Repeated circulatory arrest under hypothermia

VIKING OLOV BJÖRK AND SETH HÖGSTRÖM

From the University Hospital, Uppsala, Sweden

In cases of pulmonary valvular stenosis without infundibular constriction and in cases of atrial septal defect with or without abnormal venous return we continue to use inflow occlusion under hypothermia (29 to 31° C.) in preference to extracorporeal circulation. The reason for this is that a small but significant mortality rate must be ascribed to the perfusion technique per se, whereas in our experience the same risk does not follow a well-conducted hypothermia (Björk, Holmdahl, and Petersson, 1960).

If a second period of inflow occlusion is needed to complete the intracardiac part of the operation it is generally recommended that the circulation is restored for a period of twice the length of circulatory arrest before a second arrest is permitted (Zindler, 1957).

The aim of this paper is to explain why no such rule of thumb can be recommended. It is necessary to follow the acid-base balance continuously and to wait until a normal or alkalotic state has again been reached. This may take longer than anticipated and sometimes the addition of sodium bicarbonate may prove valuable. Two cases, one with pulmonary valvular stenosis and atrial septal defect and one with atrial septal defect combined with an abnormal pulmonary venous return, illustrate the value of these principles.

CASE REPORTS

PATIENT I A 3-year-old girl, only 10 kg. in weight, with a systolic murmur and right ventricular hypertrophy, was found to have a high pressure of 130 mm. Hg in the right ventricle at cardiac catheterization. No shunt was demonstrated. Angiocardiography showed an isolated pulmonary valvular stenosis and suggested an atrial septal defect.

After induction of anaesthesia with oxygen, nitrous oxide, and halothane the patient was connected to an Engström respirator for controlled respiration. Halothane was withdrawn and after curarization she was cooled in a bath. At the start of the operation arterial blood analysis at 31° C. showed satisfactory oxygenation and hyperventilation, pH 7.52, Pco₂ 23 mm. Hg, stand.HCO₃⁻ 19 mEq/l. and Po₂ 97 mm. Hg (Fig. 1). At 29° C. a median sternotomy was performed and both venae cavae were isolated. After opening the pericardium a significant right-to-left shunt developed with a rapid deterioration in the patient's condition.

In spite of pure oxygen, hyperventilation, and 15 mEq sodium bicarbonate (25 ml. 5% solution), the arterial blood showed a relatively low oxygen tension with Po₂ 115 mm. Hg, pH 7.32, Pco₂ 29 mm. Hg, and stand.HCO₃⁻ 15-0 mEq/l. An inflow occlusion for 2 minutes 45 seconds was immediately performed and two commissures of the fused pulmonary valves were opened via the pulmonary artery under direct vision. After restoration of the circ.-

FIG. 1. Patient 1.
calculation the patient was ventilated with pure oxygen. She
developed a rapidly increasing acidosis. In three minutes
the acid-base values changed from $\text{pH } 7\cdot 22$, $\text{PCO}_2$ 35 mm.
Hg, stand.$\text{HCO}_3^- 14\cdot 0$ mEq/l., $\text{Po}_2$ 81 mm. Hg to $\text{pH } 7\cdot 09$,
$\text{PCO}_2$ 44 mm. Hg, stand.$\text{HCO}_3^- 12\cdot 5$ mEq/l. and $\text{Po}_2$
60 mm. Hg. Thirty milliequivalents sodium bicarbonate
was given immediately and later a further 15 mEq. One
hour after the first arrest the $\text{pH}$ had stabilized at 7-50,
$\text{PCO}_2$ 19 mm. Hg, stand.$\text{HCO}_3^- 15\cdot 5$ mEq/l. and $\text{Po}_2$
89 mm. Hg. A second inflow occlusion was then
performed for six minutes and a large secundum defect
closed by one running and four isolated sutures. During
this occlusion 250 ml. oxygenated blood was given for
coronary perfusion into the root of the aorta. Curiously
the $\text{pH}$ one minute after this arrest was as high as 7-59
with $\text{PCO}_2$ 19 mm. Hg, stand.$\text{HCO}_3^- 19\cdot 5$ mEq/l. and $\text{Po}_2 > 300$ mm. Hg, later changing to $\text{pH } 7\cdot 40$, $\text{PCO}_2$
26 mm. Hg, stand.$\text{HCO}_3^- 16\cdot 5$ mEq/l. and $\text{Po}_2 > 200$ mm. Hg.
After closure of the atrial septal defect there was no
difficulty with the oxygenation and acid-base balance.

After the operation the patient had a significantly slow cerebration and her spontaneous ventilation was
inadequate although there were no signs of continued
curarization. A tracheostomy was performed and respirator treatment was given for 24 hours. After that
the patient showed no signs of cerebral damage. She was
able to take over respiration herself and the tracheal
cannula was removed. Further recovery was uneventful.

**PATIENT 2** A 16-year-old boy with fatigue as a general
symptom and with systolic and diastolic murmurs was
found to have a big left-to-right shunt at the atrial level.
The oxygen saturation was 67% in both the inferior and
superior caval veins and 82% in the pulmonary artery.
The pre-operative diagnosis was atrial septal defect with
abnormal venous return.

At 30°C a right thoracotomy was performed under
the fourth rib. The right superior pulmonary vein was
divided into two branches, one entering the superior
caval vein and the other the right atrium opposite a
high atrial septal defect. The superior vena cava was
divided lengthwise by an external partitioning with the
aid of a ring-clamp to provide two openings into the right
atrium, one for the superior vena cava and the other for
the abnormal pulmonary vein. During inflow occlusion
the edge of the pulmonary vein was sutured to the
septal defect. A coronary perfusion of 250 ml. oxygenated
blood was given into the root of the aorta. The con-
tinuous suture ruptured and another was inserted and
tied to the first. After 9 minutes 29 seconds the circulation
was restored.

According to repeated acid-base determinations (Fig. 2)
a delay of 35 minutes and the injection of 30 mEq
sodium bicarbonate were required to establish optimal
conditions for a second inflow occlusion (6 minutes
7 seconds). Five additional mattress sutures were inserted and
the patient was rewarmed in the bath. Recovery was uneventful.

**DISCUSSION**

During an inflow occlusion of six to nine minutes at
30°C for the closure of an atrial septal defect the
$\text{pH}$ will usually drop about 0.2 unit, depending
mainly on a metabolic acidosis. To counteract the
untoward effects of the acidosis *per se*, the high
risk of ventricular fibrillation, dilatation of the
peripheral vessels, elevation of the pulmonary
vascular resistance, as well as other factors, we
prefer to start the inflow occlusion at a $\text{pH}$ of 7-5
in order to obtain a final $\text{pH}$ of 7-3 immediately
after release of the occlusion. Normally the acidosis
disappears spontaneously. Before a second inflow
occlusion is undertaken we prefer to have a normal
acid-base balance and again a $\text{pH}$ of 7-5 is aimed at.
This cannot always be achieved after a short period
of circulation.

In the patients described it was necessary to wait
60 and 35 minutes respectively and to give sodium
bicarbonate before a second inflow occlusion could
be undertaken.

Also in other cases of cardiac arrest it is necessary
to pay attention to the metabolic acidosis during
prolonged cardiac massage. In one of our patients
ventricular fibrillation occurred during right heart
catheterization. Under massage the $\text{pH}$ had dropped
to 7-06 and the stand.$\text{HCO}_3^- 6\cdot 5$ mEq/l. 30 minutes
after arrest. During one hour a total of 120 mEq
sodium bicarbonate was given in repeated doses
under control of acid-base balance. The values
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became almost normal and after tracheostomy and respirator treatment for some days the patient made an uneventful recovery.

SUMMARY

When a second period of inflow occlusion during hypothermia is desired, we think it is imperative to wait until the acid-base balance is brought back to optimal values before the second circulatory arrest is performed. This optimum may not be obtained merely by a short period of circulation and hyperventilation. The best way is to observe the acid-base balance in the arterial blood. Sometimes sodium bicarbonate may prove valuable.

Two cases are reported as examples of these principles. A case of cardiac arrest is mentioned as an example of the importance of studying the acid-base situation and the value of sodium bicarbonate in large doses given rapidly.

REFERENCES
