

Successful Treatment of Mediastinitis after Cardiovascular Surgery Using Electrolyzed Strong Acid Aqueous Solution

Hideaki Hayashi, Keiji Kumon, Naoki Yahagi, Masaki Haruna, Yasuhiko Watanabe, Junki Matsui, and Reiji Hattori

Surgical Intensive Care Unit, National Cardiovascular Center, Suita, Osaka, Japan

Abstract: Dilute povidone-iodine solution has been widely used as an irrigant for the treatment of mediastinitis. However, its use is not without adverse effects and often causes poor growth of granulation tissues. To avoid the problems seen with the use of povidone-iodine solution, we applied electrolyzed strong acid aqueous solution (ESAAS) to mediastinal irrigation in 4 patients (2 infants and 2 adults) who developed mediastinitis after cardiovascular surgery. According to the "open" method, the mediastinal wound was left open and irrigated with ESAAS 1 to 3 times a day until

the infection was eradicated.

Satisfactory growth of granulation tissues was observed in all patients treated with no evidence effects attributable to ESAAS. Delayed primary sternum closure was performed abdominis for 1. Our experience suggests that irrigation with ESAAS is a safe and effective method of therapy for mediastinitis. **Key Words:** Electrolyzed strong acid aqueous solution—Mediastinitis—Median sternotomy—Povidone-iodine—Cardiovascular surgery—Postoperative complication.

Mediastinal infection is an uncommon but life-threatening complication after median sternotomy. The generally accepted method of therapy for this complication consists of antibiotic therapy and surgical treatment including drainage, debridement, and irrigation. Closure or wound space with musculocutaneous flaps or omentum is also performed as an optional treatment.

Povidone-iodine is an excellent bactericidal and fungicidal agent, and its dilute solution (0.5%) has been widely used to irrigate infected tissues (1). The use of povidone-iodine solution is not, however, free from adverse effects. Growth of granulation tissues is often impeded because povidone-iodine can substantially damage underlying healthy tissues. Thyroid dysfunction (2), electrolyte derangement, metabolic acidosis (3,4), and restrictive pericarditis (5) have also been reported as toxic or adverse effects attributed to the use of povidone-iodine solution.

Electrolyzed strong acid aqueous solution (ESAAS) is produced, by electrolyzing sodium chloride solution. It has unique and strong sterilizing effects, and no significant deleterious effects due to ESAAS have been reported. Herein,

We present the application of ESAAS to mediastinal irrigation for the treatment of mediastinitis. ESAAS aims to overcome the problems seen with the use of povidone-iodine solution.

CASE REPORT

Four patients (2 infants and 2 adults) sustained extensive mediastinitis involving underlying vascular and cardiac structures after cardiovascular surgery and were treated with open mediastinal irrigation using ESAAS. Successful eradication of the infection was achieved in all patients treated, and no evidence of adverse effect attributable to ESAAS was seen. Delayed primary closure of the sternum was performed for 2 patients, and musculocutaneous transposition of rectus abdominis was performed for 1 (Table 1).

Case 1

A 4-month-old girl underwent repair for residual subaortic stenosis 4 months after the surgical correction for coarctation of the aorta, ventricular septal defect, patent ductus arteriosus, subaortic stenosis, and hypoplastic aortic arch. Postbypass hemodynamic instability did not allow closure of the median sternotomy, which was left open with a stent. An increase in the patient's white blood cell count was noticed

Received March 1996.

Address correspondence and reprint requests to Dr. Hideaki Hayashi, Surgical Intensive Care Unit, National Cardiovascular Center, 5-7-1 Fujishirodai Suita, 565 Japan.

TABLE 1. Clinical profile of patients

Patient Data	Case 1	Case 2	Case 3	Case 4
Age	4 months	16 days	79 years	67 years
Sex	Female	Female	Female	Female
Primary diagnosis	CoA, VSD, PDA, Hypoplastic aortic arch, Subarotic AS	ASD, VSD, PDA Interrupted aortic arch, Subarotic AS	TAA	MS, MR, Atrial fibrillation
Operation	Repair of residual AS	Surgical repair	Total arch replacement	MVP, Maze operation
Postoperative days to mediastinitis	5 days	12 days	60 days	30 days
Organism cultured	<i>S. epidermidis</i>	<i>P. aeruginosa</i>	<i>S. caitis</i>	<i>S. aureus</i>
Antibiotics	Cefotiam, Minomycin	Cefsulodin, Amikacin	Cefsulodin, Amikacin	Piperacillin Amikacin
Duration of irrigation	9 days	16 days	42 days	19 days
Associated procedure	Delayed primary closure	Delayed primary closure		musculocutaneous flap

CoA, coarctation of aorta; VSD, ventricular septal defect; PDA, patent ductus arteriosus; AS, aortic stenosis; ASD, atrial septal defect; TAA, thoracic aortic aneurysm; MS, mitral stenosis; MR, mitral regurgitation; MVP, mitral valve plasty.

postoperatively, and bacterial culture was taken from the pericardial hematoma and effusion and the peritoneal dialysate on the 5th postoperative day (POD). Diagnosis of mediastinal infection by *Staphylococcus epidermidis* was made, and mediastinal irrigation using ESAAS was started on the 8th POD. Systemic administration of cefotiam combined with minomycin was also initiated on the basis of the result of the bacterial sensitivity test. The wound irrigation was continued once a day until the 16th POD when negative culture was confirmed. The patient's condition gradually improved, and the sternum was primarily closed on the 26th POD. She required prolonged mechanical ventilatory support after the sternum closure. However she was successfully weaned from mechanical ventilation and was discharged from the intensive care unit (ICU) on the 109th POD.

Case 2

A 16-day-old girl underwent surgical repair for interrupted aortic arch, atrial septal defect, ventricular septal defect, patent ductus arteriosus, and subaortic stenosis. Because of postbypass hemodynamic instability, the patient was admitted to the ICU with the sternum left open using a stent. The patient's hemodynamic condition gradually improved, and the sternum was closed on the 4th POD. After this procedure, the patient's white blood cell count began to increase and exceeded 20,000 mm³ on the 11th POD. On the 12th POD, hemorrhage and suppurative discharge from the sternotomy wound developed. The skin incision was opened for exploration, which indicated the presence of infection involving the deeper mediastinal structures, and reopening of the sternotomy was performed. *Pseudomonas aeruginosa* was cultured from the wound drainage, mediastinal tissues, arterial blood, and urine. Diagnosis of mediastinitis complicated by sepsis was made, and the patient was started on cefsulodin and amikacin. The mediastinal wound was irrigated twice a day using ESAAS. On the 4th day after starting the irrigation (16th POD), the wound culture was negative. Blood culture turned negative on the 27th POD. The irrigation was continued until the sternum was primarily closed on the 28th POD. The patient was discharged from the ICU on the 53rd POD.

Case 3

A 79-year-old woman underwent total aortic arch replacement for thoracic aortic aneurysm. Postoperatively, she was dependent on mechanical ventilatory support because of respiratory failure. In the process of weaning her from mechanical ventilation, dehiscence of the sternotomy wound developed, and reclosure of the sternum was performed on the 34th POD. However, she sustained circulatory failure due to cardiac tamponade 5 days after the sternum closure, and an emergency open drainage was performed. Bleeding from the divided sternal edges was revealed. Because the sternum could not be primarily closed, only the skin incision was closed. Her condition remained poor, and she suffered renal and hepatic failure and coagulopathy in addition to cardiac and respiratory failure. Three weeks after the drainage, dehiscence of the sternal skin incision was noticed, and an abscess involving the deeper mediastinal space was revealed. *Staphylococcus caitis* was cultured from the purulent discharge. Mediastinal irrigation with ESAAS twice a day and systemic antibiotic therapy by a combination of cefotiam and amikacin were commenced. Ten days after starting the irrigation, the wound culture turned negative, and the patient's condition gradually began to improve. She overcame multiple organ failure and was discharged from the ICU on the 125th day after the initial operation.

Case 4

A 67-year-old woman having mitral stenosis and regurgitation with atrial fibrillation underwent mitral valve plasty and Maze operation. She developed cardiac tamponade on the first POD and received open drainage. After the event, her postoperative course was uneventful, and she was transferred to a ward on the ninth POD. She convalesced well in the ward until the 30th POD, when dehiscence of the median sternotomy incision and supportive discharge developed. Wound culture revealed infection by methicillin-sensitive *Staphylococcus aureus*. The median sternotomy was reopened, and wound irrigation was started using ESAAS along with the systemic administration of piperacillin and amikacin. After the irrigation was begun, the supportive

wound condition began to improve, and growth of clean granulation tissues was observed. The irrigation was continued 3 times daily until the mediastinal space was closed with a rectus abdominis musculocutaneous flap on the 19th day after starting the irrigation. The patient took an uneventful course after the mediastinal reconstruction and was discharged from the ICU on the 19th day after the procedure.

DISCUSSION

Mediastinitis is a devastating wound complication after median sternotomy. Its incidence has been reported to be 0.4-5% after cardiac surgery, and the mortality after this complication remains more than 10% (6,7)

Superficial sternal wound infections can be treated by systemic antibiotic therapy. For deep mediastinal infection, or mediastinitis, surgical treatment including reopening of median sternotomy, debridement, and irrigation is required. Two approaches to the surgical management of mediastinitis have been widely used.

In the open method, the mediastinal wound is left open and packed with dressing material. Wound irrigation and dressing changes are continued until the infection is eradicated, and a delayed primary closure is performed (8). Reconstruction using musculocutaneous flaps or omentum is also attempted to close the mediastinal space as an option of secondary closure (4,9-12). The advantage of this technique includes the elimination of a potentially undrained space and active debridement by irrigation and dressing changes during convalescence. However, the loss of sternal apposition requires prolonged mechanical ventilation. Hemorrhage from exposed mediastinal vessels is a potentially disastrous complication.

In the closed method, open sternotomy is reclosed over catheters following debridement and intraoperative irrigation. Postoperatively, the mediastinum is continuously irrigated using the catheter system (1). Dressing changes are not required in this technique. However, closing the sternum wound may create a potentially undrained cavity. The mediastinal catheters may erode adjacent tissues, leading to life-threatening hemorrhage.

More recently, single-stage closure with musculocutaneous flap reconstruction has been reported (13). This simplified approach eliminates open wound care and postoperative irrigation by combining debridement and bilateral pectoralis major musculocutaneous flap reconstruction in a single operation.

Our series of patients had extensive mediastinitis involving underlying vascular and cardiac structures. Although the last method appears to be the treatment of choice for mediastinal infection, our experience has not indicated that the technique is generally effective in any form of mediastinitis. Considering the extent of the infection, we chose the open method for our patients.

Several irrigants have been used for wound irrigation. These include antibiotic solutions and dilute povidone-iodine

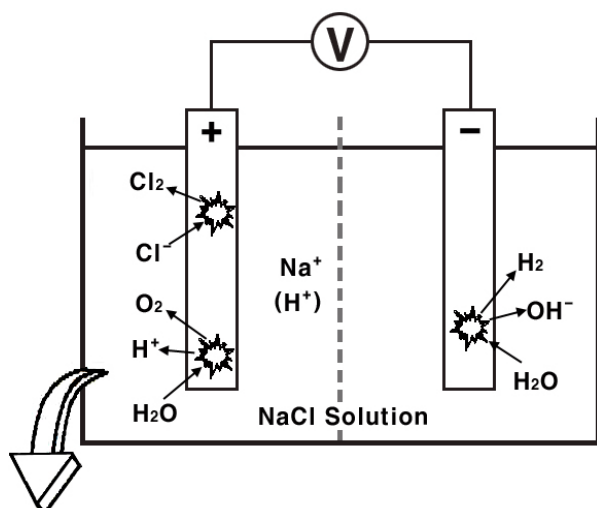
solution. The use of these irrigants, however, is not without adverse effects. Antibiotic solution may induce systemic toxicity and predispose one to fungal superinfection. Povidone-iodine is effective against both bacteria and fungi, and its dilute solution (0.5%) has been widely used to irrigate infected tissues. However, the growth of granulation tissues is often impeded by povidone-iodine solution because it can substantially impair underlying healthy tissues as well. Thyroid dysfunction (2), electrolyte derangement, metabolic acidosis (3,4), and restrictive pericarditis (5) have also been reported as toxic or adverse effects related to the use of povidone-iodine solution.

We applied ESAAS to wound irrigation to overcome the limitations of the conventional irrigants. ESAAS is produced, by electrolyzing the sodium chloride solution using an ion-exchange membrane that separates the positive and negative electrodes. A small amount of sodium chloride is added to the water to facilitate electrolysis and increase the concentration of dissolved chloride (Fig. 1). ESAAS has a strong sterilizing effect against both bacteria and fungi, which is comparable with povidone-iodine solution. There have been no reports on adverse effect in association with the use of ESAAS.

The precise sterilizing mechanism of ESAAS remains to be clarified. It has unique physicochemical properties including high positive oxidation-reduction potential (OPR > 1,100 mV), strong acidity (pH < 2.7), and high concentrations of dissolved chloride (> 30 ppm) and oxygen (> 20 ppm). Because bacteria can only live in a pH environment between 2 and 12 and an ORP between -400 and +840mV, ESAAS is thought to exhibit its bactericidal effect, in part, by providing the condition that does not allow bacteria to survive. However, the presence of dissolved chloride is essential for the solution to maximize its antibacterial effect. Therefore, dissolved chloride and its derived radical substances are thought to contribute to the bactericidal reaction as well.

ESAAS has several favorable features. First, the bactericidal effect of ESAAS is not confined to a specific group of bacteria but covers a wide spectrum of microorganisms, including fungi. Second, ESAAS can be applied to almost all kinds of tissues except to the respiratory tract. Third, ESAAS does not appear to impede the healing process but might facilitate growth of granulation. Fourth, the solution is promptly inactivated on reaction with organic substances (plasma, tissue proteins, etc.) and changes to weak acid solution leaving no residual toxicity. Of note, ESAAS does not provide a long-lasting antibacterial effect after irrigation. Therefore, infected tissues should be irrigated with a sufficient amount of solution to obtain the satisfactory effect. We used 100-200ml of ESAAS for infants and 1,000-1,500ml for adults. We also packed the mediastinal wound with iodoform dressings to compensate for the short-lasting effect of ESAAS and to maintain sterilization of the wound.

Our experience suggests that the antibacterial effect of ESAAS is no less than that of povidone-iodine solution for



Electrolyzed Strong Acid Aqueous Solution

FIG. 1. Production of ESAAS is shown. ESAAS is produced, by electrolyzing sodium chloride (NaCl) solution utilizing an ion-exchange membrane that separates the positive and negative electrodes, NaCl is added to the water to facilitate electrolysis and increase the concentration of dissolved chloride. ESAAS is obtained from the positive electrode compartment.

the treatment of mediastinal infection with the added advantage that no adverse effects were seen with the use of ESAAS. In contrast with irrigation with povidone-iodine solution, the satisfactory growth of healthy granulation tissues was observed during convalescence in all patients treated. Our experience, however, does not necessarily indicate that ESAAS can replace antibiotic or povidone-iodine solutions in all clinical situations. Additional clinical data are necessary to establish guidelines for the appropriate application of ESAAS to the treatment of infected wounds.

CONCLUSIONS

We applied ESAAS to mediastinal irrigation in 4 patients who developed extensive mediastinitis after cardiovascular surgery. The infection was successfully eradicated in all patients with no evidence of adverse effects related to the use of ESAAS. Most impressively, satisfactory growth of healthy granulation tissues was seen after starting irrigation with ESAAS. Our clinical experience suggests that irrigation with ESAAS is a safe and effective treatment of choice for mediastinal infection and can avoid problems seen with the use of povidone-iodine solution.

REFERENCES

1. Thurer RJ, Bognolo D, Vargas A, Isch JH, Kaiser GA. The management of mediastinal infection following cardiac surgery. An experience utilizing continuous irrigation with povidone-iodine. *A Thorac Cardiovasc Surg* 1974;68:962-8.
2. Bryant WP, Zimmerman D. Iodine-induced hyperthyroidism in a newborn. *Pediatrics* 1995;95:434-6
3. Glick PL, Guglielmo BJ, Tranbaugh RF, Turley K. Iodine toxicity in a patient treated by continuous povidone-iodine mediastinal irrigation. *Ann Thorac Surg* 1985;39:478-80
4. Stiegel RM, Beasley ME, Sink JD, Hester TR, Guyton RA, Perrella AM, Williams WH. Management of postoperative mediastinitis in infants and children by muscle flap rotation. *Ann Thorac Surg* 1988;46:45-6
5. Kratz, JM, Metecalf JS, Sade RM. Pericardial injury by antibacterial irrigants. *J Thorac Cardiovasc Surg* 1983;86:785-7
6. Demmy TL, Park SB, Liebler GA, Burkholder JA, Maher TD, Benckart DH, Magovern GJ Jr. Magovern GJ Sr. Recent experience with major sternal wound complications. *Ann Thorac Surg* 1990;49:458-62
7. Sart MG, Gott VL, Townsend TR. Mediastinal infection after cardiac surgery. *Ann Thorac Surg* 1984;38:415-23
8. Johnson JA, Gall WE, Gunderson AE, Cogbill TH. Delayed primary closure after sternal wound infection. *Ann Thorac Surg* 1989;47:270-3
9. Cheung EH, Craver JM, Jones EL, Murphy DA, Hatcher CR Jr, Guyton RA. Mediastinitis after cardiac valve operations; Impact upon survival. *J Thorac Cardiovasc Surg* 1985;90:517-22
10. Pairolo PC, Arnold PG, Danielson GK. Management of recalcitrant median sternotomy wounds. *J Thorac Cardiovasc Surg* 1984;88:357-64
11. Scully HE, Leclere Y, Martin RD, Tong CP, Goldman BS, Weisel RD, Mickleborough LL, Baird RJ. Comparison between antibiotic irrigation and mobilization of pectoral muscle flaps in treatment of deep sternal infections. *J Thorac Cardiovasc Surg* 1985;90:523-31
12. Seguin JR, Loisanse DY. Omental transposition for closure of median sternotomy following severe mediastinal and vascular infection. *Chest* 1985;88:684-6
13. Jeevunandam V, Smith CR, Rose EA, Malm JR, Hugo NE. Single-stage management of sternal wound infections. *J Thorac Cardiovasc Surg* 1990;99:256-63