Carbon Dioxide Field Flooding: A Retrospective Study

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Abstract: The carbon dioxide surgical field flooding technique has long been tried with varying degrees of success. A recent revival of the technique that began over 40 years ago in cardiac surgery, has brought promise as well as improved results attributable to improved technology. Studies at JFK Medical Center have been very successful using the carbon dioxide surgical field-flooding technique. Establishing new guidelines will assist other institutions in attempting this "old" technique with renewed success. Modern, more efficient equipment make use of carbon dioxide to displace intracardiac gases a safe procedure. The carbon dioxide field-flooding technique is safer, easier, and more efficacious than traditional de-airing techniques. This study shows that a long-standing procedure is valuable by observing the results, and, retrospectively evaluating stroke rates among cardiac valve cases at the hospital. Keywords: surgery, cardiac surgery, carbon dioxide, valve surgery, intracardiac air.

As one of the leading causes of neurological dysfunction, air emboli must be eliminated (1–5). Conventional de-airing procedures tend to be cumbersome and inefficient (5). Avoiding the danger of air emboli is a primary objective of carbon dioxide surgical field flooding and has proved to be an efficient means of this objective.

Even as early as 1940, researchers were safely injecting carbon dioxide. Moore and Braselton injected 3 cc of carbon dioxide per pound of body weight in a cat (3). Knowing that carbon dioxide was heavier than air and twenty times more soluble than air made it the perfect medium for replacing air (6).

Originally, Nichols credits Sones (1957) with proving the safety of carbon dioxide by injecting it directly into the aortic root with no neurological impairment (3). Other methods were tested to eliminate intracardiac air. At the time these methods included the use of vents and injection of Lactated Ringers. As early as 1958, Nichols (3) describes the use of gaseous carbon dioxide to prevent air embolization and subsequent neurological sequelae. Huock Bolton performed 22 operations utilizing the gaseous carbon dioxide technique with no adverse effects (3).

Many studies since the beginnings of cardiac surgery have attempted to describe the types of surgery where stroke is more prevalent, specifically by what mechanism they occur. Four surgeries were associated with an increased level of stroke in the Buffalo Cardiac-Cerebral Study Group. They are: redo cardiac surgery, carotid artery stenosis, valve surgery and prior stroke (7). In the other studies, age had been eliminated as a determining factor for increased incidence of stroke (8).

Throughout the history of cardiac surgery, there have been extreme differences in the reporting of neurological impairment and possible stroke. Taylor (9) reports neurological impairment of 15–44% following cardiac surgery. Webb (5) reports the presence of neurological impairment at 32–83% for bypass procedures. Webb’s study is as recent as 1997 and the variability reflects the confusion in reporting any neurological deficits as to whether they are transient or permanent.

In 1985, Heikkinen (1) describes his own results for clinically significant neurological deficits as 5.8%. Then Heikkinen reports his literature review reveals values from 4.8–4% from the late 1970’s and the early 1980’s. It is apparent that a definition of neurological impairment versus stroke is needed in the field of cardiac surgery.

Cerebral dysfunction can exhibit itself in many different forms. According to Taylor (9), this can include changes in mood and other subtle changes such as those that can be detected by Psychometric tests such as word rotation, memory recall, and conceptual logic. These can represent some of the higher figures reported in the literature.

MATERIALS AND METHODS

The study was conducted at JFK Medical Center in Atlantis, Florida. Over a period of six months (February 2000-August 2000), the carbon dioxide surgical field flooding technique was utilized for all valve cases. The circuit was comprised of Jostra-Bentley (Jostra-Bentley, Irvine,
CA) components in an open system configuration with vacuum-assisted venous drainage. A Jostra-Bentley spiral gold oxygenator, a 4500 cc Jostra-Bentley reservoir and 40 micron arterial filter are all duraflow coated, as is the entire circuit. A Medtronic (Medtronic, Eden Prairie, MN) biomedicus BP-80 biohead was used on all cases.

A small carbon dioxide tank (750 psi) was connected to a conventional 0.2 μm gas filter. The gas filter in turn is connected to a suction line from the surgical field (7). A vent adapter (Texas Medical Products, Woodlands, TX) is placed in the pericardial well after having many holes cut into it. The vent adapter is connected to the suction line which is then sutured with 2-0 ethibond. Other surgeons have used multi-perforated catheters or a drain instead (10, 11).

While the heart was open, carbon dioxide was run at 10 LPM continuously. This rate was consistent with other programs that have tried this surgical field flooding technique. (5, 6). Sweep rates were adjusted appropriately to the varying levels of carbon dioxide in the patient’s blood. This was the limiting factor of utilization of this technique for many decades. The removal of carbon dioxide was the limiting factor in performance of the original membrane lung in the 1950’s and the bubble oxygenator in the sixties and seventies. Carbon dioxide removal was a limiting factor until the development of microfibrillar polytetrafluoroethylene (ePTFE) or microporous sheets of teflon in the modern membrane oxygenator. (12).

The use of TEE (Transesophageal Echocardiograph) was performed on every valve case before, during, and after surgery. This also was consistent with the protocol of other programs (2, 5, 6, 8, 13, 14). Utilization of the TEE allows for a definitive visualization of intracardiac air. At the end of any valve case, the air found in the left ventricle is especially a dangerous source of air emboli potentially leading to neurological dysfunction (2).

DISCUSSION

Approximately 20% of our open heart cases at JFK are valves. The carbon dioxide surgical field flooding technique was used on all valve cases. Previous studies of this technique have reported that over 90% of the air can be displaced from the operative field. In Sellman’s studies, carbon dioxide levels were measured as high as 86–98% in the operative field (6).

At the beginning of the study at JFK, 10 LPM of carbon dioxide was introduced throughout the operation. The vent and drop sucker was placed as in the past. Unfortunately, the sweep was not raised at the beginning of the first case and the PaCO₂ values were as high as 50–60 mmHg. This produced systemic hypotension that was intractable to pharmacological intervention (ie., Phenylephrine, epinephrine). At JFK, the protocol was to draw an arterial blood gas every 20–30 minutes, so the rising level of carbon dioxide was not discovered until it had progressed further than desired. An inline gas monitor would be a preferential method of measurement with this technique. Fortunately, this patient had no neurological sequelae as a result of the episode.

Webb (5) also describes a case of hypercarbia on pump during his experiences (ie., 36–50 mmHg). O’Connor (10) states the same effect but his values are even higher, from 60–67 mmHg. He goes on to claim, as others have, that hypercarbia increases cerebral blood flow by vasodilatation as well as systemic hypotension. Nevin (13) states the opposite about hypocapnia causing constriction of cerebral blood flow and that this could cause neurological deficits postoperatively. O’Connor’s initial response was to eliminate other potential sources of carbon dioxide such as malignant hyperthermia, thyroid storm, and neuroleptic malignant anesthesia (10).

Without a family history of malignant hyperthermia and no adverse response upon induction, this potential source of severe hypotension was eliminated. This same scenario upon induction allowed the team to eliminate neuroleptic malignant anesthesia as a possibility. Since the patient had never had a problem with thyroid function, this was eliminated as a potential source of hypotension. Insufficient anesthesia was also considered. More narcotics were given. An adequate SVO₂ also helped the team deduce sufficient anesthesia was given.

Once the major source of the carbon dioxide was discovered, the sweep was turned up to 10 LPM. For subsequent cases, the sweep was raised up to 10 LPM as soon as the carbon dioxide began. This met the needs of the average sized adult. The struggle still existed to maintain a normal PaCO₂. After using this technique on a dozen people, the vent was targeted as a source of air introduction rather than a means of removing it. Cases were tried without a vent. The team discovered that it was much easier to remove the carbon dioxide circulating in the patient with sweep rates twice what was normally expected. The period where the heart started beating after the cross clamp was taken off revealed no air in any of the cardiac chambers.

Now that the source of the air introduction near the end of the case, and, the overwhelming source of carbon dioxide were discovered, the technique was modified to reveal excellent results every time. This was also documented in another paper, and, the amount of sweep was directly correlated with the amount of venting during the case (6). Now twice the calculated sweep rate was utilized the excess circulating CO₂ was eliminated easily and without the mysterious appearance of air after removing the cross clamp. In addition, the vacuum was usually kept at zero during cases to reduce the introduction of air.

Other researchers have described a period during open-
heart surgery when the heart starts beating as a period when air emboli are at their greatest amount (2). Observation of the TEE at the end of the case demonstrated that the carbon dioxide had completely displaced all of the air.

SUMMARY

In the last six months, surgical and perfusion techniques have been modified to accommodate the carbon dioxide surgical field flooding technique. This has proven to be a very worthwhile technique. It has become apparent through observation after instituting this technique that patients are now waking up more alert than in the past. In addition, the stroke rate has diminished greatly among valve cases.

Reviewing the discharge summaries of patients in the last year revealed that only one valve case in the past nine months has had a stroke. That patient had carotid disease also. This is opposed to the previous six months of last year which revealed a total of six valve cases that had resulted in stroke. In retrospect, it appears that the technique has had a profound effect on our results.

Obviously, the need for a controlled study is needed. Patients could be assigned randomly to test group and control group. Again, it would be difficult to evaluate each patient neurologically without a foundation of definitive tests to measure cognitive function as well as the incidence of much more serious complications such as: hemiplegia, dysphagia and visual disturbances.

More subtle changes as described by some researchers and those that have a higher incidence may be reduced greatly by this technique. The TEE works very efficiently to verify that air is not present at critical times during bypass. Cognitive function tests could then prove that many of these subtle neurological changes could be eliminated utilizing the carbon dioxide surgical field flooding technique.

REFERENCES


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