A novel wall water system for cardiopulmonary bypass may reduce the risk of aerosolized infection

Gregory S. Matte, CCP, LP, FPP,^a Thomas J. Sandora, MD, MPH,^b Robert J. Howe, CCP, LP, FPP,^a William L. Regan, CCP, LP,^a Gail Potter-Bynoe, BS, CIC, FAPIC,^c James R. Neal, BS, CCP,^d and Pedro J. del Nido, MD^e

ABSTRACT

Objective: Oxygenators for cardiopulmonary bypass require water flow for their integral heat exchanger. Heater-cooler units are nearly universally used for this requirement. Heater-cooler units pose the risk of aerosolized infection. The Centers for Disease Control and Prevention recommended discontinuing use of Stöckert 3T heater-cooler units (LivaNova PLC, London, United Kingdom) in October 2016 because of this risk. We aimed to reduce the risk of aerosolized infection posed by heater-cooler units by eliminating those devices from our operating rooms.

Methods: The cardiac surgery division collaborated with in-house specialties to engineer a novel wall water system. The design called for service to 4 operating rooms with the actual water mixing valve in an operating room closet. Remote temperature control was mounted next to the heart-lung machine. Primary safety systems built into the water system include 5 μ m filtration, pressure regulating and relief valves, flow quantifiers, limits to the hot and chilled input temperatures, and a novel bridge near the heart-lung machine that allows the perfusionist to test the system before patient use and to quickly disconnect the patient in case of system malfunction. In addition, all water line connections can be made with the tubing drained and never under pressure.

Results: This novel wall water system has successfully provided heat exchanger water flow on 625 patients undergoing congenital heart surgery requiring cardiopulmonary bypass during its first 9 months of use.

Conclusions: Wall water systems are an option for oxygenator heat exchangers that allow for improved heat exchange performance while reducing the risk of heater-cooler unit-associated infection during cardiac surgery. (*J Thorac Cardiovasc Surg* 2018;156:318-24)

Wall water hardware that provides water flow to the oxygenator heat exchanger.

Central Message

Wall water is an option for oxygenator heat exchangers that allows for improved heat exchange performance while reducing the risk of heater-cooler-associated infection during cardiac surgery.

Perspective

Oxygenators for cardiopulmonary bypass require water flow for their integral heat exchanger. HCU are universally used for this requirement but have been associated with infections and deaths. We report a custom-engineered wall water system that reduces known risks by removing HCU from the OR and providing water flow with a novel system.

See Editorial Commentary page 325.

From the ^aDepartment of Cardiac Surgery, ^bDivision of Infectious Diseases, and ^cInfection Prevention and Control, Boston Children's Hospital, Boston, Mass; ^dDepartment of Cardiac Surgery, Mayo Clinic, Rochester, Minn; and ^eDepartment of Cardiac Surgery, Boston Children's Hospital, Harvard Medical School, Boston, Mass.

All funding was provided internally.

Received for publication Aug 23, 2017; revisions received Jan 23, 2018; accepted for publication Feb 9, 2018; available ahead of print March 31, 2018.

Address for reprints: Gregory S. Matte, CCP, LP, FPP, Department of Cardiac Surgery, Boston Children's Hospital, 300 Longwood Ave, Boston, MA 02115 (E-mail: gregory.matte@cardio.chboston.org).

0022-5223/\$36.00

Copyright © 2018 by The American Association for Thoracic Surgery

<https://doi.org/10.1016/j.jtcvs.2018.02.077>

Oxygenators for cardiopulmonary bypass require water flow for the integral heat exchanger. In the earlier years of cardiac surgery, wall water systems were used to provide the water flow for this purpose. These systems were referred to as “wall water” because the perfusionist typically

Scanning this QR code will take you to a supplemental video for the article.

Abbreviations and Acronyms

HCU	= heater-cooler unit
HLM	= heart-lung machine
LPM	= liter per minute
OR	= operating room
PSI	= pounds per square inch

hooked up water lines to high-pressure wall outlets. These dedicated hot and chilled water supplies were then sent through a mixing valve in or near the heart-lung machine (HLM). Eventually, the advancement of low-pressure, stand-alone HCU technology effectively retired more expensive wall water systems that required significant infrastructure and high-pressure water connections in the operating room (OR), and suffered from fewer temperature regulation safeguards. The majority of cardiac surgery centers moved away from wall water by the 1990s, with the last centers doing so in 2010. Now, heater-cooler units (HCUs) nearly universally provide the heat exchanger water flow. HCUs actively cool and heat a reservoir of recirculating water to effect patient temperature change during cardiopulmonary bypass. The transition to HCUs from wall water did not come without patient risk.^{1,2} This risk has received increasing attention in recent years after unusual infections, some with lethal outcomes, were associated with cardiac surgery at centers around the world.²⁻⁶ Bacteria including *Legionella*, *Pseudomonas* and *nontuberculous mycobacteria* may be present in hospital water sources, and these sources are commonly used to fill HCU reservoirs.^{2,3,6-14} Infections from these and other bacteria in cardiac and noncardiac surgical patients have been described.^{2,4,6-14} Although the HCU water never comes in contact with the patient, contaminated water can aerosolize in the device and contaminate surfaces within the device's cooling fan air flow. This can lead to aerosolized bacteria in the OR, which can then enter the surgical wound directly or via an implanted item retrieved from the sterile instrument table.

In 2015, an international outbreak of *Mycobacterium chimaera* infections among patients undergoing cardiac surgery was identified.^{10,12,15-17} By 2016, data from investigations of these cases had revealed a point-source outbreak related to intrinsic contamination of Stöckert 3T HCUs (LivaNova PLC, London, United Kingdom) during manufacture.¹⁸ Additional data suggested the mode of acquisition of the patients' infections was likely aerosolization of contaminated HCU water by the cooling fan, with subsequent direct inoculation of exposed tissues in the OR.^{12,19} The *M chimaera* infections linked to the Stöckert 3T HCUs were associated with significant morbidity and mortality^{3-5,7,14,15} and have typically been identified late after exposure.^{10,15,20} Maquet Cardiovascular (Wayne, NJ)

HCUs and Sarns (Terumo Cardiovascular, Ann Arbor, Mich) TCM II HCUS have also been associated with *M. chimaera* in their water tanks.^{17,21} CardioQuip (Bryan, Tex) HCUs have been reported to be contaminated with *Legionella*.²² We aimed to rapidly reduce the risk of aerosolized infection, potentially posed by all cardiopulmonary bypass HCUs, by eliminating those devices from the OR. We collaboratively engineered a novel wall water system that importantly did not require cooling fans in the OR to serve our heat exchanger needs during cardiac surgery.

MATERIAL AND METHODS

The wall water system for cardiac surgery consists of dedicated hot and chilled water supplies that are copper-piped into each OR. There, the water is directed to a mixing valve before flowing to the oxygenator heat exchanger. Our institution had a wall water system that had not been used in 6 years. The dedicated hot and chilled water supplies reside on a mechanical floor above the OR. Piping of this system to 3 of 4 ORs was still intact. Those parts of the system did not change when we undertook the effort to reinstitute wall water in October 2016. Before that time, we were using 5 portable Stöckert 3T HCUs for heat exchange during cardiopulmonary bypass.

The major changes required to implement our novel system included piping the hot and chilled water sources to a fourth cardiac OR, reengineering the mixing valve system in the OR, and adding a remote control system because the mixing valve itself had been moved into an OR closet away from the HLM. A medical grade mixing valve was not available to integrate into the former system. Therefore, we leveraged technology from other industries that require precise water temperature control, namely, the pharmaceutical and beverage industries. In-house divisions for cardiac surgery, infection prevention and control, plumbing, construction, and electrical services were engaged to collaboratively reengineer and install the new system.

The reengineered system sends 43°C hot water to the OR floor of the hospital at 120 pounds per square inch (PSI), which is regulated down to 50 to 60 PSI en route. Hot water is created with a steam-powered coil (Patterson-Kelley Corp, East Stroudsburg, Pa) that includes a backup device. Chilled water is sent at 14°C and is also downregulated to 50 to 60 PSI. The chilled water is created with a model PC-1500S-180ARL industrial chiller unit (Filtrine Manufacturing Company, Keene, NH) that also has redundancy. Both water supplies are separately filtered to 5 μ m with paired Aqua-Pure AP110-2 water filters (3M Purification, Inc, Meriden, Conn) before entering the OR mixing valve closet at approximately 45 to 50 PSI. Filtration to 5 μ m was added as a precaution to prevent small particles from possibly affecting the operation of the mixing valve. The hot and chilled water supplies are further regulated in the mixing valve closet down to 7 to 12 PSI before meeting at the water mixing valve assembly. This assembly is located in the mixing valve closet that was designed out of Corian (Dupont, Inc, Waltham, Mass) and includes a see-through LEXAN door (SABIC Innovative Plastics, Pittsfield, Mass) that allows for parameter monitoring during surgery, as shown in Figure 1. The mixing valve assembly includes an Emech G1 digital actuator and a 3-port F3 mixing valve (Armstrong International, Three Rivers, Mich), both distributed by the RL Stone Company of Penfield, New York. We found this mixing system to be ideal for our application because of its accuracy and independence from fluctuations in input temperature and pressure. Water in the mixing valve closet is regulated down to a delivery pressure of 5 to 10 PSI and flow rate of 9 to 12 liters per minute (LPM) before running through the oxygenator heat exchanger. Pressure regulation and its position in the mixing valve closet importantly limit the noise impact in the OR. We found the sound measured with this wall water system comparable to HCUs at less than 60 decibels. Water is sent to drain after passing through the

FIGURE 1. Mixing valve closet with see-through door in open position.

oxygenator heat exchanger. Remote temperature management for this system consists of a model CM10 electronic controller (ABB Customer World, Zurich, Switzerland), which is installed next to the HLM as depicted in Figure 2.

Primary safety systems built into the wall water system include 5- μ m water filtration, pressure-regulating and relief valves (maximum oxygenator system pressure is limited with a pop-off set at 20 PSI), flow quantifiers, limits to the hot and chilled input temperatures, and an actuator that stops mixing valve water flow if chilled or hot water flow ceases, thus preventing a wide swing in heat exchanger temperature. The HLM remains an important temperature monitoring component with alarm limits for high and low measured blood temperature. Moreover, a significant safety component in the system is the custom water flow bridge near the HLM. The bridge allows the perfusionist to test the system before patient use and to quickly disconnect the patient in case of system malfunction. The water flow bridge consists of a hard-piped H-bridge interposed between flexible water tubing from the floor box and the oxygenator heat exchanger connections as shown in Figure 3. This unique bridge allows the water system to run without connection to the oxygenator so that flow, pressure, and temperature can be verified before patient use. Additionally, the bridge allows the water lines to be depressurized and drained before disconnection at the end of a cardiopulmonary bypass case. This reduces the risk of aerosolized bacteria in the OR from potentially

FIGURE 2. Remote temperature control for wall water system.

contaminated water, which has also been associated with high pressure wall water connections.^{3,13} The use of this novel bridge is an important safety element in our reengineered wall water system.

RESULTS

We immediately ceased use of the Stöckert 3T HCUs in October 2016 after the Centers for Disease Control and Prevention announced the recommendation to stop using those intrinsically contaminated devices. Of note, many families inquired about this specific risk of infection once it was announced in the public domain. Those families were counseled that we had immediately removed the Stöckert 3T HCUs from service when the Centers for Disease Control and Prevention announcement was made and that we implemented the use of alternate HCUs as we engineered a new system. Our wall water system was restored and reengineered over a 6-week period. The wall water system (Figure 4) includes a novel wall water mixing valve closet designed to house the essential end-user elements (Figure 5). We sequentially brought the wall water system

FIGURE 3. Water flow bridge for water circuit testing and emergency disconnect (turn off supply).

FIGURE 4. Wall water system schematic.

online in 4 cardiac ORs (1 OR every 7-10 days as we verified system function and capacity). When the new system was fully implemented, we removed the alternate HCUs from the ORs and 2 of those units became our backup devices in case of wall water system failure. Our novel wall water system has provided oxygenator heat-exchanger water flow for 625 patients undergoing congenital heart surgery during its first 9 months of use. There have been no system failures requiring emergency disconnect from the system or a changeover to backup devices. Although we do not have historical data to compare the heat exchange efficiency of the wall water system against the Stöckert 3T HCUs the system replaced, it is clear that heat exchange efficiency has increased. The system provides the desired

water temperature nearly instantaneously, whereas HCUs require active cooling or heating of a recirculating volume of water over the course of several minutes to effect patient temperature change. [Table 1](#) reviews the advantages and disadvantages of our novel wall water system. [Video 1](#) walks the clinician through the process of turning on the wall water system and implementing a temperature change.

DISCUSSION

The first use of wall water for cardiac surgery was described in 1957²³ and evolved over the ensuing decade, but such systems increasingly fell out of favor from the 1970s to 1990s as companies developed effective stand-alone HCUs.²⁴ This progression to HCUs eventually removed business incentive to maintain wall water system products. In the modern era, the lack of available medical grade wall water mixing valves and control systems requires innovation and teamwork to develop a safe and effective solution. We have demonstrated that it is possible to engineer a method of heat exchange for cardiopulmonary bypass that does not rely on portable HCUs, that does not introduce robust cooling fans to the OR, and that effectively isolates the required water from the OR because the water flows into and out of the OR through tubing. We have also shown that such a system can be constructed by in-house divisions for plumbing, electrical, and engineering services. Although we estimate that a new wall water system covering 4 ORs would cost an institution at least \$1 million in upfront expenses and \$30,000 annually for the water supply, this expense must be

FIGURE 5. Location of wall water system in the cardiac OR relative to the HLM.

TABLE 1. Advantages and disadvantages of our wall water system

Advantages	Disadvantages
Reduces risk of aerosolized infection by eliminating HCUs from OR	Substantial upfront capital expense
High-pressure water connections are located in an OR closet to prevent possible water leaks from affecting the OR environment	Potential for difficult implementation of the system within existing OR facilities
Maximized heat exchange performance	Requires water input temperatures outside of normal operating range for patient management in for the mixing valve to work
Mitigation of system noise because of location of water mixing in closet	Increased annual water expense for hospital
System test and emergency mitigation bridge allow immediate access to the supply valve in case of system malfunction	Water is not currently recycled (new building will include drainage to a gray water system)
Significantly reduced clinician hours required for maintenance (backup units only require monthly disinfection)	System obligates users to maintain backup HCUs

HCU, Heater-cooler unit; OR, operating room.

VIDEO 1. The video walks the clinician through the process of turning on the wall water system and implementing a temperature change on the remote controller. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(18\)30618-4/fulltext](http://www.jtcvsonline.org/article/S0022-5223(18)30618-4/fulltext).

weighed against the cost of multiple HCUs, including backup units, daily perfusionist labor and time commitments for maintenance, the cost of third-party service contracts, and the risk of infection associated with models currently on the market that, when contaminated, store that water in the OR next to cooling fans where it can be aerosolized.

Oxygenator manufacturers commonly specify heat-exchanger water to be provided at 8 to 15 LPM and a pressure not to exceed 28 PSI.^{19,25,26} Our wall water system normally operates at 9 to 12 LPM with a system pressure of 5 to 10 PSI. An increasing number of cardiac surgery centers are moving their HCU devices outside of their OR^{27,28} or devising exhaust capturing solutions to mitigate risk.²⁹ These solutions minimize the risk of infection in the OR, but with current HCU design, they come at the expense of decreased heat exchange performance due to longer water line connections. Longer water lines increase system resistance and decrease water flow rate, negatively affecting efficiency.^{24,26} In fact, HCU manufacturers specify the maximum water line length to ensure efficient cooling and heating with their device.³⁰ In contrast, heat exchange performance with a wall water system actually increases because the system relies on mixing dedicated hot and chilled water sources and not actively heating or cooling a volume of recirculating water. Moreover, water line lengths with wall water systems do not affect performance because increased water line lengths can be compensated for with a larger gradient at the mixing valve resulting in the desired water temperature being delivered to the oxygenator heat-exchanger. These qualifications are important considerations for cardiac surgery programs using hypothermia during cardiopulmonary bypass, particularly congenital cardiac surgery programs.

Although the source of contamination of Stöckert 3T HCUs was intrinsic during manufacture, all currently

available HCUs can harbor contaminated water that could then be aerosolized, posing the risk of infection to patients in the OR.^{2,6,10,20-22,31} Numerous studies have reported the unique infection risk that HCUs pose for patients undergoing cardiac surgery.^{2,6,8,10,12,14,31} Disinfection procedures for currently available HCUs are likely inadequate to eliminate the risk of infection because not all internal surfaces of the HCU are in contact with the disinfectants during the disinfection cycle and those that are may not be adequately disinfected to the formation of biofilm.^{2,6,19,32,33} Furthermore, the manpower to perform time-consuming daily maintenance for HCUs can be burdensome and disruptive to perfusion practice. These concerns were motivators in our decision to reengineer a wall water system.

We continue to maintain 2 Hemotherm CE HCUs (Cincinnati Sub-Zero, Cincinnati, Ohio) as backup devices for 2 ORs in case of wall water system failure. These devices require monthly maintenance per manufacturer recommendations. In addition, we have water lines prepared that would allow for heat exchanger water flow to be obtained from the in-room patient blanket devices for 2 additional ORs. These Blanketrol III temperature management devices (Cincinnati Sub-Zero) are not designed for CPB heat exchanger water flow, but we have found them to be adequate backup units after having tested them clinically when we ceased use of the Stöckert 3T HCUs.

An additional consideration for wall water systems is whether to recycle the water after use and if so, how. We were not comfortable designing a recirculating water system that recycled the cardiac OR wall water because infections have been linked to such a system, albeit likely from aerosolization in the OR due to the presence of high pressure water line connection/disconnection.¹³ Although the current system sends water to drain, we are planning to send the used water to a gray water tank in our upcoming facilities expansion as a way to safely reuse the water for hospital operations, including toilet flushing.

CONCLUSIONS

We have demonstrated that it is possible to design and implement a novel solution to provide heat exchange during cardiopulmonary bypass. Our wall water system actually provides enhanced heat exchange performance because the system simply mixes hot and chilled water instead of heating or cooling a reservoir of water. Institutions that opt to introduce wall water systems must engineer their own system because no commercially available options currently exist. We believe that wall water systems are a compelling option for patients undergoing cardiac surgery because such systems clearly reduce the risk of HCU-associated infection and intuitively may even eliminate the risk.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

The authors thank Paul Williams, Tim Byrne, Tim Kelly, Paul Colonelli, and the Engineering Team for their efforts to make this project a success so quickly.

References

- Weitekemper HH, Spilker A, Knobl HJ, Korfer R. The heater-cooler unit: a conceivable source of infection. *J Extra Corpor Technol*. 2002;34:276-80.
- Toigo J, Giraud S. What's growing in your cooler/heater? Cleaning and sanitization for temperature control systems. *Perfusion Life*. 1993;10:8-9.
- Centers for Disease Control and Prevention. CDC advises hospitals to alert patients at risk from contaminated heater-cooler devices used during cardiac surgery. *CDC Health Alert Network*. October 13, 2016. Available at: <https://www.cdc.gov/media/releases/2016/p1013-contaminated-devices-.html>. Accessed October 31, 2016.
- Aleccia J. Contaminated devices may put heart-surgery patients at risk. *The Seattle Times*. October 13, 2016. Available at: <https://www.seattletimes.com/seattle-news/contaminated-devices-may-put-heart-surgery-patients-at-risk/>. Accessed October 31, 2016.
- Interlandi J. The frightening new risk in heart surgery. *Consumer Reports*. October 13, 2016. Available at: <https://www.consumerreports.org/doctors-hospitals/frightening-new-risk-in-heart-surgery/>. Accessed October 31, 2016.
- Schreiber PW, Kuster SP, Hasse B, Bayard C, Rüegg C, Kohler P, et al. Reemergence of mycobacterium chimaera in heater-cooler units despite intensified cleaning and disinfection protocol. *Emerg Infect Dis*. 2016;22:1830-3.
- Brown-Elliott BA, Wallace RJ Jr, Tichindean C, Sarria JC, McNulty S, Vasireddy R, et al. Five-year outbreak of community- and hospital-acquired *Mycobacterium porcinum* infections related to public water supplies. *J Clin Microbiol*. 2011;49:4231-8.
- Wang SH, Pancholi P, Stevenson K, Yakus MA, Butler WR, Schlesinger LS, et al. Pseudo-outbreak of "Mycobacterium paraffinicum" infection and/or colonization in a tertiary care medical center. *Infect Control Hosp Epidemiol*. 2009;30:848-53.
- Wallace RJ Jr, Brown BA, Griffith DE. Nosocomial outbreaks/pseudo-outbreaks caused by nontuberculous mycobacteria. *Annu Rev Microbiol*. 1998;52:453-90.
- Sax H, Bloemberg G, Hasse B, Sommerstein R, Kohler P, Achermann Y, et al. Prolonged outbreak of *Mycobacterium chimaera* infection after open-chest heart surgery. *Clin Infect Dis*. 2015;61:67-75.
- Astagneau P, Desplaces N, Vincent V, Chicheportiche V, Botherel A, Maugat S, et al. *Mycobacterium xenopi* spinal infections after discoveterebral surgery: investigation and screening of a large outbreak. *Lancet*. 2001;358:747-51.
- Perkins KM, Laws A, Hasan NA. Notes from the field: *Mycobacterium chimaera* contamination of heater-cooler devices used in cardiac surgery - United States. *Morb Mortal Wkly Rep*. 2016;65:1117-8.
- Nagpal A, Wentink JE, Berbari EF, Aronhalt KC, Wright AJ, Krageschmidt DA, et al. A cluster of *Mycobacterium wolinskyi* surgical site infections at an academic medical center. *Infect Control Hosp Epidemiol*. 2014;35:1169-75.
- Achermann Y, Rossle M, Hoffmann M, Degging V, Kuster S, Zimmermann DR, et al. Prosthetic valve endocarditis and bloodstream infection due to *Mycobacterium chimaera*. *J Clin Microbiol*. 2013;51:1769-73.
- Kohler P, Kuster SP, Bloemberg G, Schulthess B, Frank M, Tanner FC, et al. Healthcare-associated prosthetic heart valve, aortic vascular graft, and disseminated *Mycobacterium chimaera* infections subsequent to open heart surgery. *Eur Heart J*. 2015;36:2745-53.
- Svensson E, Jensen ET, Rasmussen EM, Folkvardsen DB, Norman A, Lillebaek T. *Mycobacterium chimaera* in heater-cooler units in Denmark related to isolates from the United States and United Kingdom. *Emerg Infect Dis*. 2017;23:507-9.
- Public Health England. Infections associated with heater cooler units used in cardiopulmonary bypass and ECMO: information for healthcare providers in England. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/605639/Infections_Associated_with_Heater_Cooler_Units_Used_in_Cardiopulmonary_Bypass_and_ECMO.pdf. Accessed May 17, 2017.
- Haller S, Höller C, Jacobshagen A, Hamouda O, Abu Sin M, Monnet DL, et al. Contamination during production of heater-cooler units by *Mycobacterium chimaera* potential cause for invasive cardiovascular infections: results of an

- outbreak investigation in Germany, April 2015 to February 2016. *Euro Surveill.* 2016;21:30215.
19. Hoffman PN, Parks S, Alveranga M, Fricker P, Lilley A, Heggie A. Cardiac bypass heater-coolers and mycobacteria: a problem well stated is a problem half-solved. *J Hosp Infect.* 2016;93:221-2.
 20. The Society of Thoracic Surgeons. STS Meeting Bulletin: "New Information Revealed on Infections Related to Heater-Cooler Devices." Available at: https://www.sts.org/sites/default/files/documents/53AM_MeetingBulletinMon.pdf. Accessed November 29, 2017.
 21. U.S. Food & Drug Administration. MAUDE adverse event report: terumo cardiovascular systems corp. sarns TCM II heating and cooling system controller, temperature, cardiopulmonary bypass. Available at: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfMAUDE/Detail.CFM?MDRFOI_ID=5554175. Accessed November 22, 2017.
 22. Aleccia J. Operating-room machines test positive for Legionella at UW Medicine. *The Seattle Times*. September 19, 2016. Available at: <https://www.seattletimes.com/seattle-news/health/operating-room-machines-test-positive-for-legionella-at-uwmc/>. Accessed October 31, 2016.
 23. Sealy WC, Brown IW, Young WG, Smith WW, Lesage AM. Hypothermia and extracorporeal circulation for open heart surgery: its simplification with a heat exchanger for rapid cooling and rewarming. *Ann Surg.* 1959;150:627-38.
 24. Reed CC, Stafford TB. Heat exchangers and hypothermia. In: *Cardiopulmonary Bypass*. Woodlands, TX: Surgimedics/TMP; 1989:320-30.
 25. Matte GS. Letter to the Editor: It is time to update membrane oxygenator testing standards and their instructions for use. *J Extra Corpor Technol.* 2016;48:148-51.
 26. Matte GS. Equipment for bypass. In: *Perfusion for Congenital Heart Surgery: Notes on Cardiopulmonary Bypass for a Complex Patient Population*. Oxford: Wiley-Blackwell; 2015:1-12.
 27. Sommerstein R, Jenni H, Carrel T, Marschall J. Cardiac surgery, nosocomial infection, and the built environment. Response to: heater-cooler units: contamination of crucial devices in cardiothoracic surgery. *J Hosp Infect.* 2016;93:240-1.
 28. Evans G. Heater-cooler units commonly used in heart bypass surgery linked to fatal infections. *HICprevent*. May 26, 2016. Available at: <https://www.ahcmedia.com/blogs/2-hicprevent/post/137939-heater-cooler-units-commonly-used-in-heart-bypass-surgery-linked-to-fatal-infections>. Accessed May 17, 2017.
 29. Tremblay I, Tyrell G, Shandro C, Louie T, McCloskey B, Menzies S, et al. Application of risk mitigation procedures after failure to disinfect heater cooler units of *mycobacterium chimaera* with biofilm removal techniques and multiple disinfection cycles. Poster presented at: The Society for Healthcare Epidemiology of America conference, March 29-31, 2017, St Louis, Mo.
 30. Heater-Cooler System 3T Operating Instructions. Version 02/2015 with Field Safety Notice Updates. Arvada, CO: Sorin Group USA.
 31. Stammers AH, Riley JB. The heater cooler as a source of infection from nontuberculous mycobacteria. *J Extra Corpor Technol.* 2016;48:55-9.
 32. Sousa S, Bandeira M, Carvalho PA, Duarte A, Jordao L. Nontuberculous mycobacteria pathogenesis and biofilm assembly. *Int J Mycobacteriol.* 2015;4:36-43.
 33. Garvey MI, Ashford R, Bradley CW, Bradley CR, Martin TA, Walker J, et al. Decontamination of heater-cooler units associated with contamination by atypical mycobacteria. *J Hosp Infect.* 2016;93:229-34.

Key Words: cardiac surgery, heater-cooler devices, heater-cooler units, nontuberculous mycobacterium, Sorin 3T, Stöckert 3T, surgical site infections, wall water