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Advancing pectus deformity care: evaluation of current treatments, complications and future innovations

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Part II

Pectus excavatum

Chapter 6

15 years of vacuum bell therapy for pectus excavatum: long-term outcomes and influencing factors

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ABSTRACT

Background

Long-term results and factors affecting outcomes of vacuum bell therapy for pectus excavatum are relatively unknown.

Methods

We conducted a retrospective study on patients (<18y) treated with vacuum bell therapy between May 2008 and October 2021. Primary outcome was treatment success; secondary outcomes were analysis of daily time spent on treatment, treatment duration, complications, long-term follow-up, treatment for patients awaiting a Nuss procedure, treatment for female patients, and factors affecting outcomes.

Results

Of 259 patients treated with vacuum bell therapy, 18.9% (49/259) were still being treated, 17.4% (45/259) were lost to follow-up and 63.7% (165/259) completed treatment, with a 52.1% (86/165) success rate. Median follow-up was 64.0 months (interquartile range 48.0-87.0). More time spent daily on vacuum bell therapy, total treatment duration, and overnight use led to a higher success rate (P=.002, P<.001, P<.001 resp.). Complications (22.8%, 59/259) were minor, recurrence occurred in 2.3% (2/86) of patients. Of the patients treated while awaiting a Nuss procedure, 26.7% (4/15) no longer required the Nuss procedure. Breast growth made 39.3% (11/28) of female patients quit treatment. Deeper deformities (P=.02, P=.009), flexible chest wall (P=.007) and symptomatic pectus excavatum (P=.02) resulted in lower success rates.

Conclusions

Vacuum bell therapy is successful in up to 52.1% of patients. Overnight vacuum bell use and treatment while awaiting a Nuss procedure should be encouraged. Older patients with a stiff chest wall can be successfully treated with prolonged treatment. For female patients watchful waiting or early treatment, to prevent challenges during breast growth, is preferred.

INTRODUCTION

Pectus excavatum (PE) is a chest wall anomaly with an incidence of 0.1-0.8%, predominantly affecting males (2:1 to 9:1 ratio). PE is usually discovered during or at the start of puberty.[1] Patients may suffer from physical complaints, but also experience psychological distress due to a disturbed body image.[2, 3]

Minimally invasive repair of PE is currently the most common treatment.[4] The results are usually excellent, however sometimes serious complications occur.[5, 6] An alternative non-surgical treatment option is vacuum bell (VB) therapy, which is usually used in patients with relatively mild deformities.[7] VB therapy is effective for treating PE; however, the treatment period is long, and a relatively large number of patients continue active treatment thereafter.[8] Additionally, in recent literature percentages of success vary, and high percentages of non-compliance (9.7%-36.1%) are reported.[9-12] Furthermore, most studies comprise small numbers of patients and lack long-term follow-up, which is needed to evaluate the long-term results and the risk of recurrence. Numerous studies have tried to identify factors that may contribute to success or compliance, but the outcomes vary.[11, 13-16]

We share our 15 years' experience with VB therapy in the Amsterdam Pectus Center, focusing on long-term outcomes and factors influencing the treatment outcomes.

PATIENTS AND METHODS

Study population and design

We performed a retrospective cohort study of patients (<18 years) undergoing VB (Eckart Klobe Vacuum Bell) therapy in the Amsterdam Pectus Center between May 2008 and October 2021. A Medical Ethics Review Committee (METC) official waiver of ethical approval was granted by the METC of the Amsterdam Medical Center. Informed consent was obtained from all patients (or their parents).

Data extraction

Data were retrospectively obtained from patient records. Patients who had not visited or contacted the outpatient clinic for over twelve months, without completing their treatment, were contacted by phone; those unreachable were considered lost to follow-up.

Overnight hours were excluded from the calculation of daily time spend on VB therapy, because some patients mention that the VB detaches during the night while they are asleep, and it is unclear at which time point this occurs, making it impossible to count these hours. Therefore nightly use was included as a separate, nominal variable. Chest wall flexibility was assessed by attaching the VB to the patient's chest, applying suction, and subsequently assessing sternal elevation. Flexibility was deemed present when sternal elevation occurred effectively within minutes. Sternal depression was measured using the method described by Obermeyer et al.[10]

Treatment protocol

After anamnesis and physical examination, patients are offered the choice between the Nuss procedure and VB therapy. The Nuss procedure is typically recommended, and we explain that VB therapy is most effective in cases of mild to moderate PE, as assessed by the physician based on sternal depression and visual evaluation. If the patient or their parents prefer to avoid surgery, or if the patient is not eligible for the Nuss procedure due to very mild PE, VB therapy is advised. Before starting VB therapy, patients undergo a trial fitting of the VB to evaluate their suitability for treatment.

X-rays or CT scans are not routinely performed unless pectus arcuatum is suspected by the clinician. Initially, our protocol included conducting electrocardiograms and echocardiograms to assess for cardiac abnormalities before starting VB therapy. However, after determining that cardiac abnormalities did not impact the effectiveness of VB therapy, we removed these tests from the standard procedure, except in severe symptomatic cases where patients are referred for cardiac and pulmonary evaluations.

Patients are instructed to begin using the VB two to three times per day for 30 to 60 minutes, gradually increasing the duration and the applied suction as tolerated. We recommend wearing the VB overnight and during routine activities such as eating, homework, or gaming, to help accumulate the necessary wearing hours. However, it is important to note that overnight use should not begin in the first two to three months, since the skin has to adapt in order to endure the prolonged suction applied overnight. There is no standard treatment duration; if there is still progression and the patient remains motivated, we advise them to continue using the VB. After the chest wall is fully corrected, patients enter the retainer phase, i.e., the treatment phase in which wearing time is gradually reduced to maintain chest wall correction. Treatment is considered successful if patients, parents and surgeon regard the result as aesthetically pleasing and VB therapy is stopped.

While we aim to offer VB therapy to all patients on the waiting list for the Nuss procedure, financial constraints prevent us from doing so.

Outcomes

The primary outcome of the study was percentage of patients which were successfully treated; secondary outcomes consisted of analysis of daily time spent on VB therapy, treatment duration, complications, long-term follow-up, VB therapy for patients awaiting the Nuss procedure, VB therapy for female patients, and prognostic factors influencing the treatment (familiar predisposition, sex, age, length, weight, Body Mass Index (BMI), comorbidities, flexibility chest, symmetry, flaring, scoliosis, symptomatic PE, increase during puberty, use of VB after treatment for pectus carinatum (PC), sternal depression, type of VB, frequency of wearing, wearing at night, complications).

Statistical analysis

Descriptive measurements were utilized to characterize the study population. Statistical significance was set at $P<0.05$. Data were analyzed using IBM SPSS Statistics 28.0.

RESULTS

All (N=259) patients who started VB therapy in the study period were included in the analysis. Median age was fifteen (13.0-16.0) years and 89.2% of patients were male (231/259). Median follow-up was 64.0 (interquartile range (IQR) 48.0-87.0) months. Baseline characteristics are described in Table 1. Eight patients suffered from cardiovascular comorbidities (supraventricular tachycardia (n=2), atrial septal defect (n=1), ventricular septal defect (n=1), cardiac souffle (n=2) and bradycardia (n=2)). Twenty-seven patients suffered from respiratory comorbidities (asthma (n=12), allergic rhinitis (n=8), hyperreactive airway disease (n=5), history of bilateral pneumothorax (n=1) or bronchiolitis (n=1)). Twelve patients were treated for chest wall deformities in the past (PC treated with Ravitch (n=5) or the Dynamic Compression System (DCS) (n=2), PE treated with the Nuss procedure (n=3)), or had chest wall deformities (Poland syndrome (n=1) and costal flaring (n=1)). Characteristics of PE deformities and symptoms are described in Table 2. Treatment characteristics and outcomes are described in Table 3 and Table 4.

Success of treatment and loss to follow-up

At the time of analysis, 18.9% (49/259) of patients were actively treated, 17.4% (45/259) were lost to follow-up and 63.7% (165/259) had finished treatment. Of the latter group, 52.1% (86/165) had finished treatment successfully (Figure 1).

Of the patients lost to follow-up, 35.6% (16/45) were lost before their six-month check-up and 68.9% (31/45) before their eighteen-month check-up. The median treatment duration until the final check-up was ten months (IQR 2.0-18.0).

Daily time spent on VB therapy, treatment duration

The average, minimum and maximum daily time of wearing the VB was higher in the successfully treated group (3.0 (IQR 2.0-4.3) versus 2.0 (IQR 1.3-3.0), 2.0 (IQR 1.0-3.0) versus 1.5 (IQR 1.0-2.0) and 3.5 (IQR 2.5-6.0) versus 3.0 (IQR 2.0-5.0), respectively). All were related to a higher success rate (P=.002, P=.004, P=.01, respectively). Total treatment duration was longer in successfully treated patients (24.0 (IQR 20.0-38.0) compared to 13.5 (IQR 8.0-26.0), P<.001)) in unsuccessfully treated patients.

Complications and long-term follow-up

Of all patients 22.8% had one or more complications (Table 3). All complications were minor, mainly skin-related and did not affect treatment success (P=.17). Pain (P=.03) and other complications (motivation problems (n=5), acne (n=2), thickened glandular disk (n=3) and shortness of breath (n=2)) (P=.04) were more prevalent in the unsuccessfully treated group. There were no significant long-term complications. Of all patients who were treated unsuccessfully, 45.6% (n=36/79) underwent a Nuss procedure.

In 2.3% (2/86) of patients who were initially treated successfully, PE recurred. One of them was treated at a young age (11y) and experienced recurrence when his growth spurt began.

VB therapy for patients awaiting the Nuss procedure

Not every patient awaiting the Nuss procedure received VB therapy due to financial constraints. Of the patients that did start with VB therapy, 53.3% (8/15) did not undergo a Nuss procedure yet. Two of them were lost to follow-up, two were unsuccessfully treated with VB therapy and refrained from a Nuss procedure, two patients finished treatment successfully and two patients are still being treated with VB therapy.

Table 1. Patient characteristics

	All patients *(N=259)*	**Patients who finished treatment** *(n=165)*		**P-value**
		Successful (n=86)	*Unsuccessful (n=79)*	
Sex [b]				.78
Male	231 (89.2)	75 (87.2)	70 (88.6)	
Female	28 (10.8)	11 (12.8)	9 (11.4)	
Age [a]	15.0 (13.0-16.0)	15.0 (14.0-16.0)	14.0 (13.0-16.0)	.22
Length (cm) (n=140) [a]	175.0 (167.0-182.8)	175.0 (167.5-182.5)	174.5 (165.8-180.0)	.33
Weight (kg) (n=136) [a]	57.0 (47.3-65.0)	58.0 (49.3-65.0)	53.8 (45.8-62.3)	.22
BMI (n=131) [a]	17.7 (16.1-19.3)	17.8 (15.7-19.7)	17.7 (15.9-18.7)	.51
Follow-up (months) [a]	64.0 (48.0-87.0)	74.0 (54.8-90.3)	64.0 (50.0-84.0)	.10
Family history PE/PC [b]	95 (36.7)	37 (43.0)	29 (36.7)	.48
Comorbidities [b]	110 (42.5)	39 (45.3)	35 (44.3)	.89
Type of comorbidities [b]				
Cardiovascular	8 (3.1)	4 (4.7)	1 (1.3)	.21
Respiratory	27 (10.4)	10 (11.6)	11 (13.9)	.66
Gastrointestinal	9 (3.5)	3 (3.5)	2 (2.5)	.72
Chest wall deformities	12 (4.6)	3 (3.5)	5 (6.3)	.40
Other musculoskeletal	18 (6.9)	6 (7.0)	5 (6.3)	.87
Cutaneous	16 (6.2)	7 (8.1)	6 (7.6)	.90

Table 1. Patient characteristics *Continued.*

	All patients *(N=259)*	**Patients who finished treatment** *(n=165)*		**P-value**
		Successful (n=86)	*Unsuccessful (n=79)*	
Other	42 (16.2)	14 (16.3)	15 (19.0)	.65
Abnormalities electrocardiogram (n=81) [b]	17 (6.6)	9 (10.5)	5 (6.3)	.34
Abnormalities echocardiogram (n=83) [b]	9 (3.5)	4 (4.7)	3 (3.8)	.79

[a] Continuous variables expressed as median (IQR)
[b] Data displayed as n (%)
BMI = Body Mass Index, PC = Pectus Carinatum, PE = Pectus excavatum

Table 2. Pectus excavatum characteristics, symptoms

	All patients *(N=259)*	**Patients who finished treatment** *(n=165)*		**P-value**
		Successful (n=86)	*Unsuccessful (n=79)*	
After treatment for PC [b]	10 (3.9)	5 (5.8)	2 (2.5)	.30
Increase of PE during puberty [b]	140 (54.1)	46 (53.5)	43 (54.4)	.90
Flaring [b]	110 (42.5)	39 (45.3)	28 (35.4)	.20
Scoliosis [b]	32 (12.4)	11 (12.8)	9 (11.4)	.78
Symmetrical [b]	203 (78.4)	22 (25.6)	11 (13.9)	.06
Flexible [b]	132 (51.0)	33 (38.4)	47 (59.5)	.007
Sternal depression (cm) (n=67) [a]	2.0 (1.5-2.5)	1.8 (1.5-2.0)	2.1 (1.9-2.5)	.02
Sternal depression (narrative) [b]				.009
Mild/light	63 (24.3)	38 (44.2)	21 (26.6)	
Moderate	104 (40.2)	34 (39.5)	30 (38.0)	
Deep/severe	92 (35.5)	14 (16.3)	28 (35.4)	
Symptomatic [b]	120 (46.3)	34 (39.5)	46 (58.2)	.02
Pain/stabbing pain	65 (25.1)	18 (20.9)	21 (26.6)	.39
Pressure on chest	20 (7.7)	7 (8.1)	5 (6.3)	.66
Palpitations	12 (4.6)	3 (3.5)	5 (6.3)	.40
Endurance problems	69 (26.6)	16 (18.6)	29 (36.7)	.009
Appearance/shame [b]	135 (52.1)	38 (44.2)	44 (55.7)	.14

[a] Continuous variables expressed as median (IQR)
[b] Data displayed as n (%)
PC = Pectus Carinatum, PE = Pectus excavatum

Table 3. Treatment characteristics

	All patients *(N=259)*	**Patients who finished treatment** *(n=165)*		**P-value**
		Successful (n=86)	*Unsuccessful (n=79)*	
Type of VB [b]				.08
Mini	62 (23.9)	23 (26.7)	20 (25.3)	
Small	149 (57.5)	43 (50.0)	48 (60.8)	
Bodybuilder	26 (10.0)	13 (15.1)	5 (6.3)	
Woman	15 (5.8)	7 (8.1)	3 (3.8)	
Big	7 (2.7)	0 (.0)	3 (3.8)	
Average daily time of VB therapy (h) (n=225) [a]	2.5 (1.6-4.0)	3.0 (2.0-4.3)	2.0 (1.3-3.0)	.002
Minimum daily time (h) (n=228)	2.0 (1.0-2.5)	2.0 (1.0-3.0)	1.5 (1.0-2.0)	.004
Maximum daily time (h) (n=227)	3.0 (2.0-6.0)	3.5 (2.5-6.0)	3.0 (2.0-5.0)	.01
Frequency of wearing (daily) (n=233) [a]	1.0 (1.0-2.0)	2.0 (1.0-2.0)	1.0 (1.0-2.0)	.16
Minimal frequency (n=231)	1.0 (1.0-2.0)	1.0 (1.0-2.0)	1.0 (1.0-2.0)	.13
Maximal frequency (n=231)	2.0 (1.0-3.0)	2.0 (1.0-3.0)	2.0 (1.0-3.0)	.08
At night/during sleep [b]	119 (45.9)	50 (58.1)	24 (30.4)	<.001
Complications during treatment [b]	59 (22.8)	21 (24.4)	27 (34.2)	.17

Table 3. Treatment characteristics *Continued.*

	All patients *(N=259)*	**Patients who finished treatment** *(n=165)*		**P-value**
		Successful (n=86)	*Unsuccessful (n=79)*	
Type of complications [b]				
Skin discoloration	29 (11.2)	13 (15.1)	9 (11.4)	.48
Pain	16 (6.2)	3 (3.5)	10 (12.7)	.03
Ulcers/blisters	5 (1.9)	2 (2.3)	1 (1.3)	.61
Wounds	4 (1.5)	1 (1.2)	1 (1.3)	.95
Edema	5 (1.9)	1 (1.2)	2 (2.5)	.51
Other	12 (4.6)	2 (2.3)	8 (10.1)	.04

[a] Continues variables expressed as median (IQR)
[b] Data displayed as n (%)
VB = vacuum bell, h = hours

Table 4. Outcomes of patients who finished treatment

	All patients who finished treatment	**Successful**	**Unsuccessful**	**P-value**
	(n=165)	*(n=86)*	*(n=79)*	
Start retainer phase after (months) [a]	21.0 ± 10.1	21.8 ± 10.7	.	.
Average retainer phase duration (months)	10.0 (6.0-17.0)	10.0 (6.0-17.0)	.	.
Total wearing time (months)	23.0 (12.0-32.5)	24.0 (20.0-38.0)	13.5 (8.0-26.0)	<.001
Age at end of treatment	16.0 (15.0-18.0)	17.0 (16.0-18.0)	16.0 (14.0-17.0)	<.001
Nuss after VB [b]	36 (21.8)	0 (.0)	36 (45.6)	<.001
Retreatment with VB [b]	6 (3.6)	2 (2.3)	4 (5.1)	.35

[a] Continues variables expressed as mean ± standard deviation; all remaining continuous variables are expressed as median (IQR)
[b] Data displayed as n (%)
VB = vacuum bell

VB therapy for female patients

There was no difference in outcomes between female and male patients (P=.78). Female patients (n=28) started treatment at a younger age compared to male patients (11.5y (IQR 10.0-13.8) versus 15.0y (IQR 14.0-16.0), P<.001). The treatment duration (months) was equivalent to male patients (20.5 (IQR 13.0-43.5) versus 23.0 (IQR 12.0-32.0), P=.49), which resulted in a younger age for female patients at the end of treatment (13.0 (IQR 11.5-15.0) versus 17.0 (IQR 16.0-18.0), P<.001). Breast growth caused 39.3% (11/28) of female patients to quit treatment. Eight of them were treated unsuccessfully and three were lost to follow-up.

Similar to the overall patient group, there was no relationship between type of VB and treatment outcomes in female patients (P=.15). Only 9.1% (1/11) of female patients who stopped treatment because of breast growth was wearing a woman type VB.

Prognostic factors

Both objective and subjective deeper PE were associated with a lower rate of success (resp. P=.02, P=.009), with a median sternal depression of 1.8 (IQR 1.5-2.5) versus 2.1 (IQR 1.9-2.5) centimeters in the successfully versus unsuccessfully treated group. Sternal depression was evaluated as mild/light in 44.2% of all patients treated successfully,

compared to 26.6% in the unsuccessfully treated patients. Conversely, severe sternal depression was noted in only 16.3% of the successfully treated patients, compared to 35.4% in the unsuccessfully treated group.

Chest wall flexibility was related to age (P=.008), but not to treatment duration (P=.97). Fewer successfully treated patients had a flexible chest wall (38.4%) compared to unsuccessfully treated patients (59.5%) (P=.007). Patients with a symptomatic PE (P=.02), especially with endurance problems (P=.009), had a lower chance of success. Clinical outcomes did not vary in comparing patients under the age of ten (n=12), eleven (n=20), and twelve (n=31) to those over the ages of ten, eleven and twelve (P=.72, P=.65, P=.23, respectively).

Previous treatment for pectus deformities (Ravitch surgery (n=3), Nuss procedure (n=2) or DCS-bracing (n=2)) had no influence on treatment outcomes (P=.59).

A higher percentage of successfully treated patients wore the VB overnight compared to those unsuccessfully treated (58.1%, 50/87 versus 30.4%, 24/78, P<.001). Nighttime use correlated with longer treatment duration (26.0 (IQR 18.0-38.0) versus 20.0 (IQR 12.0-26.8) months, P=.004).

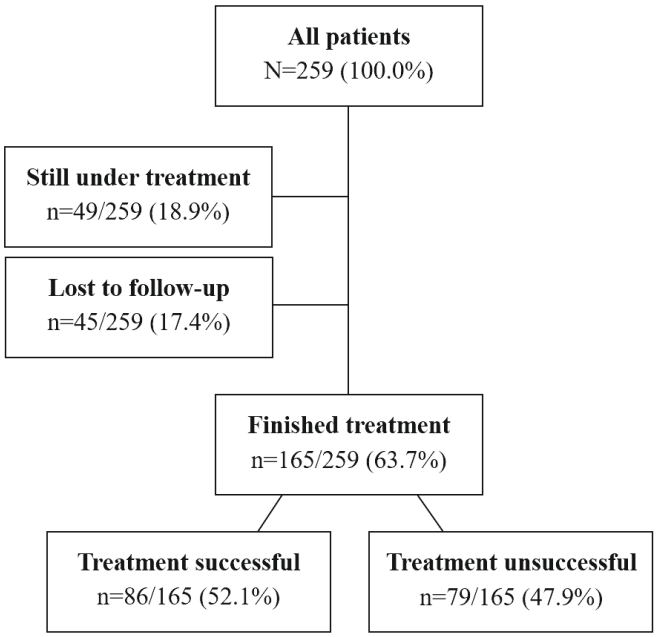

Figure 1 Flowchart showing treatment status and patient outcomes (n / N = number)

DISCUSSION

Of all patients finishing treatment, 52.1% finished treatment successfully. Factors contributing to a successful treatment were longer hours of daily VB use, overnight VB use and a prolonged treatment duration. A flexible thorax, deeper deformity and symptomatic PE were related to worse outcomes. Complications during treatment were minor and there were no long-term complications.

Success of VB treatment

Despite 52.1% of all patients finishing treatment achieving success, loss to follow-up was 17.4%. Median treatment time before being lost to follow-up was ten months (IQR 2.0-18.0), compared to 24.0 months (IQR 20.0-38.0) for successfully treated patients. This suggest those lost to follow-up may not have achieved favorable outcomes. If those patients are considered as treatment failures, the success rate would drop to 41.0% (86/210), which is comparable with the largest available study until now, which reported 43.6% (61/140).[7]

There is however, considerable variability in defining success among the literature. Some studies use a formula based on change in PE depth.[10, 11, 16] While useful for monitoring progress, this formula is based on a small reference group (n=30), and it does not capture the satisfaction and subjective assessment of the deformity by patients, parents and surgeons. Although objective measurement can guide treatment decisions, the final assessment of success should involve consultation with patients, parents and the surgeon, due to the significant subjective component of PE.

Lost to follow-up

Addressing the substantial percentage of patients lost to follow-up stands as the primary challenge in VB therapy. Our study had a loss to follow-up of 17.4%, comparable to other studies (3% to 36.1%).[7, 10, 11, 16-18]

Three important factors contribute to this. First, we lost contact with some patients nearing the end of treatment and switching to retainer mode, though they likely still use the VB for maintenance. Despite the positive impact of VB therapy, they are nevertheless categorized as lost to follow-up. Still, this group comprises only a small portion of drop-out, since most patient are lost to follow-up in an early stage. More importantly, the Amsterdam UMC covers PE treatment costs for patients under 18, which might reduce financial motivation and adherence to therapy. Additionally, once patients turn eighteen they must pay for the treatment themselves, which might also result in loss to follow-up.

A solution may be to call patients more often. Currently, patients are contacted by phone between the first and third month, and again at six months after initiating treatment. Their first physical check-up typically occurs after one year, although there is some variance between surgeons.

Daily time spend on VB therapy and treatment duration

Our results, which show that more daily hours of VB therapy lead to better results, are consistent with others, which showed better results with an average daily use of >6 hours,[16] >4 hours,[8] and >2 hours.[17] Additionally, two studies advocated wearing the VB >12 months.[10, 11]

In our opinion, based on these studies and our own results, more hours of daily wearing leads to better results, but we do not suggest a specific number of hours. The most effortless and comfortable way to add more hours is to wear the VB at night, despite described difficulties with VB dropping off or deflating. Although using the VB overnight was associated with better outcomes, treatment duration was a confounding factor since those also had longer treatment durations. Nonetheless, we strongly advise overnight use since it is the easiest way to add hours.

Long-term follow-up and complications

During our follow-up of more than four years recurrence occurred in 2.3% (2/86) of patients, which shows that results of VB therapy last. One of the patients with recurrence started VB therapy before the growth spurt. Similar to DCS-bracing, starting too early might cause recurrence during puberty.[19] The amount and type of complications were comparable to the literature.[14, 16] Pain, reported by 6.2% of patients, was associated with worse outcomes. We have not identified a cause of the pain.

VB therapy for patients awaiting the Nuss procedure

Some patients (15) opted for VB therapy while awaiting a Nuss procedure. This resulted in 26.7% (4/15) either finishing treatment successfully, or still being treated, without needing a subsequent Nuss procedure. Although this group is small, this suggests VB therapy during waiting periods may reduce the need for Nuss procedures.

Although there is a long waiting list at our Amsterdam Pectus Centre, other centers may not face this issue. In such cases, we recommend reserving VB therapy for patients with mild PE or those who strongly wish to avoid surgery.

VB therapy for female patients

The results of VB therapy in males and females are equivalent. Female patients start treatment earlier due to their earlier onset of puberty and focus on physical appearance. Breast development seems to be associated with early termination of treatment, causing 39.3% (11/28) of female patients to quit treatment, finishing treatment unsuccessfully or dropping out. This could also be a result of breast development which masks the PE, making further treatment unnecessary.

In all patient initially treated with a mini or small VB, clinical evaluation showed that the woman model VB did not fit either after the start of breast development. Currently there is no literature on the outcomes of the use of different models of VB in female patients. In our opinion, when breast development makes treatment of PE with a mini or small VB impossible, the woman model VB adds little to the treatment. Asymptomatic female patients often accept a moderate PE, since breasts masks the deformity.

Prognostic factors

Deeper sternal depth/depression and a flexible thorax correlated with worse outcomes. Age showed no outcome correlation, despite literature suggesting various upper age limits (twelve years,[13] eleven years[10, 18]). Interestingly, our study population was older (median age 15.0) compared to other studies (11.5-14.0).[8, 10, 16-18] Prada Arias et al. argued that young age leads to good results because of a flexible chest wall. In our study the relationship between a young age and a more flexible chest wall was confirmed.[16]

However, our finding that a flexible chest wall leads to worse outcomes contrasts with this and other studies, which often cite flexibility as a predictor of success.[10, 14] This discrepancy may be due to our subjective method for assessing thorax flexibility. Therefore we still believe that flexibility should be regarded as a positive prognostic factor, as supported by existing literature.

The prolonged treatment duration in our successfully treated patients (24.5 months, compared to 10.0-25.7 in the literature)[7, 8, 16] might be the key in explaining their good outcomes despite older age and a stiffer chest well, with the latter likely contributing to lasting results. Of note, not all studies mention exact treatment duration.[10] This heterogeneity makes comparison on treatment duration with other publications challenging.

Additionally, the follow-up periods in other studies are relatively short (average follow-up of 27.6, 12, 12, 18 and 40 months respectively,[7, 10, 13, 17, 18] or not mentioned[8]) compared to our median follow-up of 64.0 months. Shorter follow-up periods may miss

recurrences during or after the growth spurts in young patients, who were initially treated successfully in a short period of time due to their flexible chest wall.

Our results suggest that VB therapy can be successful and lasting in older patients with a stiff chest wall if treatment duration is long enough and patients remain motivated.

Two patients were treated with VB therapy after initial Nuss correction, but in both cases, treatment was unsuccessful. Despite only two cases, this suggests that further treatment after initial correction with a Nuss procedure should not be recommended.

Limitations

Some of the conclusions from our sub-analysis are based on results from a small number of patients. These conclusions need to be tested in larger populations to ensure they are reliable and generalizable.

Some variables had a high percentage of missing data, making multivariable logistic regression challenging. We recommend considering this approach for future studies.

Conclusions

VB therapy has a success rate of up to 52.1%, depending on how patients lost to follow-up are considered. Complications were minor. Prolonged treatment and overnight VB use to add extra treatment hours should be encouraged. Older patients with a stiff chest wall can be successfully treated with prolonged treatment. VB therapy is recommended while awaiting the Nuss procedure. Early treatment in female patients is preferred to avoid wearing the brace during breast growth.

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