Thoracic Endovascular Aortic Repair with Chimney Technique (Chimney TEVAR) for Aortic Arch Pathologies: Cardiovascular Problems during Anesthesia

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Background: *Chimney TEVAR is a new alternative surgical treatment for aortic arch pathologies. As being a developing surgical technique, there might be some unknown cardiovascular problems during anesthesia.*
Objective: *To investigate cardiovascular problems during anesthesia.*
Material and Method: *Retrospective review of medical records between 2010 and 2013 found that chimney TEVAR were operated in 16 cases. From anesthetic records, cardiovascular parameters were collected and descriptive statistic and pair-t-test were applied; abnormal events were focused, traced, and logically depicted.*
Results: *During chimney insertion, NIBP (at left) were used instead of IBP (at right) in 50% of cases, MAP was lowest, and CVP was increased. Overall during surgery, decreasing of MAP from baseline (mean = -36.25±21.94 mmHg) was observed throughout the operation and with statistical significance. Serious cardiovascular instability of 12.5% were observed. Base on blood transfusion and hematocrit level, the assessed amount of blood loss was inappropriate and underestimated in 75% of cases.*
Conclusion: *1) It was not safe to monitor blood pressure only at right arm, 2) underestimated assessment of blood loss was common and caused hypotension, 3) volume status was hardly assessed by basic monitors and CVP did not help for volume assessment, and 4) fatal cardiovascular instability could happen.*

Keywords: *Chimney, TEVAR, Innominate, Blood loss estimation, Hypotension*

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Thoracic endovascular aortic repair (TEVAR) has been an effective alternative treatment for thoracic descending aortic aneurysm or dissections for a decade(1). Recently, TEVAR has been developed to be implemented for thoracic arch pathologies in accordance with cerebral blood flow-provided techniques. To establish cerebral blood flow after placing the aortic stent at arch of aorta, debranching arch technique (hybrid TEVAR), or chimney stent placement (chimney TEVAR) is needed to be cooperated with TEVAR. However, chimney TEVAR has been reported to be safer in many aspects(2,3). Therefore, chimney TEVAR presently becomes a preferable treatment of choice.

Chimney TEVAR is to place chimney (small-diameter) stent into supra-arch vessels to prevent brain and upper limbs ischemia from covering of non-fenestrated aortic stent at arch. Surgical plan of arteries to insert chimney stents might be different. The arteries that can be chosen to insert a chimney stent are commonly radial, axillary, or subclavian arteries both left and right. As a result, such a surgical procedure is likely to cause disturbance of blood pressure monitoring during anesthesia. Moreover, as a new surgical technique, some unknown cardiovascular problems during anesthesia have not been revealed. Therefore, the present study was aimed to investigate cardiovascular problems during anesthesia for chimney TEVAR.

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Material and Method

This retrospective study was approved by the Institutional Ethic Committee (IRB No. 472/57). Medical records of operation in cardiothoracic operating theater between 2010 and 2013 had been reviewed. The words ‘chimney or chimney TEVAR’ that were stated at a section of ‘operation done’ on summary charts were included in the present study.

There were 16 cases of operating chimney TEVAR. These medical records were reviewed in aspects of demographic data, site and type of pathology, surgical techniques, and cardiovascular problems during anesthesia. Cardiovascular problems were firstly defined as abnormal cardiovascular status during anesthesia. Thus, cardiovascular parameters that were recorded in anesthetic records (blood pressure, heart rate, central venous pressure (CVP), urine output, and amount of blood loss) were collected. All the recorded data were separately reviewed by two reviewers. If the recorded parameters from the two reviewers were different, another review (3rd) by the two reviewers together was taken in order to verify for the actual data. Descriptive statistic was applied. Pair-t-test was applied for differences of blood pressure, heart rate, and CVP from the baseline.

The second operational definition of cardiovascular problems was unusual events during anesthesia that could be related to cardiovascular instability. Therefore, unusual events that were observed from the anesthetic records were focused, traced, and depicted case by case. Perioperative hematocrit level and blood transfusion were traced and logically analyzed.

Results

Chimney TEVAR were operated in 16 patients. Among 16 patients, 13 patients were male (81.25%). Almost of the patients were age over 60 years (81.25%). Comorbid underlying diseases were found in 13 patients (81.25%). Hypertension (HT) was the most common underlying disease. Co-underlying diseases were usually ischemic heart disease (IHD), diabetes (DM), and chronic renal failure (CRF). The aortic arch pathologies were usually combined with the descending aorta. Proximal pathology and distal pathology were defined as the involvement at the innominate artery and at left carotid artery, respectively[3]. Distal pathologies were found more common (13 patients, 81.25%) than those of proximal pathologies (Table 1).

The surgical technique of chimney TEVAR was to place the main stent via the left or right femoral artery and insert only a chimney stent at an innominate artery via the right subclavian artery in all 16 cases. In addition, a carotid-to-carotid bypass was done with an artificial graft diameter size 6 to 10 mm before the intervention procedure. There were two patients who received another bypass procedures (left carotid to left subclavian artery bypass graft) due to surgical indication. Chimney TEVAR was started after completion of the bypass procedures. The Chimney stent placing was done simultaneously with the aortic arch stent placing. This process took 42.50±12.28

Table 1. Demographic data and aortic pathologic involvement

Case	Sex	Age	Comorbid	Arch pathologies involvement		Other aortic pathologies
				Proximal	Distal	
1	M	85	HT, COPD		X	Proximal descending
2	M	55			X	Proximal to mid descending
3	M	78	HT		X	Proximal descending
4	F	62			X	Proximal descending
5	M	51	HT		X	Proximal descending
6	M	60	HT, IHD		X	Proximal to mid descending
7	F	77	CRF, IHD	X		
8	M	64	DM	X	X	
9	F	72	IHD	X	X	
10	M	66	CRF, DM, HT	X	X	Supra and infra renal
11	M	47	HT		X	Proximal descending
12	M	77	HT, DM	X		
13	M	73	HT, CRF	X		
14	M	65	HT, DM, CVA		X	Proximal to mid descending
15	M	77			X	
16	M	71			X	

HT = hypertension; IHD = ischemic heart disease; CRF = chronic renal failure; DM = diabetes mellitus; CVA = cerebrovascular accident; COPD = chronic obstructive pulmonary disease minutes. After that, some cases needed several aortic stents at distal to the arch stent. The average total duration of operation was 3.96±0.99 hours.

General anesthesia with endotracheal tube was a technique of choice for all of the cases. Induction of anesthesia was intravenous (IV) induction and was different in type of IV anesthetics (thiopental, propofol and etomidate). Maintenance of anesthesia was proceeded by sevoflurane and fentanyl in all of the cases. Pancuronium and cistracurium were commonly used for relaxation.

Non-invasive blood pressure (NIBP) and invasive blood pressure (IBP) were set at right arm and left radial artery in all cases respectively. Intraoperative blood pressure was problematic during insertion of chimney stent, which was approximately in the beginning of 2-hour (Table 2). Firstly, lower mean arterial blood pressure (MAP) from the baseline were detected in most cases (93.75%). The averaged MAP was down to the lowest value, as low as 70 mmHg. The mean value of MAP changes was -36.25±21.94 mmHg. Secondly, there had been events that anesthesiologists used NIBP instead of IBP for monitoring in eight cases (50%). The average MAP variation during the chimney procedure in cases that were monitored by IBP and NIBP were -33.75±25.60 and -38.75±19.04 mmHg. The MAP during anesthesia was a tendency to be lower from the baseline till the end of operation (Fig. 1). Differences of MAP at the 1-, 2-, and 4-hour were statistically significant (*p*-value <0.05).

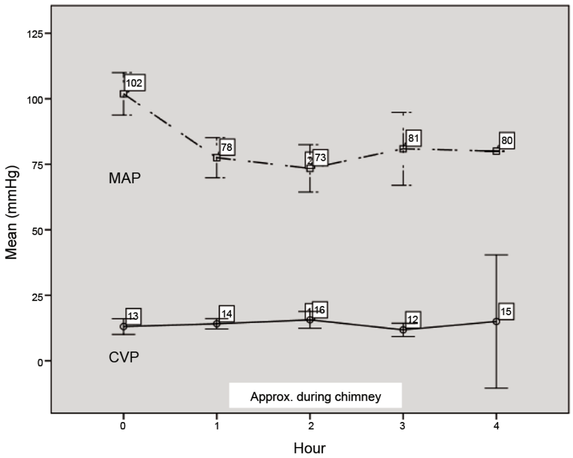
CVP was monitored, the average baseline value was 13.06±5.58 mmHg. During the chimney procedure, CVP showed increasing up to the highest value approximately 15.63±6.01 mmHg (Fig. 1). The differences between CVP at the 1-, 2-, and 4-hour and the baseline were not statistically significant.

Arrhythmias were demonstrated in 3/16 cases (18.75%). Serious dysrhythmia was occurred in one case (case 9) due to migration of a chimney stent down to aortic valve. As a result, severe aortic regurgitation suddenly happened then followed by asystole. Aggressive management to support cardiovascular function was done with epinephrine bolus and infusion. Blood pressure could not be maintained in an acceptable level until the migration stent was removed out of the aortic valve. Premature ventricular contraction (PVC) with no cardiovascular instabilities were presented in two cases (Table 3). The variation of heart rate during anesthesia was not statistically significant.

Table 2. Variation of MAP and site of blood pressure monitoring during chimney procedure

Case	MAP baseline (mmHg)	MAP during chimney (mmHg)	MAP difference from baseline (mmHg)	Monitor used during chimney (n)
1	120	80	-40	IBP
2	100	60	-40	NIBP
3	90	80	-10	NIBP
4	100	90	-10	IBP
5	110	70	-40	NIBP
6	110	80	-30	IBP
7	70	70	0	IBP
8	100	70	-30	IBP
9	120	50	-70	NIBP
10	120	50	-70	IBP
11	100	80	-20	IBP
12	110	40	-70	IBP
13	70	55	-15	NIBP
14	110	70	-40	NIBP
15	100	50	-50	NIBP
16	100	55	-45	NIBP
Frequency, mean ± SD	101.88±15.15	65.63±14.48*	-36.25±21.94	NIBP 8/16 (50%)

MAP = mean arterial blood pressure;IBP = invasive blood pressure; NIBP = non-invasive blood pressure
* *p*-value <0.05



Significant differences of MAP at 0 hour and MAP at 1-, 2-, or 3-hour at p-value <0.05. No significant difference of CVP at any hour

Fig. 1 The average MAP and CVP throughout the operation.

Urine output monitoring was found an unusual event. No record of urine output found in anesthetic record with no reasons noted (Table 3). Averaged total urine output during anesthesia per the operation hour were calculated (Table 3). Unacceptable urine output (<0.5 mL/kg/hour) were found in 3 cases (18.75%). Low but acceptable urine output (0.5 to 1 mL/kg/hour) were found in six cases (37.50%).

Inotropic drugs were used for circulatory support in 4/16 cases (25%). Dopamine infusion was used in two cases (case 10 and 15). It was possibly due to a decrease of blood pressure. For the first case, norepinephrine infusion was started after induction of anesthesia. For the ninth case, epinephrine was administered intravenously for cardiovascular resuscitation as previously stated. Both expired in the early postoperative period. The first case was dead from severe stroke. The ninth case was dead from multiple organ failure.

Surgical blood loss monitoring noticed some abnormal events (Table 4). No record of surgical blood loss in the anesthetic records was found in 5/16 (31.25%). In addition, there were Pack red cell (PRC) transfusion in four cases that noted amounts of blood loss as 100, 150, 50, and 100 mL (case 10, 13, 14, and 15). These findings might imply that much more blood loss than that of the records.

Pre- and postoperative hematocrit levels had to be traced for estimating the actual blood loss (Table 4). Postoperative hematocrit level (hematocrit at arrival ICU) was found lower than that of the baseline (preoperative hematocrit) in 12/16 cases (75%). Mean value of the hematocrit differences (baseline hematocrit-postoperative hematocrit) was -3.82±4.78%. These findings confirmed that more blood loss than those presented in the records.

PRC transfusion had to be traced together with the hematocrit levels (Table 4). Among five cases (case 3, 5, 6, 7, and 11) that presented no record of blood loss, PRC was not transfused intraoperatively. However, the hematocrit differences had very negative values (-4.4%, -7.2%, -9%) in 3/5 cases (case 5, 7, and 11, respectively). Among 11 cases presenting record of blood loss, the hematocrit difference had high negative values (-6%, -4%, -6.2%, -15.7%, -7.3%) in five cases (case 1, 4, 8, 9, and 14, respectively). Five cases (case 10, 12, 13, 14, and 15) were noted that the amount of surgical blood loss were 50 to 150 mL, but 1 or 2 units of PRC were transfused in four cases, in which their postoperative hematocrits did not correspond to the number of blood transfusion. In fact, the postoperative hematocrits should be higher than that of the presented values. Therefore, these findings demonstrated that assessment of blood loss were lower than the actual blood loss in 12 cases (75%).

Table 3. Abnormal cardiovascular status or unusual events: abnormal rhythms, urine output, and cardiovascular instability

Case	Arrhythmia	Total urine output (mL/kg/hour)	Cardiovascular support infusion
1		0.81	Norepinephrine
2		1.90	
3		No record	
4		0.45	
5		1.41	
6		1.21	
7	PVC	1.23	
8		1.03	
9	Asystole	0.88	Epinephrine
10		Chronic renal failure	Dopamine
11		0.38	
12		0.66	
13		0.38	
14		0.77	Dopamine
15	PVC	0.93	
16		0.77	

PVC = premature ventricular contraction

Table 4. Unusual events: irrelevance of surgical blood loss and PRC transfusion and hematocrit level

Case	Surgical blood loss (mL)	PRC transfusion (unit)	Hematocrit baseline (%)	Hematocrit at ICU arrival (%)	Hematocrit difference (%)
1	500	2	40.0	34.0	-6.0
2	300	0	41.0	39.0	-2.0
3	No record	0	48.3	46.3	-2.0
4	200	0	42.0	38.0	-4.0
5	No record	0	34.8	30.4	-4.4
6	No record	0	39.0	40.0	1.0
7	No record	0	36.2	29.0	-7.2
8	300	0	36.1	29.9	-6.2
9	1,500	6	40.7	25.0	-15.7
10	100	1	32.0	32.5	0.5
11	No record	0	40.0	31.0	-9.0
12	50	0	34.0	31.4	-2.6
13	150	2	27.0	31.0	4.0
14	50	1	36.3	29.0	-7.3
15	100	1	32.0	33.0	1.0
16	200	0	34.0	32.7	-1.3

PRC = pack red cell; ICU = intensive care unit

Discussion

Chimney TEVAR claims high success rate, reduction of stroke, and reduction of mortality[3-6]. Therefore, chimney TEVAR is an operation that will be increasingly applied for aortic arch surgeries in the near future. The procedure of chimney TEVAR is more complicated than that of basic TEVAR. The difference between Chimney TEVAR and basic TEVAR is to open more artery sites for chimney TEVAR than the basic TEVAR (approach only at both femoral arteries). For chimney stent placement, one or two arteries of upper limbs are opened, based on the decision of the surgeon. The surgical technique for chimney graft insertion in the present study was to open right subclavian artery for introducing the chimney graft into the innominate artery. For this procedure set up for blood pressure monitoring is needed to be planned in accordance with the surgical technique before starting anesthesia.

Normally, IBP should be set at right radial artery because the aorta arch pathology might be extended down to the origin of left subclavian artery, which causes lower blood pressure than the actual systemic blood pressure. The present study revealed 81.25% of descending aorta involvement. Thus, blood pressure measured at right upper limb is assumed to approximate the actual systemic blood pressure. Base on this reason, IBP was set at right radial artery in the present study. However, NIBP was set at left arm for possible monitoring while being occlusion at right subclavian artery during chimney stent placing. Base on the study results, it found that 50% of cases had to monitor by NIBP during chimney stent insertion because blood pressure could not be measured due to stent occlusion. This observation reconfirmed that blood pressure should be monitored more than one site. Even though, the blood pressure measured from the left arm might not truly represent the systemic blood flow as previously mentioned. However, the present study revealed the variation of blood pressure during the chimney procedure monitored by IBP and NIBP seemed not to be different. This finding might imply that monitor by NIBP could be used. In other words, it may not be necessary to monitor two sites of IBP. However, it needs two upper limb sites of blood pressure monitoring.

During the chimney procedure, profound hypotension had been detected for all of the cases. Occlusion of blood flow to distal during chimney stent inserting was priority postulated. However, permissive hypotension was a co-cause of hypotension. Permissive hypotension during aortic stent is for preventing distal migration of the aortic stent, which is an anesthetic consideration[7]. As aortic stent is normally manipulated just after the chimney stent, lowering the blood pressure has to be started during the chimney procedure. Thus, permissive hypotension was an existing cofactor of hypotension. Although causes of profound hypotension during chimney procedure could be clearly explained, but profound hypotension should not be ignored, because end organ ischemia might occur if there is inadequate cardiac output. In summary, profound hypotension in chimney TEVAR commonly occurs.

Assessment of blood loss seemed to be a problem. As shown in the findings, no record of surgical blood loss was recorded in 30% of the cases. A reason in common sense of no record of blood loss in anesthetic record might be due to minimal blood loss. However, there was evidence that some cases had significant low postoperative hematocrit levels (>3% from baseline). That meant blood loss in these cases could be at least 300 mL[8,9]. Thus, the question was why the amount of blood loss could not be detected? Firstly, the nature of blood loss in TEVAR comes from femoral arteries that are opened in order to insert aortic stents. Since the femoral areas have no chamber for collecting blood loss, almost of the blood loss is absorbed by surgical drape cloths[10]. For chimney TEVAR, it is harder to assess blood loss than basic TEVAR because more sites of arteries are opened. Also, before placing aortic and chimney stents, the procedure needs to take some time to simultaneously adjust for according positions between the aortic stent and the chimney stent. The more time it takes, the more bleeding occurs from the opening arteries[10]. For the last reason, anesthesiologists have to pay attention to blood pressure that is abruptly decreasing during chimney stent insertion as the first priority. Therefore, continuous assessment of blood loss is perhaps interrupted. In summary, assessment of blood loss during chimney TEVAR was so difficult that it was most likely being underestimated.

Continuous decreasing blood pressure from the baseline was a cardiovascular problem during chimney TEVAR. This finding was striking because of the significant low blood pressure presented as high as -70 mmHg. A cause of decreasing blood pressure explained by underestimation of blood loss that leaded to hypovolemia. Despite the fact that low cardiac output during permissive hypotension was another cause of low urine output, but this mechanism should affect only an hour after permissive hypotension and should not effect throughout the operation. Unacceptable and low urine output (total urine count) that were found in most of the cases were likely to be a supporting evidence of existing hypovolemia. In addition to hypovolemia and permissive hypotension, causes of decreasing blood pressure might also be low systemic vascular resistance (from brain or spinal cord ischemia, reaction to stent, general anesthesia), and myocardial dysfunction[11]. Therefore, once hypotension occurs; multifactor should be introspected. Regarding to the present study, vivid evidences were demonstrated that continuous decreasing blood pressure predominately caused by hypovolemia.

CVP is a basic tool for assisting volume assessment, in which the tendency of decreasing CVP value might imply hypovolemia. The present study demonstrated that CVP could not be a useful monitor to follow volume status during chimney TEVAR. As CVP is increased by a mechanism of aortic stent-induced release of endothelial vasopressin during stent insertion[12]. As a result of endothelial vasopressin circulating in blood flow for a while, CVP is increasing after placing the aortic stents for a moment. The present study demonstrated that the mentioned mechanism was real as CVP was increasing after stent placing despite the fact that hypovolemic status was most likely occurred at that time. Therefore, monitoring of CVP could not be interpreted for volume assessment in chimney TEVAR.

Vasopressor or inotropic drug infusion were provided in 25% of case. Fatal cardiovascular complication was approximately found 12.5% in the present study. Arrhythmia was found in 18.75%. Serious cardiovascular instabilities that presented in the present study could be traced in the ninth case caused mainly by surgical intervention, but in the first case might be caused by his medical conditions with or without surgical intervention. Focus on the surgery cause, a high possibility of cardiovascular instability occurred because the procedure is near to the heart. Endovascular guidewire is needed to pass more proximal than the pathologies, which is commonly introduced into the heart. Unlike basic TEVAR still which was viewed as safer than in the past[13], chimney TEVAR remains in the phase of learning. Therefore, anesthesiologists should always be aware of serious cardiovascular instabilities during chimney TEVAR.

Chimney TEVAR in the present study was the modified surgical technique to reduce the number of open artery sites in order to reduce blood loss by only opening at the right subclavian artery. Importantly, there was a reduction of time for chimney stent insertion and a reduction of direct manipulation in carotid arteries by only inserting a chimney stent at the innominate artery. This modified surgical technique assumed that single endovascular carotid procedure would be less likely to produce mobile plaques inducing stroke[14]. However, bi-carotid bypass had to operate before single-chimney TEVAR. Regarding to the present study, pathology of aortic arch commonly occurred with pathology at descending aorta. Therefore, inserting a few aortic stents for treatment of the descending aorta after treating arch pathology might be done simultaneously. As a result, chimney TEVAR is a more sophisticated operation than the basic TEVAR. In addition, surgical approaches are usually modified. Therefore, surgical plans are varied and different despite the same pathologies. Thus, anesthesiologists should be aware of this point of view. In other words, anesthesiologists need to exactly know current pathologies and surgical plans.

General anesthesia can cause some degree of hypotension. However, in the present study, general anesthesia with endotracheal tube is a safe and standard technique for this modified operation. As previously mentioned, the operation was not pure endovascular surgery, it began with carotid-to-carotid bypass. As a result, intravenous sedation technique or general anesthesia with laryngeal mask airway might not be safe for securing airway. Moreover, general anesthesia is not the contraindication for cardiovascular instability condition.

A limitation of the present study was a small sample size, which is too small to be confident that the results are generalizable. A future study with more samples should be done. However, as being a pilot study, the present study could reveal the overall picture of cardiovascular dynamics and problems during anesthesia for chimney TEVAR.

Conclusion

Cardiovascular problems to be concerned were 1) it was not safe to monitor blood pressure only at right upper limb, 2) underestimated assessment of blood loss was common and caused hypotension, 3) volume status was hardly assessed by basic monitors and CVP did not help for volume assessment, and 4) fatal cardiovascular instability could be happened.

What is already known for this topic?

Anesthesiologists have gained much experience for providing anesthesia for Basic TEVAR as it has been an effective alternative for aortic type B pathologies (involving only descending aorta) for many decades. Chimney TEVAR is a recent surgical technique to treat the pathologies of aortic arch. Its outcomes have just been reported based on a reasonable sample size in form of a meta-analysis study[6]. These reported outcomes sound fruitful based on comparing with open repairs. However, these studies were mainly about technical success and surgical complications, such as stroke rate, morbidity, and mortality. No study in aspect of intraoperative adverse event has been done despite the fact that the surgical procedure of chimney TEVAR is more sophisticated than that in basic TEVAR. In summary, cardiovascular problems during anesthesia in chimney TEVAR for aortic arch lesions have not been documented.

What this study adds?

This study is the first study that documents cardiovascular instabilities during chimney TEVAR. Moreover, this study revealed problems of monitoring of blood loss and volume status during anesthesia. The value of this study results at least in highlighting the incidents of cardiovascular changes. Therefore, this knowledge might help anesthesiologists to be aware of the cardiovascular instabilities and to prepare to confront some difficult situations.

Potential conflicts of interest

None.

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การผ่าตัดใส่ขดลวด (chimney TEVAR) สำหรับพยาธิสภาพหลอดเลือดแดงเอออร์ตาส่วนโค้ง: ปัญหาเกี่ยวกับระบบหัวใจและหลอดเลือดขณะให้การระงับความรู้สึก

วัชริน สินธวานนท์, ฝนทิพย์ ลีลาเชี่ยวชาญกุล

ภูมิหลัง: *การผ่าตัดใส่ขดลวดและขดลวดขนาดเล็ก (chimney TEVAR) เป็นการรักษาทางเลือกสำหรับพยาธิสภาพหลอดเลือดแดงเอออร์ตาส่วนโค้ง เนื่องจากเทคนิคนี้มีการนำมาใช้ในการรักษาไม่นาน จึงยังไม่มีองค์ความรู้เกี่ยวกับปัญหาเกี่ยวกับระบบหัวใจและหลอดเลือดในระหว่างให้การระงับความรู้สึก*

วัตถุประสงค์: *เพื่อสืบค้นปัญหาเกี่ยวกับระบบหัวใจและหลอดเลือดในขณะให้การระงับความรู้สึก*

วัสดุและวิธีการ: *ทำการทบทวนเวชระเบียนในระหว่าง พ.ศ. 2553 ถึง พ.ศ. 2556 โดยเวชระเบียนที่บันทึกว่ามีการผ่าตัด chimney TEVAR มีจำนวน 16 ราย ทำการรวบรวมตัววัดการทำงานของระบบหัวใจและหลอดเลือดที่ติดตามระหว่างการระงับความรู้สึก ใช้สถิติเชิงพรรณนาและเชิงอนุมานช่วยแสดงผล และติดตามเหตุการณ์ที่ไม่ปกติจากใบดมยา โดยสืบค้นสาเหตุเบื้องหลังด้วยความเป็นเหตุเป็นผลเชิงตรรกะ*

ผลการศึกษา: *ในขณะใส่ขดลวดขนาดเล็ก (chimney stent) พบว่ามีการใช้ค่าความดันโลหิตแบบ NIBP (ด้านซ้าย) แทนการติดตามด้วยค่าความดันโลหิตแบบ IBP (ด้านขวา) ร้อยละ 50 ของผู้ป่วย พบความดันโลหิตต่ำที่สุด และร่วมกับค่า CVP สูงขึ้นในระหว่างผ่าตัดโดยรวม พบว่าความดันโลหิต MAP ลดต่ำจากค่าเริ่มต้นและต่ำลงเรื่อยตลอดการผ่าตัด (ค่าเฉลี่ยความดัน MAP ที่ต่ำลง เท่ากับ -36.25±21.94 มม.ปรอท) ซึ่งมีนัยสำคัญทางสถิติ ระบบไหลเวียนโลหิตไม่คงที่อย่างมากซึ่งคิดเป็นร้อยละ 12.5 ของผู้ป่วย และร้อยละ 75 ของผู้ป่วยได้รับการประเมินปริมาณเลือดออกที่ไม่สอดคล้องเมื่อพิจารณาจากการให้เลือดรวมทั้งค่าความเข้มข้นของเม็ดเลือดแดง พบว่าเป็นการประเมินการเสียเลือดน้อยที่กว่าความเป็นจริง*

สรุป: *1) ไม่ปลอดภัยหากติดตามความดันโลหิตเฉพาะที่แขนขวา 2) มีการประเมินเลือดออกน้อยกว่าความเป็นจริงและเป็นเหตุนำไปสู่ภาวะความดันโลหิตต่ำ 3) การประเมินปริมาณสารน้ำด้วยเครื่องมือการติดตามพื้นฐานกระทำได้ยาก และนำค่า CVP มาช่วยประเมินไม่ได้ และ 4) ภาวะหัวใจและหลอดเลือดผิดปกติที่อันตรายถึงชีวิตอาจเกิดขึ้นได้*