# Setting body temperature during aortic arch surgery

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Aortic arch surgery has been one of the highest mountains to overcome in the history of cardiovascular surgery. Aortic arch surgery presents several problems, including organ protection, particularly brain protection. Arch replacement would inevitably affect brain function due to cerebral ischemia during manipulation of supra-arch vessels. In the developmental period of aortic arch surgery, hypothermia represented a simple solution to preserve the brain during aortic arch surgery. Griepp *et al.* applied the hypothermic circulatory arrest procedure for aortic arch surgery in 1975 (1). The concept of using hypothermia to temporarily reduce the oxygen and metabolic requirements of hypoxic tissues is intuitive and was later supported by decades of laboratory, translational, and clinical science (2). The cerebral metabolic rate is lowered to 56% at 30 ℃ and 16% at 15 ℃ compared with 100% at 37 ℃. Accordingly, the calculated safe duration for interruption of brain perfusion is 9 minutes at 30 ℃ and 31 minutes at 15 ℃ (3). Despite the limitation of the circulatory arrest period, this simple method remains a standard strategy for aortic arch surgery (4).

Electroencephalogram (EEG) is used to measure brain activity, and electrocerebral silence (ECS) is defined as absence of electrical activity in cerebral tissues. Historical research by Woodhal *et al.* using a canine model revealed that ECS is attained at a brain temperature of 20–21 ℃ (5). A clinical study of giant intracranial aneurysms treated with deep hypothermia and circulatory arrest revealed that ECS was obtained at a brain temperature of 20 ℃ (6). However, in the setting of aortic arch surgery, brain temperature is not easily measurable, and no peripheral body temperature, including bladder, rectal, esophageal, and nasopharyngeal temperature, can consistently predict the temperature for ECS (7). Moreover, Stecker *et al.* reported that only 60% of patients demonstrated ECS at either a nasopharyngeal temperature of 18 ℃ or a cooling time of 30 minutes (8). This led them to conclude that the only absolute predictors of ECS were nasopharyngeal temperature below 12.5 ℃ and cooling time over 50 minutes. Similarly, James *et al.* reported that cooling to a nasopharyngeal temperature of 12.7 ℃ for a duration of 97 minutes achieved ECS in over 95% of patients in their study population (9). In a study involving 27 patients who underwent cardiopulmonary bypass and deep hypothermic circulatory arrest for a giant cerebral aneurysm clipping, Stone *et al.* reported that measurements from the nasopharynx, esophagus, and pulmonary arteries tend to correlate with the brain temperature (10). Camboni *et al.* reported that the temperature monitored in bladder and tympanum reliably reflects brain temperature, whereas the temperature monitored in the pulmonary artery and rectum is less optimal (11). These are interesting findings; however, the setup for brain surgery is different than that for standard aortic arch surgery. In brief, the chest wall is not opened at all for brain surgery, and their cannulations are placed at the femoral artery and vein. Akata *et al.* measured the jugular bulb temperature as a standard for brain temperature and recommended pulmonary artery temperature measurement to estimate brain temperature during deep hypothermic cardiopulmonary bypass (12). Thus, the site that should be monitored to accurately reflect the brain temperature in the setting of hypothermia remains debatable.

Previous aortic arch surgery studies reported different sites to measure the body temperature. However, temperature measurements from these sites were dissimilar to the actual brain temperature. When aortic cannulation is placed at the femoral artery, the temperature measured in the upper body (such as esophagus and tympanum) tends to be higher than that measured in the lower body (such as

**Table 1** Recent literatures of aortic arch surgery

| Study | Years | No. of patients | Body temp (℃) | Cite | TND (%) | PND (%) | Mortality (%) |
|---|---|---|---|---|---|---|---|
| Leshnower *et al.* (19) | 2004–2014 | 82 | ≤24 | NA | 7.3 | 8.5 | 14.6 |
| | | 206 | ≥24 | NA | 4.9 | 8.3 | 9.2 |
| Okita *et al.* (20) | 2009–2012 | 7,038 | 24.2 | NA | 4.1 | 6.7 | 6.0 |
| | | 1,141 | 21.2 | NA | 4.4 | 8.6 | 7.1 |
| Ziganshin *et al.* (21) | 2003–2013 | 490 | 18.7 | Bladder | 1.4 | 1.6 | 2.4 |
| Preventza *et al.* (22) | 2005–2014 | 334 | 20.1–23.9 | NA | 2.1 | 2.1 | 4.8 |
| | | 331 | 24.0–28.0 | NA | 0.9 | 2.7 | 5.4 |
| Vallabhajosyula *et al.* (23) | 2008–2012 | 301 | ≤20 | NA | 0.7 | 2.3 | 1.3* |
| | | 75 | 25–28 | NA | 0 | 0 | 1.3* |
| Zierer *et al.* (24) | 2000–2011 | 1,002 | 26–34 | Rectal | 4.2 | 2.5 | 5.2 |
| Keeling *et al.* (25) | 2005–2014 | 679 | 14.1–20.0 | NA | 7.0 | 7.9 | 13.6 |
| | | 2,586 | 20.1–28.0 | NA | 6.9 | 6.7 | 10.1 |

*, 30-day mortality. TND, permanent neurological deficits; PND, transient neurological deficits; NA, not available.

bladder and rectum).

In addition, there is no consensus on the definition of hypothermia. In 2013, aortic experts at high-volume aortic institutions defined "profound hypothermia" as ≤14 ℃, "deep hypothermia" as 14.1–20.0 ℃, "moderate hypothermia" as 20.1–28.0 ℃, and "mild hypothermia" as 28.1–34.0 ℃ (13). In addition, they utilized nasopharyngeal temperature for the hypothermia classification. Standardization of the terminology will enhance the accuracy of scientific discussions.

As mentioned above, deep hypothermia is an established strategy for brain protection. Harky *et al.* suggested that until reliable data regarding other methods of brain protection are available based on controlled clinical studies, deep hypothermia remains an excellent method for brain protection during complex aortic arch surgery (14). New techniques to ensure better cerebral protection have been attempted by aortic surgeons worldwide. Retrograde cerebral perfusion, which was first described as a treatment for massive air embolism by Mills *et al.* (15), was introduced by Ueda *et al.* as an adjunct of aortic surgery (16). Although this adjunct could not elevate the body temperature, the safety margin for aortic arch surgery was broadened. Selective cerebral perfusion (SCP), established in the early 1990's by Kazui *et al.* (17), has been widely utilized and enables safe cerebral protection with a raise of body temperature. The limit of the safe margin at high temperature is still unknown; however, a few studies have reported that profound hypothermia is not essential for SCP, and many studies have reported that the lowest body temperature at aortic arch replacement can be safely raised up to approximately 30 ℃. Yet, these reports often utilize a variety of cites to measure the body temperature. Therefore, we should be cautious to read the reports regarding the body temperature.

In 2013, Englum *et al.* (2) stated that "*until definitive comparative studies have been completed, we suggest deep hypothermia remains the gold standard for end-organ protection with circulatory arrest during aortic arch repair*." However, this aortic surgery group began to utilize SCP following the report. With propensity-matched comparison in hemiarch replacement, they reported that MHCA compared with DHCA during hemiarch replacement may marginally reduce perioperative blood-loss and plasma transfusion requirement. Essentially, these findings did not translate into postoperative mortality and morbidity data. Minatoya *et al.* conducted a similar comparative study in patients who underwent total arch replacement (18). They divided 229 patients into three groups according to the lowest temperature at lower body circulatory arrest as follows: a 20 ℃, a 25 ℃, and a 28 ℃ group. Mortality and morbidity rates were not different among the three groups. Therefore, raising the temperature during aortic arch surgery up to 28 ℃ is safe, and a body temperature raise within this range does not significantly impact clinical results. Multiple studies of arch replacement at different temperature settings have been reported; some are listed in *Table 1*.

Regarding the change of body temperature during surgery, hyperthermia during the rewarming phase of hypothermic CPB has been shown to correlate with adverse neurological outcomes. Kaukuntla *et al.* reported a temperature analysis during cardiopulmonary bypass (26). They found that based on peripheral sites, the brain temperature during the rewarming phase is underestimated, and they cautioned about overheating of the brain during the rewarming phase.

Although the previous reports used various sites for temperature measurement, we found that raising the temperature up to 30 ℃ for aortic arch replacement with SCP was feasible. However, raising the temperature should be performed with care as long as the lower body circulatory arrest is used as a strategy for surgery. This is crucial because a safe duration of circulatory arrest to protect the spinal cord is currently unknown.

In conclusion, deep hypothermia is not indispensable for aortic surgery, and higher temperatures can be applied. However, deep hypothermia remains safe and provides an attractive temperature setting. Institutional experience, including use of empirical values could help in selecting the best strategy for aortic arch replacement. Use of high temperature should not be simply assumed to be better than DHCA (27).

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