\frac{1}{4}$ in.) for a posterior-directed force, a posterior panel (6 in. x $4\frac{3}{4}$ in.) for an anterior-directed force, and four lateral padded panels that contour around the chest (Figure 4). The panels are made from a low-density polyethylene ($\frac{1}{8}$ in.), which is flexible enough to easily conform around the patient's chest, creating an intimate and concealed fit. Over time, the body heat emitted from the patient helps mold the plastic panels around the chest for further customization. The panels are covered in a foam liner ($\frac{1}{4}$ - $\frac{3}{8}$ in. thickness) providing additional comfort for the patient. The panels are mounted on aluminum bars ($\frac{3}{4}$ -in. wide) with growth extensions, making it possible to adjust the circumference and fit of the orthosis as needed. Since the Trulife PC Orthosis comes in a single, "universal" size, the

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aluminum growth extensions promote ample adjustability during treatment and accommodate any anatomical changes that may occur during the patient's growth years.

The anterior and posterior sections of the orthosis are connected by a tension system composed of bilateral ratcheting buckles. There are two ratchet buckles riveted onto the anterior lateral panels that have connecting ladder straps riveted onto the posterior lateral panels. By tightening the ratchets bilaterally, anterior/posterior (A/P) forces are directed on the pectus deformity. The ratchets have a quick-release lever, which makes it easy to loosen or remove the orthosis.



Figure 4: Trulife's Pectus Carinatum Orthosis

Custom PC Orthosis

When a custom PC orthosis is indicated, we fabricate the device at Hanger's National Lab in Tempe, Arizona (Figure 5). We first obtain a digital mold of the patient's chest using the Insignia[™] motion-tracking laser scanner. We then send the scan electronically to Hanger's Central Design Center (CDC), where it is evaluated and modified using CAD software. A three-dimensional foam carving is then produced from the final image, providing a positive mold for the lab to create and fabricate the orthosis. The custom orthosis has an anterior and a posterior panel anchored to aluminum bars that contour around the patient's chest, clearing the skin. Lateral ratchet buckles and ladder straps connect the anterior and posterior sections and provide a tightening system. All components and materials can be hand-selected and customized to the patient. If materials are not specified, standard materials include $\frac{5}{8}$ in. PORON^{*}-lined Kydex A/P panels, 1 in. x $\frac{1}{8}$ in. aluminum bars, and $\frac{3}{4}$ in. buckles with $\frac{5}{8}$ in. x $\frac{81}{2}$ in. ladder straps. Each panel is customized to the shape and size of the patient's prominence and anatomy. If required, revision and adaptation to anatomical change during treatment can be achieved by adjusting the contours of the aluminum bars.

Custom vs. Prefabricated

When deciding between a prefabricated and custom PC orthosis, it's crucial to perform an accurate clinical and visual evaluation of the patient's deformity and chest anatomy. The thoracic surgeon and orthotist should collaborate to determine the orthosis design after their initial evaluations with the patient. A custom PC orthosis is indicated for patients with a moderate to severe PC deformity. Patients with an atypical or asymmetric prominence, an abnormal deformity shape or size, or an unconventional body shape or size may benefit from a custom-designed orthosis. Young children, patients with overdeveloped muscle build (especially the pectoralis major and latissi-

mus dorsi muscles), and female patients with developed breast tissue may also require customized bracing. With a custom PC orthosis, it's possible to finely contour the aluminum bars around the chest anatomy, thereby providing the appropriate clearance for a female's breasts or an athletic male's chest.

While the prefabricated design has a very intimate body fit, it does not provide the appropriate clearance for developed breasts or significant thoracic musculature. The prefabricated design is indicated for patients with a mild, moderate, or severe PC deformity, normal muscle build, and a prominence that allows a reasonably broad contact area with the anterior pad. Overall, the prefabricated version is slightly less bulky than the custom version and, in turn, is usually perceived more favorably by the patient.



Figure 5: Hanger's custom PC orthosis. Anterior (A), lateral (B), and posterior (C) views.

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Undergarment

An interface garment should be worn under the orthosis to provide maximum patient comfort. We use a Knit-Rite Protective Orthotic Body Sock as part of our PC orthosis protocol. The sock is made from Lycra®, COOLMAX®, and X-Static® fibers, which help reduce body odor, transfer heat and moisture away from the skin, and inhibit bacteria growth. The undergarment is seamless, anti-static, wrinkle free, and stretches in all directions, providing a tight fit that helps suspend the orthosis and minimize excess movement or shifting. Because of the continuous contact and pressure that the orthosis applies to the prominence, pressure marks can appear on the skin under the anterior and/or posterior panels. The soft interface of the body sock reduces common skin issues caused from heat, pressure, and hygiene during orthotic treatment.

Clinical Evaluation

PC can appear at any time during adolescence and cannot be predicted with 100 percent certainty or prevented. Once the prominence shows signs of progression and has been evaluated by a physician, orthotic treatment can be initiated. During the clinical evaluation, a detailed medical history is obtained and a physical examination is performed. Personal background information includes (1) *demographics*: gender, age, and date of birth; (2) physical characteristics: height, weight, extremity flexibility tests, sternal flexibility, and PC type; and (3) *medical history*: associated symptoms, heart murmurs, prior surgeries, family history of pectus deformities, Marfan's syndrome, unexpected early deaths, age the defect was first noted, signs of progression, and secondary medical conditions.

The physical examination includes a manual compression test, described and validated by Haje and J. Richard Bowen, MD, in 1992, to determine the level of residual flexibility in the chest wall. With one hand firmly on the prominence and the other hand supporting the thoracic spine, gentle manual compression is induced to verify the degree of flexibility. Haje stated that if partial or complete reduction is observed, the deformity is considered *flexible*; if not, the protrusion is *rigid*. Determining the flexibility of the chest wall prior to treatment is helpful in predicting clinical outcomes.

Clinical photographs and anthropometric measurements should be taken at each appointment and placed in the patient's file to track physical changes and create a chronological, visual,

and quantitative record of the patient's progress for objective comparison. Anterior, posterior, lateral, anterolateral, and supine views should be recorded.

Anthropometric measurements should be taken by a skilled, certified orthotist using a sliding mediolateral (M/L) gauge and a flexible tape measure. The measurements, which include circumference, M/L diameter, and an A/P diameter at the apex of the prominence, are taken against the skin with the patient's shirt removed for increased accuracy. Measurements should be taken at consistent intervals throughout the course of treatment to quantify correction and clarify the relationship between growth parameters and the response to the orthosis. We use a tracking form to follow progress during the treatment process (Table 1).

Fit and Follow-Up

Once the PC orthosis is fitted, the patient should be educated on adequate tightening of the ratchets to systematically increase pressure throughout treatment. A break-in schedule is recommended so that the patient can gradually adapt to the pressures of the orthosis. A typical break-in schedule is as follows:

- **Day 1:** (One hour): Wear for 30 minutes, then another 30 minutes later in the day.
- Day 2: (Two hours): Wear for one hour, then another hour later in the day.
- Day 3: (Four hours): Wear for two hours, then another two hours later in the day.
- Day 4: (12 hours): Wear for four hours during the day, and then to bed (eight hours).
- **Day 5:** (14 hours): Wear for six hours during the day, and then to bed (eight hours).
- **Day 6:** (16 hours+): Wear for eight or more hours during the day, and then to bed.

A full-time wear schedule ranges from 16 to 20 hours per day, with nighttime hours satisfying part of the required time. The orthosis should not be worn during any strenuous physical activities or taken into the shower or bath. Typically, the orthosis is worn full-time for the first three to 12 months or until significant correction has occurred. Some of our patients who choose to wear the orthosis for 18 hours or more per day had a quicker response to treatment, with significant correction typically occurring in the first three to six months.

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Table 1: Pe	Fable 1: Pectus Carinatum Tracking Form														
Patient Name:				DOB:				Physician:							
Date	Reason for Visit	Age	Height	Weight	Family Hx	Date 1 st Noted	Туре	Flexibility	Symptoms	Hours/ Day	Circum. @Apex	A/P @ Apex	M/L @ Apex	Comments	

Once full correction has been achieved, wear time can be reduced to 12–14 hours per day until the correction has been maintained for three months. After three months, wear time can be decreased to nighttime only (eight hours per day) until the end of treatment; this is the maintenance period. The patient must be watchful, as recurrence may occur when wearing the orthosis for fewer than 14 hours per day.

The patient should schedule regular follow-up appointments with his or her orthotist during the first couple months of treatment so that the rapid changes and improvement that commonly occur within the first three months of compliant treatment can be closely monitored and tracked.^{4,7} Follow-up occurs with the orthotist four weeks post-fit, eight to ten weeks post-fit, and then every three months to ensure proper orthosis fit, address any problems or concerns with protocol, monitor compliance, and track physical changes. The patient should also schedule regular follow-up appointments with the referring physician. Commonly, these appointments are scheduled for two weeks post-fit, eight weeks post-fit, and then every six months. On average, the duration of orthotic treatment is 24 months or until linear growth ceases.^{7,17}

Conclusion

Utilizing an orthosis to treat PC has gained gradual recognition over the last ten years. Physicians are increasingly considering this as a first-line treatment.¹² PC orthoses have proven to be a safe and effective way to provide favorable outcomes. The success of the orthosis increases for patients with CG PC and a flexible rib cage, and if intervention begins early. However, patient compliance is the single most important factor in achieving optimal results with an orthosis. If adequate, full-time hours are not applied during treatment, the deformity has the opportunity to progress, and orthotic treatment becomes ineffective. Therefore, it is crucial for patients and their families to understand the importance of compliance for a successful outcome. Our patients

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