The Dynamic Compression Brace for Pectus Carinatum: Intermediate Results in 286 Patients

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Background. Dynamic brace compression is a novel treatment for patients with pectus carinatum. The dynamic compression system contains a device to measure the flexibility of the thoracic wall and regulate the pressure of the brace.

Methods. Patients referred to our pediatric surgical center were screened for treatment with the dynamic compression brace. Patients with a pressure of initial correction (PIC) of 10.0 pounds per square inch or less were offered treatment with the brace. Patients with a PIC above 10.0 pounds per square inch were offered surgical correction. Between March 2013 and April 2016, 286 patients were treated with the brace; 260 were male (91%) and 26 were female (9%). Their mean age was 14 years (range, 4 to 21 years).

Results. Seventy-eight patients completed brace treatment; the mean treatment time was 14 months. Twenty-seven patients abandoned treatment because of lack of motivation, loss to follow-up, persistent protrusion of the sternal bone or flaring that required surgical correction, failure of treatment because of a bifid rib, fear of locking the brace, and delayed correction. One hundred eighty-one patients are still wearing the brace, either in the active or in the retainer phase. Patients with a high PIC also showed improvement when they were compliant. Adverse events were minor and included skin lesions (n = 4, 1%) and vasovagal reactions at the start of therapy (n = 3, 1%).

Conclusions. These data show that brace therapy can be considered a valuable treatment option to correct pectus carinatum in patients with a flexible thorax.


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Pectus carinatum (pigeon chest) is a thorax deformity with a prevalence of 0.3% to 0.7% [1–3]. Its cause involves the overgrowth of costal cartilage [4], which results in its typical form. In contrast to pectus excavatum (funnel chest), pectus carinatum is not concealed by clothing. Patients with pectus carinatum mainly have from cosmetic issues, resulting in a reduced self-image and a lower quality of life compared with control patients without this deformity [5].

Until recently, the mainstay of treatment for pectus carinatum has been surgical. The most well-known and widely used technique is the Ravitch procedure and its modifications, consisting of subperichondreal resection of cartilage and reconstruction of the sternum [6]. Nowadays this technique is also performed thoracoscopically [7]. A more recent surgical technique for the correction of pectus carinatum is the Abramson procedure (or reversed Nuss procedure), in which a steel bar is placed subcutaneously over the sternum and fixed to the ribs bilaterally, restoring normal thoracic shape [8].

Since the 1970s, pectus carinatum patients have been treated with braces that restore normal thoracic shape by applying external pressure on the thoracic wall, with predominantly favorable results [9–22]. However, patient dropout rates have been high, especially resulting from noncompliance, reaching 40% in some studies [15, 18, 21]. This is mainly caused by the discomfort of these types of braces, including shame, sweating, rash, and skin ulceration caused by high pressure. Many of these patients have remained untreated or have chosen surgical treatment. The disadvantages of surgical correction are hospitalization, scars, and high treatment costs with the risk of associated adverse events such as pneumothorax, wound infection, recurrence, and skin necrosis [23].

In 2008, Martinez-Ferro and colleagues [24] introduced the dynamic compression system (DCS). This custom-fitted brace measures and adjusts the pressure on the thoracic wall and enables lateral expansion of the thorax. It has been claimed that this brace leads to fewer difficulties in use and thus to better compliance [24–27]. The success rates seem higher than with the classic braces, with a significantly lower patient dropout rate.

In March 2013, the Pediatric Surgical Center of Amsterdam introduced the DCS for the treatment of patients with pectus carinatum [28]. The results were prospectively registered.
Patients and Methods

Materials
The DCS is a custom-fitted aluminum brace that can be adapted to the severity of sternal protrusion [24]. It contains a docking station for a pressure measuring device, which permits the clinician to measure and regulate treatment pressure. The pressure required to redress the chest into its normal position is called the pressure for initial correction (PIC) and is measured in pounds per square inch (psi). This pressure is measured at the first consultation by applying manual pressure on the thorax of a patient standing with the back against a wall. Martinez-Ferro and colleagues [24] used a PIC of 7.5 psi as a cutoff point for a thorax suitable for the DCS. Patients with a PIC above 7.5 psi have a more rigid thorax and would probably not benefit from brace treatment. Martinez-Ferro and colleagues [24] suggested a pressure of treatment (POT) with a maximum of 2.5 psi to avoid discomfort and skin lesions and hence increase patient compliance (Figs 1, 2).

Patients
Between March 2013 and April 2016, 370 patients were referred to our center for treatment of pectus carinatum. As the only center applying the DCS in the Netherlands we treated 286 pectus carinatum patients with the DCS. Patients were selected for brace treatment if the initial PIC measurement was 10 psi or below. For every patient the mean pressure of initial correction was measured from three subsequent measurements and by two pediatric surgeons for all patients. No standard diagnostic imaging was done, and computed tomographic Haller indices were not used. Our diagnostic flowchart is described in Figure 3. Approval for this study from the medical ethical committee was not required.

The 84 patients with pectus carinatum who did not receive brace treatment either had a PIC above 10 psi (n = 32), rejected brace therapy (n = 24), or were treated conservatively because of minimal findings or very young age (n = 28). In the first group, a high PIC was caused by high rigidity and low flexibility of the chest resulting from matured rib cartilage or osseous malformations (ossification/bifid ribs). In the second group, the patients rejected brace treatment mostly because of lack of motivation, feelings of embarrassment among peers, or both. Brace patients were advised to wear the brace as often as possible during day and night except during showering, bathing, or sports. Patients were followed up at our outpatient clinic initially every 4 to 6 weeks for checkup and adjustment of the POT to a pressure of around 2.5 psi.

Depending on the wearing time and decrease in POT, the follow-up period was sometimes reduced to once every 8 to 12 weeks. After total correction of the pectus carinatum, the wearing time of the brace was gradually decreased (retainer mode). During this retainer mode we subsequently decreased the wearing time to only at night (8 hours), once every 2 nights, 2 nights a week, and 1 night a week, and eventually we advised our patients to wear the brace only during the night if protrusion of the chest wall occurred. This retainer period lasted 2 to 23 months. If there was no improvement or insufficient improvement of the thoracic shape after 6 to 12 months of treatment, patients were offered operative correction.

Study endpoints
Success of the brace treatment was defined by total correction of the pectus carinatum (start of retainer mode) and the time of stopping the brace treatment. These moments were assessed by the patient and doctor together. Other endpoints were additional surgery and stopping brace treatment because of other reasons.

Results
During this study period 370 patients were referred to our center for pectus carinatum treatment, primarily to...
Fig 3. Diagnostic and therapeutic flowchart. (CT = computed tomography; MRI = magnetic resonance imaging; PIC = pressure of initial correction; psi = pounds per square inch.)
receive a brace. A total of 286 patients were included for brace treatment. Of the remaining 84 patients, 56 underwent surgical correction (54 Ravitch procedures, 2 Abramson procedures), and 28 patients were treated conservatively because of minimal findings or very young age.

The brace treatment group included 260 male (91%) and 26 female (9%) patients with a median age of 15 years (range, 4 to 21 years). One hundred eighty-four patients (64%) had a symmetric pectus carinatum. In 102 patients (36%) it was asymmetric. One hundred eight patients (38%) reported having family members with pectus carinatum, pectus excavatum, or scoliosis. Table 1 shows details of the patient characteristics.

The majority of patients experienced a variety of psychosocial issues because of their thoracic deformity. However, there were also several physical issues (Table 1). Most patients were referred to us by their general practitioner (104 patients, 36%), and 77 patients (27%) found our clinic by our website on the internet or our newspaper articles. Figure 4 shows the complete origins of referrals.

Currently, 128 patients (44.8%) are in the active phase of treatment, waiting for full correction of their thoracic deformities. Fifty-three patients (18.5%) are in the retainer mode, the phase in which wearing time is decreased after full correction has been achieved. The brace serves to stabilize the thoracic cage into its new shape. Seventy-eight patients (27.3%) have completed treatment after a mean treatment time of 14 months (range, 5 to 28 months). No recurrences were seen in this group 1 to 29 months after treatment. Table 2 shows the correlation between their PIC, age, and duration of treatment. The discontinuation (completion of therapy) of the braces over time is seen in Figure 5. Figure 6 shows a patient with a chondrogladiolar pectus carinatum before and after treatment. Younger patients completed therapy more often than did older patients.

Twenty-seven (9.4%) patients abandoned treatment, of whom 6 patients underwent an additional Ravitch procedure for correction of their chest deformity. The reasons for abandoning treatment were lack of motivation (11 patients), loss to follow-up (8 patients), persistent caudal protrusion of the sternal bone or flaring of the lower costal cartilage for which operative correction was desirable (3 patients), failure because of a bifid rib (2 patients), fear of locking the brace (1 patient with attention deficit disorder), and delayed correction (2 patients). The last 2 patients stopped treatment without achieving full correction because they were satisfied with the results.

Of the 6 patients who underwent a Ravitch procedure, 5 patients stopped brace treatment after gaining good results. The reason for an additional operation was mainly persistent flaring of the lower costal arches or persistent protrusion of cartilage at the lower costosternal joints. Only 1 patient underwent an additional Ravitch procedure after stopping brace treatment because of low compliance.

So far, we have included 10 patients with a PIC above 10.0 psi. Three patients in this group (PIC 10.2, 10.2, and 12.5) have completed their treatment with excellent results. Their total treatment time was 23 to 24 months, and they had fairly good compliance (Fig 7). Four patients are still in the active treatment phase and show progression under treatment. They have PICs of 10.2, 10.1, 13.3, and 11.0 psi, respectively. Even the patient with a PIC of 13.3 is making progress, however slowly. He is thinking about getting surgical correction. Treatment has been unsuccessful in 3 patients because of low compliance. They had PICs of 10.2, 10.2, and 11.4 psi, respectively.

Adverse events resulting from wearing the brace were seen in 7 patients: 4 patients (1%) experienced skin lesions caused by the pressure of the brace on the skin. This was handled by discontinuing the wearing of the brace until the skin lesions had healed and subsequently restarting with a lower POT. Three patients (1%) had a short vasovagal reaction at the start of brace treatment,
probably because of the sudden correction of the thorax. In these patients we started with a lower POT and let the patients get used to the brace at home.

Several patients experienced mechanical or material problems from the brace: 15 patients (5%) reported damaged T-shirts or bed linen, 9 patients (3%) reported broken hinges, and 8 patients (3%) reported clip breakage.

**Comment**

The results of our study are consistent with the results of previous smaller studies of the DCS [24–27]. Patients who in the past were unsuccessfully treated with the classic brace had to choose between either an operative correction, with all of its disadvantages, or remaining untreated. In our study, treatment with the DCS appears to be effective and safe for patients with pectus carinatum. It has a lower rate of adverse events than the classic brace because of the advantage of pressure regulation. Patients who cannot be treated with the DCS, either because of an initial inflexible thorax with a high PIC or because of lack of compliance, can be treated with operative correction. Although no recurrences were seen 1 to 29 months after the treatment had stopped, it remains unknown whether protrusion of the chest may recur in the long run.

In line of expectation, our study shows the degree of psychosocial impact of pectus carinatum on our patients, but remarkable is the amount of reported physical symptoms. At least 8% to 18% of our patients describe having thoracic pain and shortness of breath at rest or during exercise.

Martinez-Ferro and colleagues [24] suggested using the DCS for patients with a relatively flexible thorax, ie, with a PIC of 7.5 psi or below. Cohee and colleagues [25] reported 1 patient with a PIC above 9.0 psi who had an excellent result after a total treatment time of 16 months. Lopez and colleagues [26] extended their maximum PIC to 9.0 psi and even included 2 patients with a PIC of 14.0 psi who were improving under treatment. They called for further research with patients in this range of PIC. In our study, we included 10 patients with a PIC above 10.0 psi. Three of those patients were compliant throughout their treatment and reported excellent results at the end of brace therapy at 24 months. Three patients were not compliant, and treatment was unsuccessful. Four patients are currently in the active phase of treatment and are making progress. Our data add evidence that patients with a high PIC can be successfully treated with the DCS if they are well motivated; ie, if they are willing to wear

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<th>Table 2. Correlation Between PIC and Duration of Treatment</th>
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<tr>
<td>Treatment Completed (total: 78 patients)</td>
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<tr>
<td>Group 1: PIC &lt; 5.0 psi</td>
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<td>Group 2: PIC 5.0–7.5 psi</td>
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<td>Group 3: PIC &gt; 7.5 psi</td>
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<td>Mean age (years)</td>
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PIC = pressure of initial correction; psi = pounds per square inch.
Fig 6. (Left) before and (right) after views of a 14-year-old patient with symmetric chondroplastic pectus carinatum and a pressure of initial correction of 5.0 psi, who finished treatment after 15 months.

Fig 7. Patient with an initially high pressure of initial correction (12.5 psi) (a, b) before treatment who showed satisfactory results (c, d) after treatment for a total of 23 months.
the brace as much as possible during the day for a long time. If the deformity cannot be corrected, surgical correction can always be offered.

In our study population 45.8% of patients either finished brace treatment or reached the retainer mode. With 14 months, our mean treatment time was longer than that previously reported by others who studied the DCS (7 to 10 months) [24–27]. One explanation is that we included patients with a higher PIC. However, the mean treatment time in our patients with low PIC and moderate PIC was 12 and 14 months, respectively (Table 2), which was also longer than previously reported. This was mainly due to longer retainer mode. Many patients were reluctant to decrease their wearing time because they feared recurrence of the deformity, and many of them chose to wear the brace at night as a part of their routine. The brace was generally not experienced as a burden.

Five of our patients who underwent a Ravitch procedure were initially satisfied, had positive results, and even reached the retainer mode but had persistent cartilage protrusion on the lower part of the sternum or persistent flaring of the lower costal arches. In cases of pectus carinatum with severe costal flaring (which will not be corrected by the DCS), we suggest primary surgical correction by a Ravitch operation, in which the costal arches can also be corrected. The patient should be consulted whether the costal flaring or the sternal protrusion is experienced as the most bothersome feature of their physique.

This study has its limitations. Although the outcome of brace treatment of pectus carinatum was excellent, it has to be noted that the outcome was estimated by the surgeon and patient mutually and that no hard outcome determinations could be used. Furthermore, we have to await the long-term results to assess whether protrusion of the chest will recur after brace treatment is discontinued. This will be an important factor before we can definitely recommend brace therapy as the treatment of choice in patients with pectus carinatum and a flexible chest.

References