Negative pressure therapy for post-sternotomy wound infections in young children

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Abstract

OBJECTIVES: Post-sternotomy wound infection remains a significant morbidity in congenital and paediatric cardiac surgery. However, the techniques used for this complication in children are not optimal in terms of mortality, morbidity and the use of medical resources. Negative pressure therapy is an effective modality in the treatment in adults, but reports of its use in children are limited. This study evaluated the use of negative pressure therapy in young children for post-sternotomy wound infections.

METHODS: From October 2004 to June 2012, 15 consecutive cases of post-sternotomy wound infections in patients ≤6 years of age were managed with negative pressure therapy, and these patients were followed up for ≥12 months after wound closure. The median Aristotle comprehensive complexity score was 9.9 ± 4.0. The infection was identified at a median of 16 days after surgery, and the procedure was performed within 24 h of diagnosis. No additional surgical procedures were applied.

RESULTS: No cases of hospital mortality or second surgery for infection control occurred. The median duration until wound closure was 25 days (range: 5–92 days). Further, no patient showed sternal instability at treatment termination. During the mean follow-up period of 45.8 ± 31.3 months after wound closure, no admission occurred for infection recurrence. According to a multivariable analysis, the infection depth and patient weight significantly lengthened treatment duration (P = 0.008 and 0.046, respectively).

CONCLUSIONS: Negative pressure therapy is an effective treatment modality for wound infections in paediatric cardiac surgery and results in low morbidity, mortality and medical resource use.

Keywords: Wound infection • Sternotomy • Congenital heart disease

INTRODUCTION

Post-sternotomy wound infection remains a significant morbidity in congenital and paediatric cardiac surgery [1]. Negative pressure therapy (NPT) was first introduced in 1997 for the treatment of difficult and chronic wounds [2, 3], and its use has become widely spread in the management of this complication in adults [4–8]. The principle of this therapy is based on the continuous application of a negative pressure to the wound [9, 10]. This applied pressure increases local arteriolar blood flow and reduces tissue oedema and the bacterial colonization rate, resulting in the promotion of tissue granulation [9, 10]. The negative pressure also achieves sternal stabilization. However, to date, only a few anecdotal reports on this technique have been published in regard to the paediatric population [11–14]. Moreover, none of the other techniques (e.g. muscle-flap surgery) used to treat this complication in children is optimal in terms of mortality, morbidity and the use of medical resources. Hence, the use of NPT could significantly improve treatment of post-sternotomy wound infections in children. Since 2004, we have used NPT to treat this complication in paediatric patients. Therefore, this study aimed to evaluate the use of NPT in the treatment of post-sternotomy wound infections in young children.

METHODS

Study design

The Institutional Review Board of the Keio University Hospital approved this retrospective study before the data were collected. Between February 2004 and June 2012, 671 surgical procedures were performed through a midline sternotomy in patients (age ≤6 years) with congenital heart disease at Keio University Hospital. Of these, a total of 15 consecutive cases of post-sternotomy wound infections (2.2%) involving 12 patients were identified and included in the study. Three patients developed an episode of wound infection after each of two sternotomies. All patients were followed up for 12 months or longer after wound closure.

Negative pressure therapy

Immediately after the patients developed wound infection as defined below, the NPT system was inserted. No radiological assessment using computer tomography was performed for the
determination of infection depth. After the patient was sedated with either midazolam or propofol, the surgical wound was re-explored until the depth of the pus discharge was determined; the pus discharge was then sampled for bacterial culture. The sternal sutures (wires), as well as an expanded polytetrafluoroethylene (ePTFE) pericardial membrane that was used in some of the cases during the initial operation, were removed if found to be involved in the infection. Surgical debridement was limited: only fragile and necrotic tissue was removed, and the sternum was spared. All cases of wound infection were managed with NPT alone, and no additional surgical procedures (e.g. omental flap, muscle flap or closed drainage with continuous irrigation) were used. After the initial procedure for the NPT insertion, re-exploration and subsequent use of the NPT system was repeatedly performed using the same anaesthesia protocol as the initial time, every 3 days until the defect was filled by granulation tissue. Feeding was not interrupted with the procedures. Once complete granulation had occurred, the therapy was discontinued. The sternum was not rewired.

In the 8 earliest cases, the NPT system was hand-made and had a suction pump (HAMA Servo-Drain 3000, Innomedics, Inc., Tokyo, Japan), a 6-Fr multiport catheter (Atom Medical, Inc., Saitama, Japan) and a polyurethane form (Hydrosite, Smith and Nephew, Saint Petersburg, FL, USA). A commercially available system (VAC ATS® Therapy System, Kinetic Concepts, Inc., TX, USA) was used in the remaining 7 cases. The negative pressure used for the continuous suction drainage was approximately −50 mmHg for all cases.

A 6-week course of sensitive antibiotics was chosen and applied by an infection control doctor at our institution based on the culture results of the wound. For cases involving methicillin-resistant Staphylococcus aureus (MRSA) infection, either vancomycin or teicoplanin was first administered in the treatment of the infection, and linezolid was used in cases in which renal dysfunction or other side-effects were recognized.

Data acquisition and analysis

Medical and surgical records were reviewed retrospectively. The clinical characteristics of the patients are summarized in Table 1. The demographic data collected included patient age, weight, previous operations with or without a midline sternotomy, previous episodes of wound infection, preoperative presence of bacteria, prophylactic antibiotics, coil embolization for internal thoracic or intercostal arteries and cardiac and non-cardiac diagnoses. The Aristotle comprehensive complexity score was calculated from the collected data. The initial operative procedure, the use of prosthetic cardiovascular material, prosthetic cardiovascular material exposing the mediastinum, ePTFE pericardial membrane, or of donor blood, total cardiopulmonary bypass time, aortic cross-clamp time, when applicable, deep hypothermic circulatory arrest time and incidence of delayed sternal closure were all recorded. Time from initial operation to the diagnosis of wound infection, the culture results, the depth of infection, recurrences, morbidity, second surgery for infection control, stability of the sternum at the end of treatment and mortality were evaluated.

Wound infection was defined as clinical findings of purulent discharge from the subcutaneous layer and from deeper tissues with fever and local erythema, and was confirmed by isolation of the organism from the wound discharge. The cases of wound infection were divided into three groups according to the depth of infection: (i) anterosternum infection involved an infection with the anterior plate of the sternum free from a flail joint and sternal dehiscence, (ii) posterosternum infection involved an infection with a flail joint or sternal dehiscence and (iii) pericardial infection involved purulent discharge from the pericardial cavity. Sternal instability was defined as non-physiological or abnormal motion of the sternum after either bone fracture or disruption of the wires reuniting the surgically divided sternum [15].

The statistical package IBM SPSS version 20.0.0 (IBM, Inc., Chicago, IL, USA) was used for all statistical calculations. Putative factors that

Table 1: Pretreatment characteristics of 15 cases of wound infection

| Case | Age (months) | Weight (kg) | Cardiac diagnosis | Procedure at initial operation | Aristotle comprehensive complexity score | Sternal closure | Time of diagnosis (days) | Infection depth |
|------|--------------|-------------|-------------------|-------------------------------|------------------------------------------|----------------|--------------------------|----------------|
| 1    | 2            | 4.0         | TOF/PS            | TOF repair                    | 8                                        | Primary        | 2                        | Anterosternum  |
| 2    | 3            | 3.5         | HLHS              | Norwood                       | 20                                       | Delayed        | 72                       | Anterosternum  |
| 3    | 4            | 4.1         | HLHS              | Blalock-Taussig shunt         | 13.8                                     | Primary        | 26                       | Retrosternum   |
| 4    | 36           | 14.8        | TGA/VSD/PS        | Aortic translocation          | 13                                       | Primary        | 28                       | Retrosternum   |
| 5    | 3            | 5.8         | VSD               | VSD closure                   | 6                                        | Primary        | 19                       | Anterosternum  |
| 6    | 8            | 6.5         | VSD               | VSD closure                   | 6                                        | Primary        | 116                      | Anterosternum  |
| 7    | 12           | 8.0         | TOF/PS            | TOF repair                    | 11                                       | Primary        | 6                        | Percardium     |
| 8    | 0.1          | 3.3         | TGA               | Arterial switch               | 11.5                                     | Delayed        | 15                       | Retrosternum   |
| 9    | 4            | 5.8         | TOF/PS            | Blalock-Taussig shunt         | 6.3                                      | Primary        | 7                        | Retrosternum   |
| 10   | 6            | 6.1         | PAIVS             | Bidirectional cavopulmonary shunt | 9                                        | Primary        | 5                        | Percardium     |
| 11   | 72           | 15.1        | TOF/PS            | Sternal closure               | 4.5                                      | Primary        | 16                       | Anterosternum  |
| 12   | 1            | 2.9         | CoA/VSD           | Pulmonary artery banding      | 8                                        | Primary        | 19                       | Anterosternum  |
| 13   | 7            | 5.5         | CoA/VSD           | VSD closure                   | 8                                        | Primary        | 7                        | Retrosternum   |
| 14   | 3            | 3.3         | TOF/PS            | TOF repair                    | 8.5                                      | Primary        | 7                        | Anterosternum  |
| 15   | 11           | 6.2         | TOF/PA            | Blalock-Taussig shunt         | 13.3                                     | Primary        | 19                       | Retrosternum   |

CoA: coarctation of aorta; HLHS: hypoplastic left heart syndrome; PA: pulmonary atresia; PS: pulmonary stenosis; TOF: tetralogy of Fallot; TGA: transposition of the great arteries; VSD: ventricular septal defect.
may have influenced the length of NPT were analysed univariably (Table 2). Relationships between the length of the NPT and continuous variables were examined by correlation analysis. Differences in the length of NPT with or without categorical variables were compared using Student's t-test. A stepwise forward selection procedure was then used to develop a multiple regression model predictive of the length of NPT. Variables that were significant at the 0.10 level based on the univariable analysis were considered for inclusion in the model. A P value of <0.05 was required for variables to remain in the model. Continuous values are expressed as mean ± 1 standard deviation, or the median, when appropriate. Categorical and sequential variables were expressed as the percentage of patients.

RESULTS

The patient demographics are summarized in Table 1. The primary cardiac diagnoses were tetralogy of Fallot with pulmonary stenosis or atresia in 6 cases, ventricular septal defect in 2, hypoplastic left heart syndrome in 2, coarctation of the aorta with ventricular septal defect in 2, simple or complex transposition of the great artery in 2 and pulmonary atresia with intact ventricular septum in 1.

The initial operation was a definitive repair in 8 cases and a palliative procedure in 7. Three cases involved reinfusion in patients with a past history of wound infection (case numbers 1 and 11, 2 and 3, 12 and 13). Coil embolization for internal thoracic or intercostal arteries, and deep hypothermic circulatory arrest were not used in any of the cases in the series, and these procedures were excluded from the analysis.

The preoperative presence of MRSA was diagnosed in 8 cases by either culture evidence from the nasal cavity (n = 5) or a history of wound infection (n = 3). All patients received a perioperative antibiotic prophylaxis with intravenous cefazolin, except for MRSA carriers, who received vancomycin prophylaxis as described above.

Wound infection was diagnosed at a median of 16 days (range: 2–116 days) after the initial surgery. The depth of the wound infection was in the anterosternum in 7 cases, posterosternum in 6 and pericardium in 2. NPT was commenced within 24 h in all cases after the diagnosis of wound infection. The culture results from the surgical sites are summarized in Table 2.

All patients survived during the hospitalization. There was no NPT-related morbidity, such as haemodynamic instability or major bleeding requiring blood transfusion. The median NPT duration was 25 days (range: 5–92 days). Further, none of the patients needed second surgery for infection control. At the termination of treatment, a firm granulation tissue had filled the gap between the two hemi-sternums in all patients and had stabilized the hemi-sternums without any additional procedures for sternal fixation (Fig. 1). Secondary sternal closure was performed in 1 case for a cosmetic reason during the same hospitalization. A mean follow-up of 45.8 ± 34.6 months (range: 16–116 months) was completed in all patients after wound closure. During the follow-up period, none of the patients showed recurrence of the wound infection. However, 7 cases underwent an additional sternotomy without any inadvertent cavity re-entries, and 3 cases of these with previous MRSA infection developed an MRSA infection at 2, 5 and 71 months after wound closure and were successfully treated with NPT. At the last hospital visit, none of the patients showed sternal instability as defined earlier.

Univariable analysis revealed that the depth of infection and patient weight were risk factors for a longer NPT duration. The Aristotle comprehensive complexity score, gender, age, previous operations with a midline sternotomy, previous wound infection, preoperative presence of bacteria, cyanotic lesions, residual cyanotic lesions during treatment, single ventricular lesions, the use of prosthetic cardiovascular material, prosthetic cardiovascular material exposing the mediastinum, ePTFE pericardial membrane or of donor blood, total cardiopulmonary bypass time, aortic cross-clamp time and delayed sternal closure did not influence the NPT duration. Of the two factors identified by the univariable analysis, the final model of the multiple regression analysis identified deeper infection (non-standardized coefficient = 19.7, standard error = 6.1, P = 0.008), and higher weight (non-standardized coefficient = 2.6, standard error = 1.2, P = 0.046) as predictors of a longer NPT period.

DISCUSSION

Post-sternotomy wound infection in children has been most often treated using debridement plus either muscle-flap reconstruction

| Table 2: Pretreatment patient characteristics |
|---------------------------------------------|
| Variables | n | % |
| Gender ratio (male/female) | 7/8 | 46.7/53.3 |
| Mean age at operation (months) | 11.5 ± 18.9 | Range: 0.3–72.0 |
| Mean weight at operation (kg) | 6.4 ± 3.8 | Range: 2.9–15.1 |
| Cyanotic lesions | 12 | 80 |
| Residual cyanotic lesions during treatment | 6 | 40 |
| Single ventricular lesions | 3 | 20 |
| Mean CPB time during the operation (min) | 83.9 ± 85.5 | Range: 0–331 |
| Mean cross-clamp time during operation (min) | 34.3 ± 44.0 | Range: 0–162 |
| Number of previous sternotomies (0/1/2/3) | 5/5/4/1 | 33.3/33.3/26.7/6.7 |
| Previous wound infection | 3 | 20 |
| Donor blood use during operation | 13 | 86.7 |
| Prosthesis use during operation | 9 | 60.0 |
| Infection exposing prosthesis use during operation | 8 | 53.3 |
| ePTFE pericardial membrane use during operation | 6 | 40.0 |
| Coil embolization of internal thoracic or intercostal arteries | 0 | 0 |
| Aristotle comprehensive complexity score | 9.9 ± 4.0 | Range: 5–20 |
| Delayed sternal closure at operation (days) | 2 | 13.3 |
| Median time to diagnosis of infection | 16 | Range: 2–116 |
| Depth of wound infection | | |
| Anterosternum | 7 | 46.7 |
| Posterosternum | 6 | 40 |
| Pericardium | 2 | 13.3 |
| Micro-organism isolated from the surgical site | | |
| Methicillin-resistant Staphylococcus aureus | 11 | 73.3 |
| Methicillin-sensitive Staphylococcus aureus | 3 | 20.0 |
| Methicillin-resistant Staphylococcus epidermidis | 2 | 13.3 |
| Branhamella catarrhalis | 1 | 6.7 |

CPB: cardiopulmonary bypass; ePTFE: expanded polytetrafluoroethylene.

*In 2 cases more than 1 pathogen was isolated.
or primary closure [20]. However, both techniques have been reported to result in imperfect eradication of the infection and thus to hospital deaths and recurrence of infection (Table 3). NPT can reduce the number of micro-organisms more quickly because of the high negative pressure environment in the infected tissue [2], and should therefore contribute to a more certain eradication. Our results with no patient deaths or wound infection recurrence during both the hospitalization and the follow-up periods may support this technique as possessing this essential advantage in small children.

Previously applied techniques for the treatment of post-sternotomy wound infections in paediatric patients are represented by a variety of concerns. Reconstructive surgery with the muscle-flap technique has been reported to be a risk factor for sternal instabilities complicating ventilation following repair and the development of thoracic wall deformities after child growth [18]. Further, this technique is technically demanding, especially in a very small patient with a thin muscle layer. In primary closure, wound closure without culture evidence of an aseptic condition can potentially delay the identification of residual or recurrent wound infections and can thereby jeopardize the patient. Medical costs and the use of medical resources are another issue. Indeed, the overall medical costs per patient in the treatment of post-operative wound infections have been reported to be nearly $4000 less expensive in adult NPT than in a closed irrigation therapy, even with subsequent surgeries for wound closure [6]. The fact that the daily average cost for the NPT system remained only $85 in our institute may support the economic advantage as well. The diagnosis of the wound infection depth may become less important by using NPT, because any additional surgical procedures for infection control, such as muscle-flap reconstruction, are unnecessary.

The median length of treatment in our series was 25 days. This length of treatment is similar to those of other reports using the muscle flap [16–20] and longer than the median length of 12 days reported for debridement and primary closure. However, an intravenous antibiotic administration for 6 weeks followed by an evaluation for 1 week with hospitalization is the protocol for wound infections in our institute, and the NPT was discontinued by the end of the pharmacological protocol in most cases. In our series, the depth of infection and the patient weight were significantly associated with a prolonged need for NPT. These findings are understandable, since these parameters may represent the volume of the infected tissue.

In our series, NPT promoted granulation formation between the two hemi-sternums, which were eventually connected by a narrow and firm tissue after treatment. This outcome enabled the omission of a secondary surgical fixation without resulting in sternal instability. A shorter distance between the hemi-sternums at the reopening of the sternotomy, more compliant thoracic cages and more rapid wound healing with increased active growth hormone secretion compared with adult patients may have contributed to this favourable outcome. Additionally, as shown in 7 of the present cases, re-entry after NPT stabilization was possible. However, as suggested by our findings, selected patients—especially those with a deeper infection or a heavier weight—could have their sternum secondarily closed after the resolution of infection and thereby shorten the NPT duration, without sacrificing the NPT effect.

Of potential interest, wound infection developed again following a resternotomy in 3 of 7 patients (43%) in our series. MRSA was the causative bacteria in both the initial and recurrent infection, although a genotype assessment was not available. While the recurrence of infection following resternotomy has been previously reported in only 4 patients [20, 21], true eradication of the causative bacteria itself might not be necessary for wound closure,

![Figure 1](computed tomograms of Case 4 after retrosternum wound infection (A) and Case 10 after pericardial infection (B). Note that the gaps between the two hemi-sternums are filled with a narrow granulation tissue layer.)

| Technique                  | n  | Hospital mortality (%) | Second surgery (%) | Recurrent infection (%) |
|----------------------------|----|------------------------|--------------------|------------------------|
| Muscle flap [16–20]        | 40 | 17.5 (7/40)            | 2.0 (40)           | 3.0 (1/33)             |
| Primary closure [20]       | 42 | 2.4 (1/42)             | 7.1 (3/42)         | 2.4 (1/41)             |
| Negative pressure therapy  | 23 | 0 (0/23)               | 0 (0/23)           | 0 (0/23)               |
| [11–13, and the present study] |   |                        |                    |                        |
and previous infection could be a risk factor for wound infection after re sternotomy.

The optimal negative pressure of the NPT system for wound infections in children is controversial; the pressures reported by investigators vary between −50 and −100 mmHg [11–14]. In adults, the pressure of −125 mmHg was proved as the most effective by basic research [22, 23] and is therefore the one most commonly used. However, the concern is present that the threshold for causing circulatory instability may be lower in a small patient because the cardiovascular wall is thinner and more fragile and has a higher mechanical compliance. In the present series, we applied −50 mmHg and encountered no such complications. Moreover, sternal stability may also be achieved with a lower pressure because of the higher compliance of the thoracic wall, and therefore, a higher attraction effect may occur with the two hemisternums. In adults, negative pressures of −50 to −100 mmHg have been reported to stabilize the sternum as efficiently as those of −150 to −200 mmHg [22]. Indeed, sternal stability after NPT was achieved even without surgical sternal closure in our series, which is another advantage with NPT in children. Our findings suggest that a pressure of −50 mmHg is adequate in terms of infection control, the avoidance of related complications and sternal stabilization.

The limitations of the present study include the retrospective nature of the study, the heterogeneity of the cardiac anomalies/surgical procedures and the small size of the patient cohort. A controlled randomized study may be necessary to prove the superiority of NPT relative to other techniques.

In conclusion, our on-site protocol using the NPT system as the first-line treatment for wound infections in paediatric cardiac surgery and results in low morbidity, mortality, and medical resource use. Deeper infection and greater weight are independent risk factors for the need for a prolonged treatment.

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