Primary closure for postoperative mediastinitis in children

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Objectives: Mediastinitis affects approximately 1% of children undergoing median sternotomy. Conventional therapy involves debridement followed by open wound care with delayed closure, days to weeks of closed suction or antimicrobial irrigation, and vacuum-assisted closure or muscle flap closure. We hypothesized that primary closure without prolonged suction or irrigation is an effective, less traumatic treatment for mediastinitis in children.

Methods: From January 1986 to July 2002, 6705 procedures involving median sternotomy were performed at the C. S. Mott Children's Hospital, resulting in 57 cases of mediastinitis (0.85%). Cases were divided into 2 groups, with 42 cases treated with primary closure and 15 cases treated with delayed or muscle flap closure. The 42 cases of primary closure comprised the primary study group of this institutional review board-approved, retrospective analysis. Patient demographics, surgical variables, mediastinitis-related parameters, and outcomes were evaluated.

Results: One patient had recurrent mediastinitis for an overall infection eradication rate of 97% (40/41). Three patients (7%) required re-exploration for suspected ongoing infection. Of these re-explorations, 1 patient had evidence of continued mediastinitis. The remaining 2 patients with sepsis of unclear cause had no clinical or culture evidence of recurrent infection. One of these patients ultimately died of sepsis without active mediastinitis for a hospital survival of 97% (41/42). No significant differences could be detected between the treatment successes and failures in this small cohort of patients.

Conclusions: Simple primary closure is an effective means to treat selected cases of postoperative mediastinitis in children. The results compare favorably with other more lengthy or debilitating treatments.

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Mediastinitis is a significant postoperative complication that affects 0.1% to 5.0% of all pediatric patients undergoing median sternotomy.¹⁻⁶ As in adults, treatment with debridement and primary closure in children has had reported failure rates of 50%.⁷ Current conventional therapy for mediastinitis has reduced mortality to 0% to 28%.^{8,9} The most popular conventional techniques for the treatment of mediastinitis currently include debridement followed by closure with either rectus abdominis or pectoralis major muscle flaps and primary closure with days to weeks of closed suction drainage with or without antimicrobial irrigation.¹⁰⁻¹² These techniques, developed in adults, have subsequently been applied to the pediatric population. However, concerns regarding musculoskeletal growth, breast development, sternal instability, and other morbidities associated with these complex and lengthy therapies have been raised.^{3-5,13}

Since 1986, most cases of mediastinitis occurring at the C. S. Mott Children's Hospital of the University of Michigan Health System have been treated by debridement with concomitant primary closure without muscle flaps, prolonged

suction, or irrigation. This policy is in sharp contrast with the more common use of conventional therapies for mediastinitis in children. This report reviews our experience with simple primary closure as definitive treatment for mediastinitis in children.

Methods

Patient Population

From January 1986 to July 2002, 6705 procedures involving a median sternotomy were performed at our institution. All patients who had mediastinitis in the postoperative period after median sternotomy were identified. The data that were collected included patient demographics, surgical parameters, and characteristics of the infectious process. Demographic data included patient age, weight, previous operations or episodes of mediastinitis, and both cardiac and noncardiac diagnoses. Initial operative procedure, use of prosthetic material, total cardiopulmonary bypass time, aortic crossclamp time, incidence of delayed sternal closure, and, when applicable, deep hypothermic circulatory arrest time were all recorded. Time from initial operation to the diagnosis of mediastinitis, culture results, clinical severity of infection, recurrences, morbidity, and mortality were evaluated.

Study Design

The current study is a single-center, retrospective review of the medical records of children treated for postoperative mediastinitis. Before the data were collected, appropriate institutional review board approval was obtained. Patients with mediastinitis were classified into 2 groups according to their method of treatment. One group underwent debridement with concomitant primary closure without muscle flaps or prolonged suction/irrigation. The second group underwent conventional therapy with debridement and concomitant muscle flap closure or local wound care followed by muscle flap closure, delayed primary closure, or healing by secondary intention.

The study hypothesis was that primary closure is an effective method for treating mediastinitis in children. The primary aim of the study was to determine the success rate of primary closure. The secondary aim was to compare the characteristics of the 2 groups of patients undergoing either primary closure or conventional therapy. It is important to distinguish between the outcomes of the 2 groups and the characteristics of the 2 groups in the secondary aim. This is not a prospective study, and these are clearly 2 different populations of patients. The patients were treated over many years, by several surgeons, with techniques that have evolved over time. The patients were not selected for treatment in a randomized fashion; rather they were selected according to differences in the overall clinical condition and operative findings determined by the individual surgeon. However, in an effort to define these differences, the 2 groups were compared for variations in patient demographics, surgical parameters, and infection characteristics.

For the purposes of this study, mediastinitis was defined as clinical and culture evidence of deep infection involving the pericardial space after median sternotomy. A clinical grading scale was used to classify severity of infection for use in later compar-

ison between the groups undergoing primary closure and conventional therapy. Mild mediastinitis was defined as fascial dehiscence, intact sternum, and free communication of purulent material with the pericardial space at the sternal notch or xiphoid. Moderate infection entailed sternal separation and purulence localized to the anterior surface of the heart. Involvement of the entire pericardial space with purulence was considered severe mediastinitis.

Surgical Technique

The decision to pursue primary closure or conventional therapy was at the discretion of the operating surgeon. Our technique for primary closure entailed initial debridement of all grossly infected and devitalized soft tissue, cartilage, and bone. The sternum was then closed with simple interrupted stainless steel wire over a single chest tube. Running absorbable suture was used to close the linea alba and soft tissue of the chest. The skin was closed with interrupted nonabsorbable suture. The chest tube was managed as a routine mediastinal drain. It was removed when postoperative output had ceased, generally in 24 to 48 hours. All patients were given a 6-week course of intravenous antibiotics. Conventional therapies used at our institution included primary muscle flap closure and open wound care followed by muscle flap closure, delayed primary closure, or healing by secondary intention.

Statistical Analysis

The means for each group were compared using the Mann-Whitney test and independent-samples *t* test. Normal Q-Q plots and side-by-side box plots were used to examine normality and variance assumptions. Statistical significance was determined by comparing the generated *t* statistic and corresponding *P* value with an alpha value of .5.

Results

A review of the 6705 procedures involving median sternotomy during the study period revealed 57 cases (0.85%) of mediastinitis. Of the 57 cases, 42 (74%) were treated with mediastinal debridement and concomitant primary closure. Fifteen patients (26%) underwent treatment with conventional therapies.

Patient Demographics

Comparison of the median age demonstrated no statistically significant difference between the primary closure group (6.7 months, range 6 days-75 months) and the conventional therapy group (5.4 months, range 1 day-216 months) (Table 1). The median weight at operation was also similar between the primary closure group (6.3 kg, range 3-24.5 kg) and the conventional therapy group (6.0 kg, range 4-70 kg). Seventy-four percent (31/42) of patients in the primary closure group had a cyanotic heart lesion, compared with 60% (9/15) in the conventional treatment group. Similar results were also found for the percentages of single ventricle lesions in the primary closure group (52%, 22/42) and conventional therapy group (47%, 7/15).

Figure 1. Comparison of primary closure and conventional therapy in patients: incidence of delayed sternal closure ($P = .0018$).

Figure 2. Comparison of primary closure and conventional therapy in patients: incidence of *Pseudomonas* infection ($P = .05$).

Surgical Variables

No statistically significant difference was found for mean cardiopulmonary bypass time or aortic crossclamp time between the primary closure group (93 ± 34 minutes, 50 ± 18 minutes, respectively) and the conventional therapy group (117 ± 54 minutes, 39 ± 12 minutes, respectively) (Table 1). Prosthetic material, most commonly polytetrafluoroethylene patches or grafts and pulmonary homograft patches or conduits, was used for repair in 60% (25/42) of patients who underwent primary closure and 60% (9/15) of patients who were treated with conventional therapy (Table 1). Sixty percent (25/42) of the patients who underwent primary closure had undergone a previous sternotomy compared with 52% (8/15) in the conventional therapy group. A history of mediastinitis was found in 2 patients (5%) in the primary closure group compared with none in the conventional therapy group. However, the incidence of delayed sternal closure at the initial operation was found to be higher in the conventional therapy group (47%, 7/15) when compared with the primary closure group (7%, 3/42, $P = .0018$) (Fig 1).

Mediastinitis-Related Variables

The median time from initial operation to the diagnosis of mediastinitis was 13 days (range 6-32 days) for the primary

Figure 3. Comparison of primary closure and conventional therapy in patients: severity of mediastinitis. Mild infection (white); moderate infection (diagonal lines); severe infection (black).

closure group and 16 days (range 9-127 days) for the conventional therapy group (Table 1). *Staphylococcus* species were the most common causative agent in both groups. It was isolated from 71% (29/41) of the primary closure group and 55% (6/11) of the conventional closure group. However, *Pseudomonas* was cultured in a significantly higher proportion of the patients undergoing conventional therapy compared with primary closure (45% vs 15%, respectively, $P = .05$) (Fig 2). Comparison of the clinical severity of mediastinitis revealed similar percentages of mild, moderate, and severe infection in the 2 groups (Fig 3).

Results of Primary Closure for Mediastinitis

Hospital survival for the group of patients undergoing primary closure for mediastinitis was 97% (41/42). The hospital death occurred from overwhelming sepsis in a patient without evidence of active mediastinitis. There were no late deaths related to sternal infection. Freedom from reoperation for infectious complication was 93% (39/42). The 3 patients requiring reoperation had continuing sepsis and required exploration for suspected ongoing mediastinitis. Of these 3 patients, 2 had no clinical or culture evidence of infection. One of these 2 patients was the single patient in this group who later died of overwhelming sepsis. The 1 patient with continued mediastinal infection underwent successful treatment with debridement and immediate muscle flap closure. Therefore, the overall infection eradication rate was 97% (41/42). The median length of stay was 12 days (range 4-88 days).

Results of Conventional Therapy for Mediastinitis

The hospital survival for patients with mediastinitis treated by conventional therapy was 27% (4/15). Three of the patients died with active mediastinitis and ongoing open wound care. These deaths were caused by systemic-pulmonary artery shunt malfunction (1), aortic rupture (1), and necrotizing enterocolitis (1). One patient died of fungal sepsis 5 weeks after successful muscle flap closure, presum-

TABLE 1. Comparison of primary closure and conventional therapy groups: nonsignificant variables

Variable	Primary closure	Conventional therapy
Median age	6.7 mo (range 6 d–75 mo)	5.4 mo (range 1 d–216 mo)
Median weight	6.3 kg (range 3–24.5 kg)	6.0 kg (range 4–70 kg)
Cyanotic lesion	74% (31/42)	60% (9/15)
Single ventricle lesion	52% (22/42)	47% (7/15)
Prosthetic material	60% (25/42)	60% (9/15)
Mean CPB time	93 min ± 34 min	117 min ± 54 min
Mean clamp time	50 min ± 18 min	39 min ± 12 min
Previous sternotomy	60% (25/42)	52% (8/15)
Previous mediastinitis	5% (2/42)	0%
Median time to diagnosis	13 d (range 6–32 d)	16 d (range 9–127 d)

CPB, Cardiopulmonary bypass.

TABLE 2. Comparison of the results of primary closure from the current study and the composite results of other contemporary studies using conventional therapy

Study	Technique	n	Hospital survival	Reintervention	Recurrent infection
Current study	Primary closure	42	97% (41/42)	7% (3/42)	3% (1/42)
Other studies ^{3–5,14}	Conventional therapy	36	92% (33/36)	22% (8/36)	3% (1/36)

ably related to ongoing broad-spectrum antibiotic therapy. Of the surviving patients, 1 patient (9%, 1/11) treated with open wound care and delayed primary closure had recurrent infection. The median length of stay for this group of patients was 18 days (range 7–367 days).

Discussion

Mediastinitis remains a significant complication after median sternotomy in adults and children. The most common conventional therapies currently used for children are muscle flap closure, closed suction drainage with or without antimicrobial irrigation, vacuum-assisted closure or local wound care followed by muscle flaps, delayed primary closure, or healing by secondary intention.^{1–6,13–15} All of these strategies have been developed and proven in the adult population, and subsequently applied to children. However, all of these modalities have significant disadvantages in the pediatric population. The use of rectus abdominis or pectoralis major muscle flaps has the potential to cause musculoskeletal growth abnormalities at either the donor or recipient site. There is also the concern of future breast development in girls associated with the use of pectoralis major flaps.^{4,5,13} Closure with muscle flaps and healing by secondary intention can lead to sternal instability with the resultant physical deformity, lack of protection for the heart and great vessels, and respiratory compromise. Other series, including our experience, have reported patients with significant sternal instability requiring reoperation for sternal stabilization or contributing to ventilator dependence.^{5,13} Closed suction and antimicrobial irrigation have been reported to cause significant metabolic derangement and even

death because of systemic absorption and toxicity of antimicrobials in children.³ In addition, any prolonged wound management strategy, particularly those requiring open wound care, is physically and psychologically traumatic to the pediatric patient.

Since 1986, it has been the policy at our institution to treat the majority of cases of mediastinitis in children with debridement and concomitant primary closure without prolonged suction or irrigation. Of the 57 cases of mediastinitis identified over a 16½-year period, 74% were treated with primary closure. The technique of primary closure has resulted in excellent rates of survival, freedom from reoperation, and infection eradication. These results also compare favorably with other reports in the literature of conventional therapy for mediastinitis in children (Table 2). The median length of stay of 12 days (range 4–88 days) also compares well with other published results. Erez and colleagues⁵ reported a median length of stay of 34 days (range 23–150 days) for muscle flap closure. Although the total length of stay was not addressed, Stiegel and associates³ published their mean duration of intensive care unit stay for both flap closure and local wound care with or without antimicrobial irrigation as 6.2 days and 32.8 days, respectively.

In our experience, only 26% (15/57) of patients with mediastinitis were treated with conventional therapy. Because these 2 treatment strategies were not randomly assigned, it is not particularly useful to compare outcomes. However, determining how the 2 groups differed is of interest. Although it is difficult to uncover all of the factors that led to the decision to pursue conventional therapy rather than primary closure in this retrospective study, 2 of the

variables tested did reach statistical significance. Infection with *Pseudomonas* and the need for delayed sternal closure at the initial operation were both associated with the use of conventional therapy. However, these factors should not be misinterpreted as absolute or relative contraindications to primary closure. Several patients who underwent successful primary closure had either *Pseudomonas* infection or delayed sternal closure. It is possible that these variables are surrogates for other parameters that are more difficult to determine retrospectively, such as the extent of tissue destruction in the opinion of the operating surgeon or the overall clinical condition of the patient. Because of the limited numbers of patients, and the lack of randomization, such conclusions and specific guidelines for the use of primary closure or conventional therapy cannot be defined.

The fact that children and not adults tolerate primary closure may be attributable to several factors. Many of the risk factors associated with the development of mediastinitis are found more commonly or even exclusively in adults. Obesity, chronic obstructive pulmonary disease, and smoking are widely recognized risk factors for the development of mediastinitis.^{9,16,17} Advanced age alone is a risk factor for mediastinitis, as well as for failure of successful treatment.¹⁸ A more abundant vascular supply to the sternum in children may also be a factor. The majority of adults undergo a median sternotomy for coronary artery bypass grafting. The same comorbidities associated with coronary artery disease, such as hypertension and diabetes mellitus, are also associated with vascular disease in general. In addition, harvesting of the internal thoracic arteries for coronary artery bypass grafting has been shown to result in ischemia of the sternum.¹⁹ Children may also have a more developed system of collateral circulation. The experience with coarctation repair and extracorporeal membrane oxygenation has shown that the subclavian artery and even the common carotid artery may be ligated in children with relative impunity because of an abundance of collateral circulation. Conversely, acute occlusion of the carotid artery or an extremity artery in the adult often results in catastrophic ischemia.

Primary closure is an effective treatment for mediastinitis in children. It is the treatment of choice at our institution and is appropriate for the majority of cases. Selection of primary closure or conventional therapy is based on the clinical judgment of the surgeon regarding the overall condition of the patient and the operative findings. The length of time from initial operation to the diagnosis of mediastinitis, presence of prosthetic material, and severity of mediastinitis based on a basic clinical grading scale are not indicative of a need to select conventional therapy over primary closure.

Specific recommendations based on these data are difficult because this is a nonrandomized observational study.

Intuitively, those patients who are in poor clinical condition may be better served with a conservative approach. This inference is suggested by a higher incidence of *Pseudomonas* infection and the need for delayed sternal closure at the original operation in the conservative therapy group. Our policy is to consider primary closure as the first option for any patient with mediastinitis. Candidates for conventional therapy include those with extensive tissue destruction in whom sternal closure and soft tissue coverage of bone would be problematic. In addition, patients with significant hemodynamic compromise, who may not tolerate sternal closure or even a minimal risk of ongoing mediastinitis, should be considered for conventional therapy.

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Discussion

Dr Mohan Reddy (*Stanford, Calif*). I congratulate the authors for their painstaking efforts to gather such a large amount of retrospective data spanning over 15 years to shed light on a topic that is often not considered mainstream.

Mediastinitis is a traumatic complication for the patient and family and an annoying one for the surgeon. I agree with the authors that aggressive debridement with primary closure is the technique of choice in children, who often do not have any of the risk factors that are often present in the adult population.

I have three questions for you, Dr Ohye. Did you identify any risk factors predisposing to mediastinitis? I noticed in your article that there is a preponderance of patients with cyanosis or single ventricle lesions.

Second, has leaving the chest open in the operating room or reopening in the intensive care unit been a risk factor for mediastinitis? In our experience, it has not been.

Finally, does prolonged antibiotic treatment in your group predispose to any superimposed fungal infections that had to be treated?

Dr Ohye. Thank you, Dr Reddy, for your comments.

We did not analyze risk factors for mediastinitis. We only looked at those patients who had mediastinitis. There was, as you mentioned, a high incidence of patients with cyanotic lesions and single ventricle lesions, which occurred in approximately 50% of the patients. Whether either of these constitute a risk factor was not determined, because we did not compare this cohort to the overall group who did not have mediastinitis.

All of our patients, as you alluded to, underwent 6 weeks of antibiotic therapy. We did have 1 patient who had a fungal superinfection during that period of treatment. Otherwise, we did not have any other significant complications, other than 1 patient who lost the peripherally inserted central catheter line and completed the final 2 weeks of antibiotics orally.

Dr Carl Backer (*Chicago, Ill*). I congratulate you on your low incidence of mediastinitis, and I also believe that you are on the right track with the early primary closure.

We have reported our results with mediastinitis at Children's Hospital, and we would tend to agree with you, with the exception that we were using vascularized muscle flaps for almost all of the patients.

Depending on the severity of the mediastinitis (and I think there is a little selection bias in your review), I think the introduction of a muscle flap for the patients with a true mediastinitis can be of significant help for the patient, particularly if there is an esophageal injury or a tracheal injury that caused the initial mediastinitis.

I believe that there is going to be another arm to the algorithm that you showed, and our plastic surgeons have been using the vacuum-assisted system in the last year.

We had a dramatic case of a patient with failed Fontan conversion and protein-losing enteropathy who underwent a heart transplant and reoperation for bleeding, and who had an open chest for 6 days. We irrigated the patient's chest, closed the sternum with wire, and then put this vacuum sponge with the vacuum system on. With all those risk factors (immunosuppression, pro-

tein-losing enteropathy, and failed Fontan), this child survived and his sternum healed very nicely. We have since used it in 2 other patients with some success.

What do you think about the vacuum system? Have you used it at all, and do you think that will be another part of our armamentarium in the future?

Dr Ohye. Thank you, Dr Backer.

I am aware of that therapy; it was used in a published study on adults. Do you use an antibiotic-impregnated sponge, as has been previously described?

Dr Backer. No.

Dr Ohye. For those not familiar with this therapy, a sponge is placed in the wound to which high vacuum is applied. The sponge basically distributes the vacuum throughout the wound and pulls the wound closed more quickly.

We have not used this technique. I think it would be an excellent technique; however, obviously there are still advantages to primary closure in that the wound is closed simply and immediately.

I do not believe that there is a huge amount of selection bias. When we compared the severities between the 2 groups (conventional therapy vs primary closure), there was no difference in severity, at least when using our clinical index of severity.

Dr Constantine Mavroudis (*Chicago, Ill*). Did you use bone wax?

Dr Ohye. We generally do not and essentially never in younger children. I do not find it necessary. I will rarely use it in adults and adolescents, only if there is significant, difficult to control sternal-edge bleeding.

Dr Marshall L. Jacobs (*Philadelphia, Pa*). My compliments on a clear presentation. On the basis of a smaller experience, we certainly concur with your preference for primary closure.

My question pertains to the subset of patients with single ventricle anomalies in particular. In some centers, there seems to be a pattern of behavior on the part of the cardiologists that involves catheter techniques to coil embolize "collateral vessels" that often includes the internal thoracic arteries.

Although there are conflicting data as to the efficacy of that from the standpoint of a hemodynamic benefit, it certainly affects the local blood supply to the chest wall.

Was that phenomenon of coil occlusion of internal thoracic arteries apparent at all in your single ventricle population? If that phenomenon were present, would it affect your decision to perform primary closure without bringing omentum or muscle or something else to increase the local blood supply?

Dr Ohye. We did not specifically look to see whether any of the patients had undergone coiling of their internal thoracic arteries. But to answer your question, no, it really would not change my management. The default position would still be to perform a primary closure on those patients.

Dr Christian Brizard (*Melbourne, Australia*). Congratulations on your article. I just would like to remind the audience that this technique of primary closure with a high vacuum level of drainage was presented and published by Ebluquant in 1988, with at that time about 6 years of experience.

Dr Mavroudis. Can you tell us about the findings?

Dr Brizard. It is derived from what the orthopedic surgeons used for the infection of joints. It usually concludes with a short

hospital stay, and the mediastinitis becomes a relatively minor complication.

Dr Mavroudis. Thank you for reminding us of that important article.

Dr Richard A. Jonas (*Boston, Mass*). I thank Dr Ohye and the group in Michigan for putting this together. It takes courage to publish the world's largest series of mediastinitis.

The problem that we often face is that we frequently have infectious disease consultants who read the adult literature and rotating residents from adult services who are familiar with the way that adults are handled, and there can be a lot of resistance to a conservative approach, which certainly has been our approach, so we absolutely concur with your conclusions.

I have a question on a related topic. You might not have any data, but we face the same issue with patients who have positive blood cultures who have had patches or valves or other prosthetic material implanted. It has been my sense that we can safely use short periods of intravenous antibiotics in this situation. However, once again, one faces resistance and skepticism from infectious disease consultants and residents.

Can you tell us your policy in Michigan regarding positive blood cultures when one has bioprosthetic implants?

Dr Ohye. I have exactly the same experience in that there is an automatic urge to give patients 6 weeks of antibiotics for any infection. Even if patients have a superficial wound infection with or without positive blood cultures, they can be sent home with 6 weeks of antibiotics if you do not intervene. For superficial wound infections without positive blood cultures, I do not think it is necessary to give patients 6 weeks of antibiotics.

To specifically answer your question about blood cultures, my personal preference for patients who are clinically doing well with a single positive culture and an autologous or polytetrafluoroethylene patch, in the absence of echocardiogram findings of any suspicious clot or vegetation, is to give them intravenous antibiotics for 2 weeks. I am more conservative with patients who appear toxic or who have multiple positive cultures, vegetations or clots, or prosthetic valves; I would lean toward a 6-week course. These are my opinions, based on clinical experience and not randomized data.

Dr Peter B. Manning (*Cincinnati, Ohio*). I am sure a component of your success that you did not really detail is attention to nutrition in these children.

Although hyperal has been around for 20 years, I think in the last 10 years we have done a better job of maintaining good nutrition in this complex group of kids. I would be curious if you would comment on what your strategy is nutritionally (intravenous vs enteral) and how closely you followed that in this group of kids.

Dr Ohye. Yes, I think that nutrition is important. We did not look at that as a variable for defining which patients had primary closure or conventional therapy or which patients had mediastinitis in the first place. I do echo your feelings about the importance of nutrition.

Our overall policy is that we generally give patients intravenous nutrition soon after their operations, especially those who are unlikely to be enterally fed soon, and then transition as quickly as we can to enteral feeding. Even if it is just trophic feeding, I believe that enteral nutrition is important.

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