

Research Letter

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Colloid Supplementation during Induction of Anesthesia

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ABSTRACT

The present paper puts forward the hypothesis that infusion of colloid during induction will prevent the development of an oxygen debt. The reasoning behind this hypothesis depends on there being a drop in venous tone during induction, as a result of reduced sympathetic drive. The resulting venous relaxation leads to blood volume loss from the arterial side of the circulation into the venous side. The loss of arterial volume is responsible for the reduction in arterial blood pressure. The lowered value of Mean Arterial Pressure (MAP) results in a fall in Cardiac Output (CO) below normal, in the face of little if any change in Systemic Vascular Resistance (SVR). Most clinical assessments to date have emphasised changes in Stroke Volume (SV), whereas the fall in CO is the important variable since it determines Oxygen Delivery to the tissues (DO₂). When DO₂ is lower than normal it is responsible for the development of oxygen debt, and this is the main reason for development of the complications commonly found following anesthesia. The present hypothesis is that addition of carefully titrated colloid fluid during induction can be scaled to reduce or prevent the fall in MAP and CO. Although this means the presence of extra fluid in the circulation previous work suggests this will be eliminated readily during recovery. An alternative, giving phenylephrine over the induction period reduces the anesthetic induced venous wall relaxation. Phenylephrine is already being utilised successfully and is likely to be a useful adjunct to colloid supplementation. By maintaining normal or near normal pressure, as assessed prior to induction, and hence sustaining normal blood flow, normal DO₂ will be sustained. Avoidance of an oxygen debt should reduce or even eliminate the complications which result from tissue ischaemia during anesthesia. Vasopressor administration may raise arterial pressure but will worsen the cardiac output and hence increase oxygen debt.

KEYWORDS: Anesthesia; Colloid; Induction; Volume load; Arterial pressure; Cardiac output; Oxygen debt.

ABBREVIATIONS: SV: Stroke Volume; MAP: Mean Arterial Pressure; CO: Cardiac Output; SVR: Systemic Vascular Resistance; DO₂: Oxygen Delivery.

INTRODUCTION

It has been known for many years that most tissues exert auto-regulation of their blood flow. Green, Rapela, and Conrad¹ described auto-regulation in most tissues of the body, with evidence from earlier literature showing the extent to which haemodynamic dysfunction affected it. It was clear from many sources, already available, that auto-regulation (sustaining blood flow in the face of wide pressure changes) was most robust for cardiac and skeletal muscle vasculature. Auto-regulation was least robust for renal and splanchnic circulations. Cerebral auto-regulation was intermediate in its ability to withstand, for example, low arterial pressure. Guyton, et al.² also quote multiple sources showing that auto-regulation applies to these tissues. They also illustrate the precise increase in DO₂ as VO₂ increases with exercise. The determination of individual blood flow by the tissues is also illustrated by experimental work quoted in

Guyton, et al.² where limb perfusion by either hypoxic blood or blood with normal oxygenation alter blood flow such that the rate of Oxygen Delivery to the limb is sustained. This precision adjustment of blood flow still occurred even when the limb innervation was cut, showing that the adjustment is made by the tissues in the limb, and is independent of the central nervous system. Determination of blood flow by the tissues has therefore been recognised as sub-serving delivery of oxygen to the tissues (DO_2). More recently DO_2 has been found to be maintained at a precisely controlled rate; for exercising skeletal muscle even with hypoxia and/or anaemia³ and for brain.^{4,5} An overview including auto-regulation of DO_2 by the heart and the whole body is given by Wolff.⁶ The important feature here is that DO_2 specifically exceeds the rate of oxygen consumption (VO_2) such that each tissue has a preferred $DO_2:VO_2$ ratio (or the inverse, oxygen extraction, VO_2/DO_2). So, during routine behaviour in normal subjects, the adjustments of DO_2 are precisely regulated. Several situations can interfere with the precision adjustments of DO_2 matching with VO_2 . For example, ascent to high altitude is accompanied by compensation for hypoxia with an increase in blood flow sustaining normal DO_2 in the face of lowered oxygen content. This compensation is adequate until the hypoxic insult is too great. Breakdown of the precise adjustment varies with the rate of ascent and from person to person. A second example, where the $DO_2:VO_2$ ratio falls off (oxygen extraction increases) is in severe exercise. Above a certain exercise intensity, probably the 'so called' anaerobic threshold, there is a progressive reduction in the $DO_2:VO_2$ ratio (i.e. an increase in oxygen extraction).

In anesthesia there is commonly a deficiency in the blood volume, either from relaxation of veins or from haemorrhage where under-filling of the circulation results from blood loss. Here, it is important to stress the fact that the dilatation of the veins in anesthesia is one form of vaso-dilation, the other being dilation of arterioles. It is important to recognise these two types of vaso-dilation have very different effects so, the present hypothesis specifies 'venous dilatation' in this discussion of the vascular problems of anesthesia.

CIRCULATORY PATHOPHYSIOLOGICAL CHANGES WITH INDUCTION

The relaxation of veins is a result of the anesthetic, or rather the patient's response to the anesthetic.⁷ Since the veins relax but the total blood volume remains unchanged, at least in elective surgical anesthesia, the blood volume will be redistributed, with an increase in venous blood volume and a corresponding loss of blood volume from the arterial side of the circulation. Reduction of the arterial blood volume will, necessarily, reduce arterial blood pressure.

Shoemaker, et al.⁸ were able to calculate the oxygen debt during and following surgery. Some oxygen debt occurred during anesthesia in most cases with progressive worsening

post-operatively. Morbidity and mortality were strongly related to the extent of oxygen debt. Many studies have utilised a form of goal directed therapy during the postoperative stage attempting to reach a rate of Oxygen Delivery (DO_2) index at or above 500 ml min^{-1} with varied success. Shoemaker, et al.⁹ were early contributors having found earlier that patients reaching this value spontaneously had least complications.^{10,11} Many studies since then have also attempted bringing DO_2 to this level post-operatively, with varying success.¹²

The use of colloid for volume loading rather than crystalloid has been recommended because of its retention in the circulation. Over the short term crystalloid infusion can tide over a need for extra volume in the circulation. Ueyama, et al.¹³ found considerably better results from colloid infusion than crystalloid infusion in parturient women undergoing spinal anaesthesia for elective caesarean section.

The realisation that intervention during anaesthesia rather than in the postoperative period might improve outcome occurred to Noblett, et al.¹⁴ Their study included an intervention arm, assessing volume responsiveness throughout the period of anesthesia, and responding to evidence of volume responsiveness with the infusion of colloid. The control arm of the study relied on simple clinical impression to decide whether to give fluid and in this arm of the study colloid was also given. Both groups gave colloid fluid but the intervention group fluid was given in the early stages of the operative period whereas a very similar volume of colloid fluid was given much later in the control group patients. Cardiac output was significantly greater for the intervention patients throughout the operative period. Complications only occurred in 2% of the intervention group in contrast to 15% in the control group. Hospital stay was reduced from 9 to 7 days and food taken earlier (2 days *versus* 4 days) post-operatively.

Similarly, the findings of Green, et al.^{15,16} that volume correction with colloid during anaesthesia reduced complications and avoided the need for postoperative intervention. Prior to this most studies introduced attempts at volume correction and augmentation of cardiac output postoperatively where an oxygen debt had already been incurred. A 'supranormal' cardiac output and DO_2 was aimed for and resulted in variable success.¹² The improved findings with volume loading during anesthesia¹³⁻¹⁵ lend support to the present hypothesis.

The study of Wolff and Green¹⁷ has outlined the main circulatory changes seen with the induction of anesthesia. The commonly observed pattern, of a falling arterial blood pressure with little if any change in Systemic Vascular Resistance (SVR), is illustrated in Figure 1.

Total blood volume will, of course, vary with body size, but the relative proportions of arterial and venous blood volumes will, usually, be much the same.

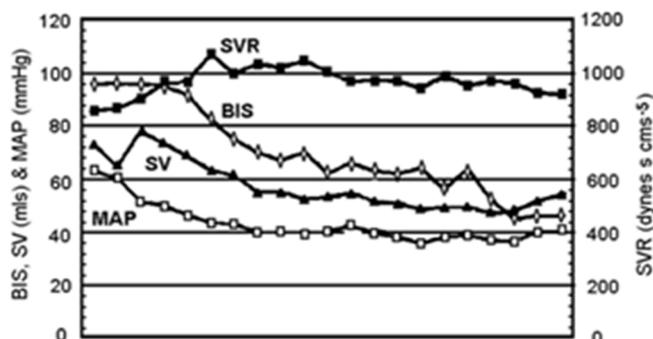


Figure 1: This shows how, with induction of anesthesia, SVR barely changes and yet Mean Arterial Pressure (MAP) falls. The better plot would include CO rather than SV but this will be falling similarly, in view of the fall in MAP (without SVR change). (From¹⁷ open access. Figure originally a slide at a conference; Abstract¹⁸).

Mitigation of the fall in MAP during induction has been achieved by Green, et al. by concurrent infusion of low doses of phenylephrine.¹⁶ An example is illustrated in the study of Wolff and Green¹⁷ comparing the use of phenylephrine during the transition from pre- to post-anesthetic induction with the worse effect where phenylephrine was not given. It can be seen to be a useful alternative or adjunct to the proposed colloid titration during induction. The ability to counteract the sympathetic effects of anaesthesia with phenylephrine arose from the finding that venous wall relaxation was mediated by sympathetic block.¹⁹

The recommended procedure, to supplement blood volume with colloid during induction, requires awareness of the optimal values of arterial pressure and cardiac output. In order to know the pre-induction values one needs to start monitoring before induction. The pre-induction values can be used as reference optimum values, if the surgery is elective, and where there is no haemodynamic problem. CO may even be a little above optimum. Shoemaker, et al.⁸ showed that with VO_2 values during anesthesia were typically 85% of pre-induction values. Hence, keeping CO (and DO_2) at or above 85% of pre-induction values should avoid development of an oxygen debt.

At this point (pre-induction) the normal circulatory volumes of the arterial, capillary and venous compartments can be envisaged, as shown in Figure 2 uppermost panel.

When the venous compartment expands during induction (say by 200 ml), there will be a shift of this volume of blood away from the arterial side of the circulation. A volume of 200 ml though small in terms of venous expansion constitutes a large proportion of the arterial volume. A loss of 200 ml from a total of 600 ml (12% of 5000 ml) constitutes a loss of 1/3rd of the arterial volume with a large fall in Mean Arterial Pressure (MAP). With little change in Systemic Vascular Resistance (SVR, see Figure 1) the reduced MAP will result in the, commonly observed, fall in cardiac output. Persistence of this low CO is the reason for development of an oxygen debt during anesthesia.⁸

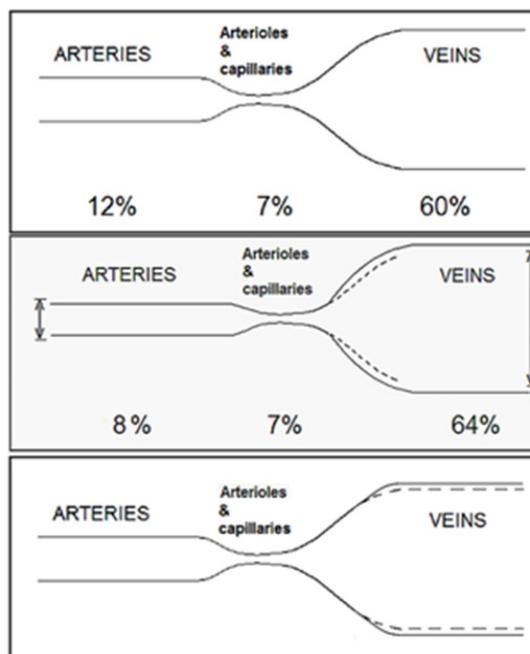


Figure 2: The upper panel shows the normal proportions of the blood volumes in arteries (12%) capillaries (7%) and veins (60%) clarifying the problem which will occur with venous relaxation (middle panel). The small proportional increase in venous volume causes a proportionally large fall in arterial volume. This causes the resulting fall in arterial pressure. Supplementation of the venous volume (lower panel) will re-expand the arteries with restoration of normal pressure.

DISCUSSION

Although infusion of colloid during induction will increase total blood volume the hypothesis is that this will, by filling the extra venous capacity, reduce the loss of blood from the arterial side of the circulation, thereby maintaining arterial blood pressure. The differences in body build will mean that differences will occur in the amount of colloid fluid required and this will mean observation of MAP and CO during induction, so that any fall can be prevented by careful infusion.

Giving volume expander (colloid) during induction

should therefore enable the reference values of pressure and cardiac output to be sustained. The procedure is a logical extension of the idea that ‘the earlier the intervention the better’; even earlier than the colloid administered during early anesthesia by the intervention group in the study by Noblett, et al.¹⁴ The different nature of colloid and crystalloid discussed in Wolff and Green¹⁷ also relates to their stress on avoidance of excessive crystalloid maintenance. Colloid infusion to counter volume dependency is simply adding a modest temporarily appropriate intra-vascular volume as distinct from the gross overfilling of total body water by excessive maintenance crystalloid.

An excessive depth of anesthesia will exacerbate the problems from venous volume relaxation. It is therefore important to be able to regulate the depth of anesthesia – not too deep and not too shallow. Although there are sceptics concerning the validity of BIS (electro-encephalographic assessment) its use has been associated with excellent results.²⁰

Cerebral oxygenation monitoring also makes a valuable contribution. When a fall is detected, cerebral oxygen monitoring has been found to help with assessment of the adequacy of blood volume.²¹ Furthermore, when therapeutic volume loading fails, it is an alert to haemorrhage sufficient to have significantly lowered blood volume.

The reduction or even elimination of complications, fundamentally due to ischaemia,²² will both ease recovery and reduce the need for patient aftercare in high dependency units.

CONCLUSIONS

The hypothesis is that mean arterial pressure and cardiac output can be sustained at, or near, pre-induction values by means of slow supplementation of blood volume with colloidal fluid during anesthetic induction. This should, hypothetically, infuse the volume by which the venous system expands, thereby preventing the usual loss of volume from the arterial side of the circulation.

This titrated colloid infusion should, theoretically, prevent the commonly found fall in both arterial pressure and cardiac output. Since, this would sustain an adequate rate of Oxygen Delivery (DO₂) it would prevent the development of an oxygen debt. Concurrent infusion of phenylephrine would also be helpful and could minimise the colloid requirement. These manoeuvres, in minimising oxygen debt should result in a considerable reduction in anesthetic complications. A clinical trial of titrated colloid infusion during induction would be of value.

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