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Original Article

The effect of vacuum-assisted venous drainage on hemolysis during cardiopulmonary bypass

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Abstract: Background: In cardiac surgery, systemic venous drainage is provided by gravity. During the procedure, the amount of venous drainage can be increased by using a vacuum-assisted venous drainage (VAVD) technique. The purpose of this study is to compare the effects of VAVD and gravitational drainage (GD) techniques on hemolysis. Methods: Totally, 60 patients were included in the study. The patients were separated into three groups, and each group designed with 20 patients: Groups are defined as Group 1 (-40 mmHg VAVD), Group 2 (-60 mmHg VAVD), and Group 3 (GD). Preoperative and postoperative values of lactate dehydrogenase (LDH), haptoglobin (Hpt), mean platelet volume (MVP), and platelet count (Plt) were evaluated. Results: The duration of cardiopulmonary bypass, cross-clamp, and vacuum assistance times were similar in all groups ($P > 0.05$), whereas Group GD required more additional volume to maintain adequate perfusion ($P = 0.034$). Preoperative and postoperative measurements showed no significant difference in terms of LDH, MVP, Plt, and Hpt among the groups ($P > 0.05$). Conclusion: There was no significant increase in hemolysis among the groups, which demonstrates that the VAVD technique, even if lower negative pressure is preferred, can be applied safely and effectively to improve venous drainage and consequently, cardiac decompression, even if smaller venous cannulas are used, and also avoid from superfluous fluid addition to sustain adequate extracorporeal perfusion.

Keywords: Venous drainage, vacuum-assistance, CABG, cardiopulmonary bypass, hemolysis

Introduction

The disruption of venous return is a common problem during cardiopulmonary bypass (CPB) in on-pump cardiac surgery. The amount of venous drainage varies depending on central venous pressure, venous cannula size, resistance to the pump line, and the height difference between the patient entrance and the venous line in the venous reservoir [1]. This standard gravitation drainage (GD) technique is sufficient for the vast majority of adult patients. The maximum flow velocity of venous drainage is limited, and the amount of venous drainage decreases, mainly if smaller, rigid cannulas are used for large, low-resistance vessels. In the circumstances where venous drainage is insufficient, systemic venous drainage may be increased through using kinetic vacuum drainage (KVD) or vacuum-assisted venous drainage (VAVD) technique.

The VAVD is a technique that provides the outflow of more blood from the patient by applying negative pressure through a vacuum regulator in the hard-shell venous reservoir. Consequently, the amount of venous drainage can be increased by using smaller cannulas. As a disadvantage, it has been thought that high negative pressure may increase blood-cell damage and hemolytic effect on the blood elements [2, 3].

Although it has also been shown that VAVD is a tool that can be positively compared with GD in terms of hemolysis and blood transfusion, especially during congenital cardiac surgery [4, 5], there is no consensus on the adverse effect of VAVD techniques on hemolysis for adult cardiac surgery based on the current literature [6].

This study aims to compare the effects of GD and VAVD techniques applied at 40 mmHg or 60 mmHg negative pressures on hemolysis of the blood elements.

Materials and methods

Patients and study design

This study was carried out by getting ethics committee approval from our hospital with the 2018.7/6-123 protocol number. The patients who had solely coronary artery bypass grafting (CABG) operation on CPB between June 2017 and December 2017 were included in this study. Consent for the procedure and data collection were obtained and verified. Patients with left ventricular dysfunction (ejection fraction < 40%), renal, hepatic or coagulation disorders, pre- or postoperative intra-aortic balloon pump (IABP), and preoperative hemoglobin value less than 11 g/dL were excluded from the study. Sixty patients were randomly and equally divided into three groups. Groups are defined as Group 1 (-40 mmHg VAVD), Group 2 (-60 mmHg VAVD), and Group GD as the control group (-20 mmHg GD).

Surgical technique

Surgical procedures and CPB methods were standardized in all groups. A median sternotomy was performed in all patients. Arterial cannulation was made through the ascending aorta with a 22F (DLP curved, Medtronic, USA) arterial cannula. For venous drainage, a two-stage venous cannula sized 36/50F (MC2, Medtronic, USA) in the control group and 28/36F (MC2, Medtronic, USA) in the VAVD groups with 0.5-inch venous tubing line in 150 cm length were preferred. Cardiopulmonary bypass machine (Maquet Jostra HL20 Hirrlingen, Germany) and a hard-shell venous reservoir with a positive pressure valve and filtered arterial oxygenator (Capox FX25 Advance, Terumo, USA) were used in all patients. The venous reservoir was placed 40 cm below the heart level, and the same vacuum regulator (AMVEX 100 Digital, Canada) was preferred in the VAVD groups by applying to the Hardshell venous reservoir chamber. In contrast, the venous reservoir was placed 70 cm below the heart level to get adequate venous drainage via gravity in the GD group. In all groups, Ringer lactate (1,000 ml), 20% mannitol (2.5 ml/kg) and heparin (1.5 mg/kg) were applied for CPB prime.

VAVD management

The pressure monitor (maximum negative and positive pressure alarm), all connections in the venous reservoir, and the Y ventilation port were examined before starting the CPB. In all groups, the CPB was initiated with the heart-lung machine and terminated in the standard fashion. After the cross-clamp was placed and cardiac arrest was provided, only in the VAVD groups, the vacuum regulator was opened. After achieving appropriate blood flow velocity, the VAVD technique was utilized during the cross-clamp at the desired negative pressure as -40 mmHg in Group 1 and -60 mmHg in Group 2. The pressures were followed on the pressure monitor. Antegrade and retrograde blood cardioplegia were applied for myocardial protection. After removing of cross-clamp, the Y atmosphere ventilation line was opened to stop VAVD, and the vacuum regulator was closed. Body temperature in all groups was decreased to 32°C during CPB, and the weaning from CPB was accomplished according to the standard procedure.

Statistical analysis

In order to determine the number of samples, a power analysis was performed using the G Power (v3.1.7) program. In the calculation, the effect size was found to be 0.936. Accordingly, it was calculated that there should be at least 19 people in each group and 57 people in total. Twenty patients were included in each group. SPSS 21.0 statistical software package was preferred for statistical analysis to evaluate the findings of this study. It was tested whether the groups had a normal distribution or not. The data with a normal distribution was assessed as mean and standard deviation. The comparison between the groups was performed using the ANOVA test. In the comparison of the categorical data, a Chi-square test was utilized. The significance was accepted as $P < 0.05$.

Results

According to the preoperative characteristics of the patients, no statistical significance was observed among all groups except body sur-

Table 1. Preoperative patient characteristics

	Group 1	Group 2	Control Group	*P*
Age (year)	60.2 ± 11.6	61.3 ± 9.2	61.1 ± 9.1	0.906
Sex (men/women)	15/5	14/6	16/4	0.473
BSA (m^2)	1.85 ± 0.3	1.83 ± 0.12	1.91 ± 0.13	0.058
HT (n)	12/8	10/10	12/8	0.688
DM (n)	10/10	8/12	8/12	0.802
EF (%)	57 ± 9	55 ± 10	55 ± 10	0.891

Note: BSA: Body Surface Area, HT: Hypertension, DM: Diabetes mellitus, EF: Ejection fraction. Values are expressed as mean ± standard deviation.

Table 2. Perioperative data

Parameters	Group 1	Group 2	Control group	*P*
CPB time (min)	123.1 ± 27.8	111.6 ± 24.2	111.5 ± 26.9	0.294
ACC time (min)	76.9 ± 18.4	69.8 ± 16.2	69.1 ± 18.8	0.317
VD interval (min)	76.9 ± 18.4	69.8 ± 16.2	69.1 ± 18.8	0.317
Additional volume (ml)	280 ± 83	284 ± 83	475 ± 151	0.034
Mean pump flow (ml/min)	4477 ± 359	4452 ± 338	4310 ± 308	0.789
Venous return disturbance	20%	25%	50%	0.102

Note: ACC: aortic cross-clamp, CPB: Cardiopulmonary bypass, VD: venous drainage. Values are expressed as mean ± standard deviation.

Table 3. Blood transfusion amount

Blood transfusion	Group 1 n (%)	Group 2 n (%)	Control group n (%)	*P*
NO	15 (75)	14 (70)	12(60)	0.454
YES	5 (25)	6 (30)	8 (40)	

face area that was highest in the control group (**Table 1**). The control group patients required more additional volume to maintain adequate venous return and consequently sufficient extracorporeal circulation than VAVD groups ($P = 0.034$), whereas the flow rate of the pump was similar in all groups during CPB (**Table 2**). There was no statistically significant difference among the groups for the requirement of blood product transfusion to prevent anemia or thrombocytopenia (**Table 3**).

Interpretation of postoperative laboratory values

Lactate dehydrogenase (LDH) values at postoperative 24th and 48th hours tended to increase insignificantly in three groups when they were compared with preoperative values and this was considered as the possible effect of CPB (**Table 4**). There was no statistically significant difference among the groups in terms of platelet (Plt), mean platelet volume (MVP), and haptoglobin (Hpt) values.

Discussion

In our study, we observed that using the VAVD technique decreased any transfusion amount of blood products compared to conventional GD techniques. Blood transfusion requirement, especially red cells, was lower in Group 1 (25%) and Group 2 (30%) than the GD group (40%); however, this difference did not reach statistical significance. Without any additional administration of fluids into the circulation, the VAVD techniques sustained the adequate mean pump flow due to increased venous return. Despite using a smaller cannula in the VAVD groups, we did not observe any problem with venous drainage or cardiac decompression. Similarly, we did not find any significantly VAVD-induced blood cell destruction in all groups. Secondly, there were no postoperatively neurological problems caused by hemolysis or micro-emboli.

In the literature, it has been shown that the VAVD technique reduces the amount of blood transfusion [7-11]. Less use of blood products in CPB contributes to reducing Intra- and postoperative complications. Likewise, VAVD is used in minimally invasive and pediatric cardiac surgery with the idea to reduce the amount of blood transfusion [12-15]. Another reported benefit of the VAVD technique is its contribution to the visualization of the surgical field, whereas inadequate venous drainage makes it challenging to see the surgical site [2]. Because of its advantages, such as decreasing priming volume and the volume of blood transfused, increasing venous drainage, and maintaining an emptier heart with a dried operative field, the usage of VAVD techniques has been growing in the last decade [16, 17]. In a meta-analysis, VAVD was found to be a 79% beneficial

Table 4. The evaluation of platelet, lactate hydrogenase, and haptoglobin values

	Group 1	Group 2	Control group	*P*
Plt (10^{x9} per liter)				
Preoperative	234.9 ± 70.2	254.7 ± 82.8	236.9 ± 55.2	0.629
Postop 24th hour	156.5 ± 55.3	183.9 ± 62.1	172.2 ± 62.9	0.367
Postop 48th hour	156.1 ± 53.8	187.6 ± 60.5	165.2 ± 57.1	0.136
MPV (f/dl)				
Preoperative	8.6 ± 1.1	8.6 ± 1.2	8.9 ± 1.1	0.521
Postop 24th hour	8.9 ± 1.4	8.9 ± 1.1	9.3 ± 1.2	0.508
Postop 48th hour	8.9 ± 1.1	8.9 ± 1.3	9.4 ± 1.2	0.336
LDH (unit per liter)				
Preoperative	191.5 ± 43.8	196.4 ± 35.7	223.9 ± 85	0.188
Postop 24th hour	439.5 ± 143.1	419.2 ± 148.6	411 ± 100.3	0.782
Postop 48th hour	353.1 ± 126	339.1 ± 102.1	341.1 ± 87.7	0.487
Hpt (mg/dL)				
Preoperative	1.32 ± 0.72	1.69 ± 1.21	1.28 ± 0.66	0.298
Postop 24th hour	0.72 ± 0.41	1.26 ± 0.82	0.76 ± 0.51	0.6
Postop 48th hour	1.07 ± 0.61	1.26 ± 1.01	0.92 ± 0.54	0.336

Note: Hpt: Haptoglobin, LDH: Lactate hydrogenase, MVP: mean platelet volume, Plt: Platelet. Values are expressed as mean ± standard deviation.

technique to reduce hemodilution, blood transfusion, surgical site visibility, hemolysis, and embolism risks despite the preference of a smaller cannula [18].

One of the serious morbidities of CPB is hemolysis, which depends on mechanical circulation and its' components (e.g., pump type, oxygenator, cannula sizes, foreign surfaces, suctions). Additionally, it has been reported that the VAVD technique during CPB also may be one of the reasons for hemolysis [7]. Even though there is no consensus on the adverse effect of VAVD techniques on hemolysis, it has been observed that hemolysis at negative pressure is the same as hemolysis that occurs in GD [9]. Besides, it has also been shown that VAVD is a technique that can be positively compared with GD in terms of hemolysis and blood transfusion [10].

Kwak and colleagues [19] informed that negative pressure up to 60 mmHg did not increase hemolysis in pediatric patients, which was practiced providing effective venous drainage without hemolysis and to determine the adequate and appropriate level of negative pressure. Even more, Murai and colleagues [12] reported that there was no increase in hemolysis in mean 76 mmHg negative pressure by applying 90 mmHg negative pressure. Nevertheless, Goksedef and colleagues [2] stated that 80 mmHg negative pressure increased hemolysis, and they recommended not preferring higher vacuum pressure during CABG when they compared VAVD with -80 and -40 mmHg vacuum pressure. It ought to be considered that appropriate negative pressure range over -60 mmHg may increase the risk of hemolysis in the light of these studies.

In our study, we compared negative vacuum pressures preferred for the VAVD technique to show which negative pressure level had lower or no adverse effect on blood cells, with a similar positive impact on venous drainage and avoidance of blood transfusion. We found that the VAVD technique with moderate (-40 mmHg) or medium-high (-60 mmHg) negative pressures did not increase hemolysis by providing adequate venous drainage in this study. In contrast, the need for blood transfusion ratio and Hpt level was slightly higher in Group 2 with -60 mmHg negative pressure.

Bevilacqua and colleagues [10] examined the potential advantages of GD and VAVD technique on the prevention of blood cells. They reported that Plts were better protected since shear stress and contact were less in the VAVD group, and the red blood cell was held less in the cannula and reservoir. Hemolysis is a fact in all extracorporeal circuits, by the increasing levels of plasma-free hemoglobin and decreasing levels of Hpt during and after CPB [19-21]. However, Hayashi and colleagues [8] showed that the decrease in Hpt value remained the same between groups with GD and VAVD with -30 mmHg. Mürai and colleagues [12] stated that the postoperative maximum LDH value was similar between the groups, did not affect surgical procedures, and did not cause any clinical problems. Also, Mueller and colleagues [9] showed that LDH levels remained the same between the groups.

In this study, no significant difference was observed in the Plt values among the groups. But, Plt values in Group 2 tended to increase in comparison with preoperative Plt values in the 24^{th} and 48^{th} hours. In our study, preoperative Hpt values tended to decrease when they were compared with postoperative 24^{th} and 48^{th} hours, and the decrease rate remained insignificant among the groups but declining in the Group 2 remained lower than the Group 1. LDH values at postoperative 24^{th} and 48^{th} hours tended to increase in comparison with the preoperative values. It was observed that this increase depended on the known mechanical effect of CPB and remained at tolerable levels.

Conclusion

We consider that VAVD is a beneficial technique even with lower negative pressure value. If VAVD is used, the negative pressure can be preferred between -40 and -60 mmHg without any significant difference in hemolysis or perfusion flow. Still, lower negative pressure is more advantageous to provide lower blood transfusion and better avoidance of gas embolism without weaker venous drainage.

Disclosure of conflict of interest

None.

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