Efficacy and haemodynamic effects of vacuum-assisted closure for post-sternotomy mediastinitis in children

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Abstract

OBJECTIVES: Post-sternotomy mediastinitis is a significant morbidity with controversial management. Vacuum-assisted closure (VAC) has been used to treat mediastinitis, with many reports documenting its efficiency and feasibility, particularly in adults. However, its use is not prevalent in the paediatric population because of concerns that it may deteriorate haemodynamics. This study aimed to evaluate outcomes and effects of VAC on the haemodynamics of paediatric patients with post-sternotomy mediastinitis.

METHODS: Six patients were treated with VAC between April 2005 and March 2013. We retrospectively investigated their profiles, clinical outcomes and haemodynamic changes, including mean blood pressure (MBP), mean heart rate (MHR), urinary output, amount of diuretics and vasoactive-inotropic score (VIS), before and after VAC initiation.

RESULTS: The median age and body weight of patients were 6.4 months and 4.5 kg, respectively. Three patients (50%) had single ventricular physiology. The median VAC duration was 12 days. One patient died of pulmonary venous obstruction after mediastinitis was cured. The average MBPs in every 8-h period were examined, and there were no significant changes (P = 0.773); the average MHRs were examined in the same manner and they decreased significantly after initiation of VAC (P = 0.032). Only 2 patients required vasoactive agents. The VIS did not change in 1 patient and decreased in the other. The mean amount of diuretics administered and urinary output per body weight did not change significantly (P = 0.395 and 0.273, respectively).

CONCLUSIONS: In conclusion, the haemodynamics of children were not significantly affected by the negative pressure of VAC, indicating that this therapy may be safe and effective for post-sternotomy mediastinitis, even in small children with complex cardiac anomalies.

Keywords: Mediastinal infection • Vacuum-assisted closure • Congenital heart disease • Paediatrics • Circulatory haemodynamics

INTRODUCTION

Recently, management strategies and surgical outcomes for congenital heart disease have dramatically improved. However, in the field of paediatric cardiac surgery, infection is still a major cause of morbidity and mortality. Although mediastinitis is relatively rare in the paediatric population, it is associated with high mortality; furthermore, its management remains controversial [1]. Since the introduction of the vacuum-assisted closure (VAC) experience by Argenta and Morykwas [2] in 1997, this therapy has been used to treat mediastinitis and has been reported to be an effective treatment, particularly in adults [3]. The concept of this modality is based on the uniform application of strong negative pressure to the wound, which results in arteriolar dilatation and subsequently promotes granulation tissue proliferation [4].

In paediatric cardiac surgery, VAC is not prevalent because there is an undispelled concern of the adverse effects of the strong negative pressure on the small hearts of children and peculiar circulation due to procedural diversity (e.g. aortopulmonary shunt, bidirectional Glenn shunt, Fontan circulation, Rastelli-type procedure, etc.) [4]. Therefore, we evaluated paediatric patients with post-sternotomy mediastinitis and congenital heart disease who were treated with VAC and assessed their outcomes and the haemodynamic effects of this treatment by measuring certain clinical indices.

MATERIALS AND METHODS

Patients and data collection

In total 6 patients treated with VAC for post-sternotomy mediastinitis at Miyagi Children’s Hospital between April 2005 and March 2013 were identified through our surgical database. We retrospectively investigated their profiles, clinical outcomes and haemodynamic changes before and after VAC initiation. The data associated with circulatory condition until 48 h after the initiation of VAC were collected from their medical records. These data included mean blood pressure (MBP), mean heart rate (MHR), urinary output per body weight and maximum vasoactive-inotropic scores (VISs) [5]. VISs were calculated using the following...
formula: \( \text{VIS} = \text{dopamine dose (μg/kg/min)} + \text{dobutamine dose (μg/kg/min)} + 100 \times \text{epinephrine dose (μg/kg/min)} + 10 \times \text{milrinone dose (μg/kg/min)} + 10,000 \times \text{vasopressin dose (U/kg/min)} + 100 \times \text{norepinephrine dose (μg/kg/min)}. \) The amount of diuretics (furosemide) administered was also evaluated.

Recorded MBPs and MHRs were obtained hourly from 8 h before to 48 h after VAC initiation. We compared the averages of them in every 8-h period. Urinary output was evaluated as the average over a 24-h period for 48 h after VAC initiation. Maximum VISs and the amount of diuretics (furosemide) administered per body weight were calculated every 24 h from 24 h before to 48 h after VAC initiation. We compared each index before and after VAC initiation.

**Treatment**

After confirming the diagnosis, an empirical antibiotic was intravenously administered in all patients. If necessary, we changed the antibiotic to a more optimal one after a pathogen was revealed.

Subsequently, the patients underwent surgery involving sternotomy and mediastinal irrigation under general anaesthesia in the theatre. Adequate debridement was also performed. VAC was maintained under sedation with dexmedetomidine hydrochloride and fentanyl using mechanical ventilation.

Our VAC system comprised polyurethane foam placed in the substernal space, a silicone drain placed between the foam, a gauze soaked with normal saline to maintain wound moisture and an iodine drape, which was applied over the entire wound to maintain wound moisture and an adequate pressure (−30 mmHg). After confirming that there were no adverse events, we gradually increased the negative pressure to −100 mmHg, which was the limit in our system.

The VAC dressing was changed every 24–48 h in the ICU, and a piece of used foam was submitted for bacterial culture. The wound was then irrigated with normal saline. If necessary, debridement of necrotic tissue was performed.

The criteria for VAC removal were as follows: three consecutive negative bacterial cultures, healthy granulation and the absence of fever.

**Statistical analysis**

Data are presented as means ± standard deviation or medians (ranges). Statistical analyses were performed using one-way repeated-measures analysis of variance. A P-value of <0.05 was considered statistically significant. If Mauchly’s test of sphericity indicated that the assumption of sphericity had been violated, a Greenhouse-Geisser correction was used. SPSS for Windows version 16.0 (SPS, Inc., Chicago, IL, USA) was used for all statistical analyses.

**RESULTS**

**Patient population and characteristics**

We had 644 surgeries with sternotomy during this period. Of these, 9 children (1.4%) diagnosed with and treated for mediastinitis were identified through our surgical database. We have been prescribing VAC for all mediastinitis patients since 2010 and, of these, 6 patients (5 males and 1 female) were included in our study.

The characteristics of our patients are summarized in Table 1. The median age and body weight were 6.4 (range, 2.9–35.6) months and 4.5 (range, 3.0–12.2) kg, respectively. Three patients (50%) exhibited biventricular physiology, whereas the remaining 3 patients exhibited single ventricular physiology. Furthermore, 3 patients (50%) had cyanotic lesions that remained after their last procedure. Artificial materials were used in 4 patients (67%). Two patients with hypoplastic left heart syndrome required delayed sternal closure during the prior procedures (modified Norwood surgery with a modified Blalock-Taussig shunt).

Patient 1 had multiple anomalies, including anorectal malformation; therefore, he received a transverse colostomy at the epigastric region. No other patient had extracardiac malformations.

**Pathogens of mediastinitis**

In 5 of the 6 patients, cultured pathogens were Gram-positive cocci resistant to beta-lactam antibiotics (Table 2). Gram-negative...
Clinical outcomes

All patients but one exhibited negative culture and underwent successful delayed closure of the sternum without any flaps. The median duration of VAC was 12 (range, 4–45) days. There were no adverse events, such as haemorrhage, arrhythmias or circulatory instability due to negative pressure that resulted in VAC discontinuation.

One patient died from recurrence of pulmonary venous obstruction 31 days after successful delayed closure. Other patients are all alive and the median follow-up duration was 2.0 (range, 1.2–3.4) years. Patient 3 successfully underwent the Fontan procedure, Patient 5 underwent definitive repair and Patient 6 received a bidirectional cavopulmonary anastomosis and is awaiting the Fontan procedure.

Although the bacterial culture for Patient 6 tested negative and his chest was closed at 45 days after VAC initiation, mediastinitis recurred 11 days after sternal closure. We decided to perform VAC again and use pyoktanin around the prosthetic graft for Gram-positive micrococci according to a previous report [6]; however, his graft eventually occluded, and then reoperation was required. Following replacement of his Blalock-Taussig shunt and subsequent VAC, his sternum was closed. The duration of VAC totalled 80 days for this patient.

Mean blood pressures and mean heart rates

The average MBPs in every 8-h period (before, 0–8, 9–16, 17–24, 25–32, 33–40 and 41–48 h) were 59 ± 12.1, 58.5 ± 7.5, 59.73 ± 7.3, 58.7 ± 8.2, 58.4 ± 7.5, 57.1 ± 7.0 and 57.0 ± 11.4, respectively (Fig. 1), indicating stable values with no significant differences before and after VAC initiation (P = 0.773). The average MHRs in every 8-h period were 123.9 ± 20.2, 104.1 ± 23.2, 114.5 ± 34.8, 96.9 ± 26.8, 103.7 ± 33.3, 94.9 ± 19.3 and 105.3 ± 24.3, respectively (Fig. 1), and decreased significantly (P = 0.032).

Urinary output and amount of diuretics

As an indicator of the circulatory state, urinary outputs were also compared. First, we compared the amount of furosemide administered per body weight before and after VAC initiation in every 24-h period. The mean amount of diuretics administered before and during 0–24 and 25–48 h after VAC initiation were 2.80 ± 1.03, 3.15 ± 0.99 and 2.74 ± 0.89 mg/kg, respectively, with no significant differences (P = 0.395). The urinary outputs per body weight before and during 0–24 and 25–48 h were 3.02 ± 1.04, 2.91 ± 1.49 and 3.80 ± 0.89 ml/kg/h, respectively, with no significant differences (P = 0.273).

Single ventricular physiology

Three patients with single ventricular physiology were included in this cohort. Although we could not conduct statistical analyses because of the small number of patients, we extracted and compared their data. The data for MBP and MHR (Fig. 2A and B), amount of diuretics administered and urinary output per body weight (Table 3) appeared similar before and after VAC initiation. Given that urinary output was maintained at >3 ml/kg/h, cardiac output was considered sufficiently maintained.

DISCUSSION

The incidence rate of mediastinitis has been reported to be 0.3–5% [7–10]. Mediastinitis after sternotomy is a severe complication, even in paediatric patients, and its treatment remains controversial.
patient, all detected pathogens were Gram-positive cocci resistant to beta-lactam antibiotics, a typical feature observed of late. Therefore, we often select vancomycin as an empirical antibiotic for this potentially lethal infection.

The following surgical treatments for mediastinitis have been reported: closed irrigation [11], muscle flaps [9], primary closure with drainage [12] and VAC [7, 13, 14].

Of late, there have been a few reports on the outcomes of primary closure with drainage and the outcomes are reportedly excellent [12, 15]. However, we were concerned that if debridement or drainage was not adequately performed, a causal organism could be cultured under the sternum and result in acute septic shock. In addition, we were concerned that primary closure may be less effective for prophylaxis of artificial material infection compared with VAC. Anslot et al. [15] stated that mediastinal fluid remains infected for a few days after surgery. Despite negative culture results and appropriate drain placement, the mediastinitis in Patient 6 recurred a few days after delayed sternal closure, indicating that the drainage did not have an enough ability to cure infected material. The patient required surgery to remove the infected graft, and his mediastinitis was eventually cured after prolonged VAC. This suggests that VAC might not heal infection of artificial material, although it could be effective against mediastinitis, even in the paediatric population. When artificial material is infected, we should consider removing it or, if definitive repair is complete, adding an omental or a pectoral muscle flap [6, 9].

Although VAC has been widely recognized as an effective treatment for mediastinitis, in the field of paediatric cardiovascular surgery, this treatment is not used much because there is an undispelled concern of adverse effects caused by the strong negative pressure on the small heart of children, specific circulation and anatomy, and the existence of anastomosis on the right ventricle, such as in cases of single ventricular physiology and Rastelli-type surgery [4]. Data on the effects of VAC on haemodynamics are conflicting. Sjögren et al. [16] demonstrated that VAC of −50 to −175 mmHg did not impair central haemodynamics in a porcine model. Steigelman et al. [17] reported that VAC without a protective barrier may cause reversible depression of cardiac function in swine, which could be resolved with the use of a barrier on the interface of the heart. Petzina et al. [18] showed that VAC caused an immediate decrease in cardiac output and stroke volume using magnetic resonance imaging in pigs. However, to the best of our knowledge, there are no clinical data on the impact of VAC on the paediatric circulation.

We investigated the effects of VAC on circulatory condition in this study. There were no significant differences and changes in MBPs, VISs, amount of diuretics administered and urinary output per body weight before and after VAC initiation at least until 48 h. Moreover, MHRs decreased significantly after the initiation of VAC, which may indicate that stroke volume had been maintained. Although statistical analyses could not be performed, it appeared that VAC had no clinically significant effects on the circulation, even in patients with single ventricular physiology. Furthermore, there were no severe adverse effects, such as haemorrhage or significant arrhythmia. These data suggested that VAC clinically did not affect circulation, even in paediatric patients with specific circulatory conditions, such as those after Norwood and Fontan operations; therefore, this treatment could be used safely for mediastinitis after paediatric heart surgery.

Although the level of negative pressure is one of the most important parameters of this modality, the optimal pressure is still a controversial topic. Several studies showed that low negative

Table 3: The amount of diuretics (furosemide) administered and urinary output in single-ventricle patients

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<th>Before</th>
<th>0–24 h</th>
<th>24–48 h</th>
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<tr>
<td>Diuretics (mg/kg)</td>
<td>3.06 (1.97–3.94)</td>
<td>3.94 (1.2–3.98)</td>
<td>3.28 (2.05–4.59)</td>
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<tr>
<td>Urinary output (ml/kg/h)</td>
<td>3.92 (2.70–4.63)</td>
<td>3.25 (3.03–4.43)</td>
<td>3.36 (3.11–3.58)</td>
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Data are shown as the median (range). Statistical analyses were not conducted because of the small number of patients (n = 3). We considered their haemodynamics to be well maintained because urinary output remained >3 ml/kg/h.

First, antibiotic therapy should be indisputably used. The pathogens that caused mediastinitis in this cohort are listed in Table 2. As described above, Patient 1 had a colostomy and E. coli isolated from his wound, indicating that the cause of mediastinitis was likely to be contamination from the colostomy. Excluding 1

Figure 2: Changes of mean blood pressure (MBP) and mean heart rate (MHR) value in every 8-h period in patients with single ventricular physiology. (A) Box plots of MBP in patients with single ventricular physiology. (B) Box plots of MHR in patients with single ventricular physiology. The box plots of MBP and MHR values obtained in every 8-h period for patients with single ventricular physiology are depicted. Although statistical analyses were not conducted because of the small number (n = 3), no changes are apparent.
pressure was as efficient as and had several advantages over, high negative pressure [19, 20]. By contrast, the classical experimental paper showed that −125 mmHg was the most effective to increase tissue blood flow [21]; in fact, this pressure can be used in most adult cases [22]. Given the concern that negative pressure on a small heart could deteriorate haemodynamics, we applied relatively low negative pressure initially. Successful sternal closure without any adverse events prompted us to try stronger negative pressure. Of late, we have been using −100 mmHg, which is the highest level in our system.

In conclusion, all patients with mediastinitis, except those with infection of artificial material, were cured with VAC without any significant changes in haemodynamics caused by the negative pressure. These results indicate that VAC could be an effective and feasible treatment for post-sternotomy mediastinitis, even in small children with complex cardiac anomalies. We recognize that our cohort was very small, and that this study has the intrinsic limitation of a retrospective study. Our department was established only 9 years ago; therefore, we do not have many cases. In this study, haemodynamics was observed only for 48 h; therefore, we cannot comment about the effects of VAC after that period. Further randomized trials and clinical investigations are required to determine whether VAC is the optimal treatment for paediatric mediastinitis.

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Conflict of interest: none declared.

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