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Original Article

The Effects of Venous Cannulation Technique and Cardioplegia Type on Plasma Potassium Concentration and Arterial Blood Pressure during Cardiopulmonary Bypass

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Abstract: The cannulation method and cardioplegia solution used during cardiopulmonary bypass (CPB) may both influence plasma potassium concentrations ([K+]) and mean arterial blood pressure (MAP). Bi-caval or right atrial cannulation methods are routinely used in conjunction with crystalloid or blood cardioplegia. We investigated the influence of cannulation method and cardioplegia solutions on plasma [K+] and MAP during cardiopulmonary bypass. Sixty consecutive patients undergoing elective coronary artery bypass grafting (CABG) using CPB were studied. They were randomly divided into three groups of 20 patients. Patients in Group A underwent bi-caval venous cannulation and received crystalloid cardioplegia. Group B patients underwent right atrial cannulation and received crystalloid cardioplegia. Group C patients underwent right atrial cannulation and received blood cardioplegia. In each case, cardioplegia was administered antegrade via the aortic root. Plasma [K+], MAP, and hemoglobin concentration (Hb) were measured over an 8-min period following cardioplegia administration (pilot studies indicated pressure changes occuring post cardioplegia administration up to this time). The combination of bi-caval cannulation and crystalloid cardioplegia (Group A) was associated with the least increase in plasma [K+] and no decrease in MAP. The maximum [K+] for this Group was 4.2 mmol/L (4.6% increase). The minimum mean pressure was 57 mmHg (13.6% increase). Both right atrial cannulation groups (B and C) showed a large rise in plasma [K+] and a decrease in MAP. Group B maximum [K+] was 5.2 mmol/L (27.5% increase), Group C was also 5.2 mmol/L (26.0% increase). Group C showed the largest pressure decrease, the minimum mean pressure was 45 mmHg (21.3% decrease). The Group B minimum mean pressure was 45 mmHg (8.7% decrease). Our results show that patients undergoing CPB operations who are deemed to be at increased risk of suffering adverse effects from hypotensive episodes may benefit from bi-caval cannulation and caval snaring, in preference to right atrial cannulation. Crystalloid cardioplegia may be preferable to blood cardioplegia in these cases to maintain the MAP. **Keywords:** potassium concentration, arterial pressure, cannulation, cardioplegia. *JECT. 2001;33:148–152*

CPB and cardioplegia administration are associated with systemic hypotension and altered vascular responses (1). An increase in plasma potassium concentration ([K+]) alters vascular tone by reducing vascular smooth muscle contraction. This may be caused by activation of ATP-sensitive potassium channels (1).

The choice of venous cannulation method will influence plasma [K+] by altering vascular fluid volume, as may different cardioplegia solutions because of their different constituents and high [K+]. The venous cannulation methods in routine use for elective CABG operations are bi-caval and right atrial venous cannulation. Bi-caval cannulation uses two separate cannulae to cannulate the superior and inferior vena cavae individually. This method is normally used in conjunction with caval snares that prevent venous return to the right atrium via either vena cava during CPB. The administered cardioplegia solution, returning to the right atrium via the cardiac veins, can be retrieved using a pulmonary artery vent. Thus, it is prevented from entering or mixing with the systemic circulation.

In contrast, right atrial cannulation involves placing a single cannula directly into the right atrium. The open tip of the cannula drains the inferior vena cava. A second opening more proximal on the cannula drains the right atrium, which receives the venous return from the superior vena cava. It is not possible to retrieve the administered cardioplegia solution selectively by this method;

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therefore, it mixes with the systemic blood. Hence the cannulation method and the cardioplegia type both influence the plasma [K+] and consequently MAP.

In this study, the effects of two cannulation techniques and the administration of two cardioplegia solutions on plasma [K+] and mean arterial pressure were quantified.

METHODS

Sixty consecutive adult patients undergoing elective coronary artery bypass grafting (CABG) operations were studied. They were divided into three groups (A, B, and C) of 20 patients using stratified randomization. Patients in Group A underwent bi-caval venous cannulation with caval snares and received crystalloid cardioplegia (BiC/Cryst). Patients in Group B underwent right atrial venous cannulation and received crystalloid cardioplegia (RA/Cryst). Patients in Group C underwent right atrial cannulation and received blood cardioplegia (RA/Bl). Cardioplegia delivery in each case was antegrade via the aortic root.

The blood cardioplegia consisted of four parts pump blood mixed with one part crystalloid cardioplegia solution. The crystalloid cardioplegia solution was made by adding 20 mL of DBL® Sterile Cardioplegia Concentrate (DBL, F. H. Faulding & Co. Ltd., Mulgrave North, Victoria 3170, Australia) to 1L of Ringer's solution.The [K+] of both the blood and crystalloid cardioplegia solutions administered was 20 mmol/L.

One liter of the cardioplegia solution was administered in each case over 2 min. A pulmonary artery vent was used in Group A patients, in conjunction with external suction, to remove the cardioplegia solution returning via the coronary venous system into the right atrium of the heart. In groups B and C, no such system was used, resulting in a mixing of the returning cardioplegia solution with the systemic circulation. The pump priming solution used for all patients consisted of 1.2 L of Hartmann's solution ([K+] = 5 mmol/L), 60 mEq sodium bicarbonate, 25 g of mannitol and 5000 IU bovine heparin. An initial arterial pressure reading was recorded, and an arterial blood sample was obtained from each patient 2 min after initiation of CPB. MAP was recorded, and arterial blood samples were obtained at 1, 2, 3, 4, 5, and 8 min after cardioplegia administration. This was commenced within 3 min of the initial sample being taken in every patient The [K+] and hemoglobin concentration (Hb) of each sample were measured using a Radiometer® ABL 4 blood gas analyzer and hemoglobinometer (Radiometer, Copenhagen).

The pump blood flow for Group A and B patients was kept constant throughout the sampling period at the calculated rate of 2.4 L/min/m^2 of patient body surface area. The flow rate was increased by 400 mL/min in Group C patients during the cardioplegia administration period. This was to allow for the additional volume of pump blood per minute (400 mL) required to make the blood cardioplegia mixture.

DATA ANALYSIS

Stastical analysis was performed with data expressed as mean ± standard deviation. Differences between groups were assessed using a one-way analysis of variance (ANOVA) and were considered statistically significant at $p < .05$ level.

RESULTS

Tables 1–3 show the mean, standard deviation, and percentage change for plasma [K+], MAP, and Hb in Groups A, B, and C, respectively.The results are over an 8-min period following cardioplegia administration. The mean and standard deviation of groups A, B, and C are plotted in Figures 1–3, respectively.

Group A patients showed an increase in mean plasma [K+] within 2 min of cardioplegia administration and had the smallest mean [K+] increase of the three groups The maximum mean value was 4.2 ± 0.33 mmol/L with a range of 0.2–4.6%. Group B and C patients showed an increase in mean plasma [K+] within 1 min of cardioplegia administration, with Group C showing the largest sustained mean [K+] increase The maximum mean value was 5.2 ± 0.38 mmol/L with a range of 10.1 to 26.0%. In Group B

Table 1. Mean, standard deviation, and percentage change in mean plasma potassium concentration pre- and postcardioplegia administration for patient groups A, B, and C.

Time (min)	[K] A	% Change	[K] B	% Change	[K] C	% Change
0	4.1 ± 0.29	0.0	4.1 ± 0.36	0.0	4.2 ± 0.44	0.0
1	4.1 ± 0.40	0.2	4.7 ± 0.68	13.1	4.7 ± 0.50	12.5
2	4.2 ± 0.50	3.4	5.2 ± 0.78	26.3	5.2 ± 0.43	26.0
3	4.2 ± 0.37	4.6	5.2 ± 0.68	27.5	5.2 ± 0.38	24.0
4	4.2 ± 0.33	4.6	4.8 ± 0.51	16.0	5.0 ± 0.57	20.7
5	4.1 ± 0.30	3.2	4.6 ± 0.47	11.4	4.8 ± 0.50	16.1
8	4.1 ± 0.30	0.2	4.4 ± 0.42	6.3	4.6 ± 0.43	10.1

[K] (mmol/l) Means ± SD, % Change

Table 2. Mean, standard deviation, and percentage change in mean arterial pressure pre- and postcardioplegic administration for patient group A, B, and C.

	MAP A	% Change	MAP B	% Change	MAP C	% Change
0	50 ± 10.07	0.0	51 ± 9.64	0.0	51 ± 9.64	0.0
1	57 ± 12.02	13.6	48 ± 9.84	–6.3	48 ± 9.84	–17.9
2	59 ± 13.10	19.2	47 ± 11.03	–8.3	47 ± 11.03	–21.0
3	59 ± 13.50	19.1	46 ± 10.84	–8.7	46 ± 10.84	–21.3
4	59 ± 11.90	18.5	45 ± 17.09	–4.8	45 ± 17.09	–20.1
5	59 ± 10.30	18.6	50 ± 10.27	–0.6	50 ± 10.27	–18.3
8	58 ± 8.60	16.6	55 ± 10.63	8.9	55 ± 10.63	–6.6

MAP (mmHg) Means ± SD, % Change

Table 3. Mean, standard deviation, and percentage change in mean hemoglobin concentration pre- and postcardioplegia administration for patient groups A, B, and C.

	[HB] A	% Change	[HB] B	% Change	[HB] C	% Change
0	9.8 ± 1.36	0.0	9.7 ± 2.00	0.0	8.8 ± 1.71	0.0
1	9.7 ± 1.34	–0.5	9.3 ± 1.92	–2.1	8.6 ± 1.93	–3.4
2	9.6 ± 1.25	–1.5	9.0 ± 1.94	–7.2	8.6 ± 1.96	–3.0
3	9.5 ± 1.20	–2.3	8.8 ± 1.94	–8.9	8.5 ± 1.86	–3.8
4	9.6 ± 1.20	–1.9	8.9 ± 1.96	–7.7	8.6 ± 1.84	–3.3
5	9.6 ± 1.21	–2.2	9.0 ± 1.95	–7.3	8.5 ± 1.83	–3.2
8	9.5 ± 1.21	–2.5	9.0 ± 1.93	–7.3	8.7 ± 1.78	–3.3

[Hb] (g/dl) Means ± SD, % Change

patients, the [K+] increase was short lived, reaching its maximum value 2 min after cardioplegia administration. The maximum.mean value was 5.2 ± 0.68 mmol/L with a range of 6.33–27.5%.

Group A patients showed a MAP increase immediately following cardioplegia administration. This increase was sustained for at least 8 min monitoring time. The maximum mean value was 59 ± 10.3 mmHg with a range of 13.6–19.2%. Group B and C patients both showed a decrease in MAP that was largest for Group C patients. The Group B minimum MAP was 45 ± 17.09 mmHg with a range of –8.7 to + 8.9%. The Group C minimum was 45 ± 8.73 mmHg with a range of –21.3 to –6.6%.

Group B patients showed the largest percentage decrease in Hb. The minimum was. 8.8 ± 1.94 g/dL with a range of –2.1 to –8.9%. Group C showed the next largest

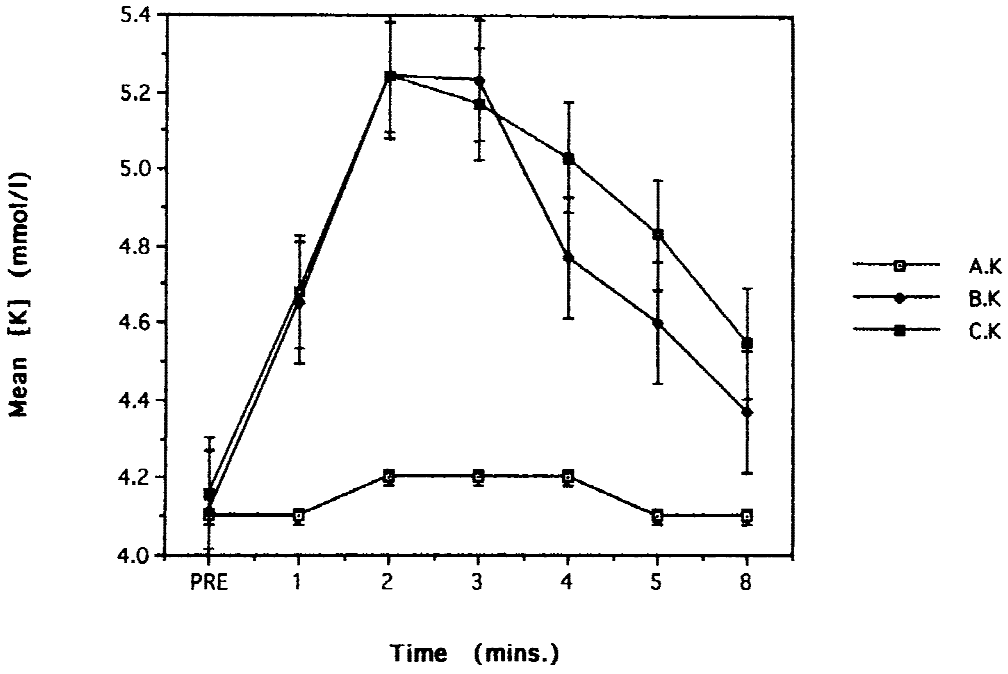

Figure 1. Mean plasma potassium concentration (mmol/L) versus time (min).

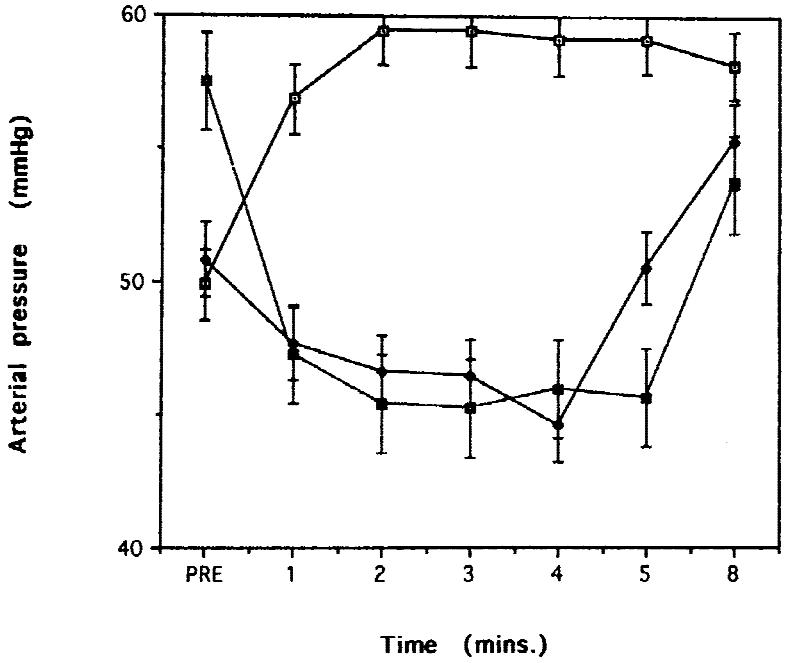

Figure 2. Mean arterial pressure (mmHg) versus time (min).

decrease in mean Hb with a minimum of 8.5 ± 1.86 g/dL and a range –3.0 to –3.8%: Group A patients showed the least percentage Hb decrease with a minimum of 9.5 ± 1.20 g/dL and a range –0.5 to –2.5%.

DISCUSSION

Systemic hypotension is frequently seen on initiation of CPB and particularly following cardioplegia administration. Carotid artery flow may be enhanced because of hemodilution, but the flow pattern discloses a pressure passive system resulting in impaired cerebral autoregulation. This phenomenon could result in qualitatively insufficient perfusion during CPB in spite of increased flow (2). As a result, certain patients, particularly those with carotid artery atherosclerosis or occlusion could suffer adverse effects from hypotensive episodes during CPB. The incidence of major neurological complications for patients undergoing CPB ranges from 1% to 6% depending on the patient population and method of reporting (3).

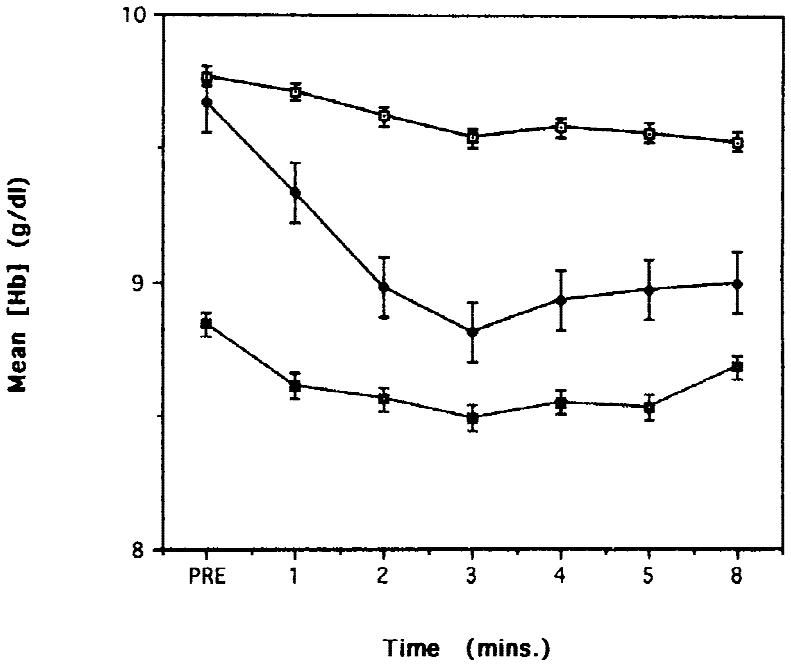

Figure 3. Mean hemoglobin concentration (g/dL) versus time (min).

These adverse perioperative cerebral effects may be attributed to two mechanisms; namely, embolization of gaseous and solid forms and reduced cerebral perfusion caused by hypotension. The latter typically results in "watershed" infarcts, affecting areas of the brain particularly vulnerable to ischemia (4).

In chronically hypertensive patients, cerebral blood flow autoregulation is maintained over a higher pressure range, impairing their tolerance of systemic hypotension (4). With the patient population undergoing CABG operations getting progressively older, the incidence of both carotid atherosclerosis and chronic hypertension is increasing, further increasing the risk of neurological complication in these patients (4).

Vasoactive agents released during CPB are numerous and include hormones, cytokines, and electrolytes (5). The high potassium content of cardioplegia solutions makes potassium particularly relevant as a vasodilator during cardioplegia administration and the subsequent initial phase of CPB.

The choice of venous cannulation method will influence plasma [K+] by altering vascular fluid volume, as may different cardioplegia solutions because of their different constituents and high [K+].

This study showed a significant increase in mean plasma [K+] in each of the three groups following cardioplegia administration.The combination of bi-caval cannulation and crystalloid cardioplegia (Group A) was associated with the least increase in plasma [K+]. The maximum [K+] for this Group was 4.2 mmol/L (4.6% increase). Right atrial cannulation combined with crystalloid (Group B) or blood (Group C) cardioplegia, resulted in very similar increases in plasma [K+]. The Group B maximum potassium concentration was 5.2 mmol/L (27.5% increase). The Group C maximum. [K+] was also 5.2 mmol/L (26.0% increase). The similarity of the [K+] increase in Groups B and C is not surprising, because an equal volume of similar strength cardioplegia solution was administered in each case, and this solution was not retrieved by a vent as for Group A. The postcardioplegia plasma [K+] would, therefore, seem to be equally affected by either crystalloid or blood cardioplegia. However, the use of bi-caval cannulae and caval snares prevents the large plasma [K+] increase during CPB as seen with the right atrial cannulation method.

Mean arterial pressure was best maintained in Group A in the immediate postcardioplegia period. This group demonstrated a significant pressure increase, which was maintained throughout the monitoring time. The minimum mean pressure was 57 mmHg (13.6% increase). Group C showed the largest pressure decrease, the minimum mean pressure was 45 mmHg (21.3% decrease). Group B also showed a pressure decrease, the minimum mean pressure was 45 mmHg (8.7% decrease). Although the minimum pressure recorded for groups B and C was 45 mmHg, Group C had a far greater percentage pressure drop. This drop was 8.7% for crystalloid cardioplegia (Group B) versus 21.3% for blood cardioplegia (Group C). The higher percentage pressure drop in Group C compared to Group B, while the plasma [K+] decrease was similar in both groups may be attributable to the influence of other vasoactive agents. All groups showed a return in plasma [K+] and MAP toward normal precardioplegia levels by 8 min postcardioplegia administration. The effects were maximal in the first 4 min following cardioplegia administration.

A statistically significant Hb decrease was seen after cardioplegia administration in all three groups. The largest decrease was in Group B. This may be attributable to the hemodilution effect of the crystalloid cardioplegia, which was not retrieved. The minimum mean Hb in Group B was 8.8 g/dL (8.9% decrease). The decrease in Hb was smallest in Group A where the bi-caval cannulation and snaring facilitated the removal of most of the administered car dioplegia solution. The minimum mean Hb in Group A was 9.5 g/dL (2.5% decrease). The use of blood cardioplegia in Group C also resulted in minimal hemodilution. The minimum mean Hb in this group was 8.5 g/dL (3.8% decrease).

Our results show that patients undergoing CPB operations who are deemed to be at increased risk of suffering adverse effects from hypotensive episodes may benefit from bi-caval cannulation and caval snaring, in preference to right atrial cannulation. Crystalloid cardioplegia may be preferable to blood cardioplegia in these cases to maintain the MAP.

Alternatively, where it is not desirable or feasible to alter cannulation method or cardioplegia type, a potent vasoconstrictor drug such as phenylepherine should be readily available following cardioplegia administration in anticipation of a hypotensive period. None of the patients studied showed evidence of major postoperative neurological complications.

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