의학석사 학위논문

Optimal Level of Transducer for Measuring Atrial and Pulmonary Arterial Pressure in Patients with Functional Single Ventricle

기능적 단심실 환자들의 심방 및 폐 동맥 압력 측정 시 최적의 변환기 위치

2016 년 2 월

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유 다 혜

A thesis of the Degree of Master of Science in

Clinical Medical Sciences

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The Department of Clinical Medical Sciences

Seoul National University

College of Medicine

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by Da Hye Yoo

A thesis submitted to the Department of Clinical Medical Sciences in partial fulfillment of the requirements for the Degree of Master of Science in Clinical Medical Sciences at Seoul National University College of Medicine

February 2016

Approved by Thesis Committee:

Professor ____________________ Chairman

Professor ____________________ Vice chairman

Professor ____________________

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지도교수 김 진 태

이 논문을 의학석사 학위논문으로 제출함

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2016 년 2 월

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ABSTRACT

Introduction: Obtaining accurate hemodynamic data is the first step in making a correct decision for the hemodynamic management of patients with congenital heart disease. This study was conducted to investigate the optimal transducer position for atrial and pulmonary arterial pressure monitoring in the supine and sitting position in patients with functional single ventricle.

Methods: Contrast enhanced chest computed tomographic data of 108 patients who underwent either bicaval pulmonary shunt (BCPS) placement or the Fontan procedure were retrospectively reviewed. From the transverse-section images, vertical distances between the skin of the back and the uppermost fluid levels of the single atrium and pulmonary artery, and their ratios to the largest anteroposterior (AP) diameter of the thoracic cage were calculated for the supine position. For the sitting position, distances between the mid-sternoclavicular joint and the most cephalad fluid levels of the atrium and the pulmonary artery and their ratios to the sternal length were calculated. Each level was determined with regard to the corresponding rib or intercostal space.

Results: The ratios of the uppermost blood level of the atrium and pulmonary artery to the largest AP diameter of the thorax in the patient who underwent BCPS placement in the supine position were 76.0 ± 8.1%, and 56.3 ± 5.5 %, respectively. These values were 79.3 ± 10.0% and 58.3 ± 5.8% respectively, in the patients who underwent the Fontan procedure.

In the sitting position, the ratios of the most cephalad blood level of the atrium and pulmonary artery to the sternal length in the patients who underwent BCPS placement were 51.4±11.2%, and 42.2±8.1% respectively, whereas those in the patients who underwent the Fontan procedure was 52.7 ± 8.6% and 41.4 ± 7.1% respectively. The external land mark corresponding to the most cephalad atrium and pulmonary artery was the second intercostal space for both the patients who underwent BCPS placement and those who underwent the Fontan procedure.

Conclusions: Taken together, the optimal transducer levels for measuring atrial and pulmonary arterial pressures in the supine position were at 75-80% and 55-60% of the AP diameter of the thorax respectively for patients with functional single ventricle. For the sitting position, the optimal transducer level for measuring atrial and pulmonary arterial pressures was approximately the second intercostal space.

Keywords: Central venous pressure; supine position; sitting position; congenital heart disease

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INTRODUCTION

For patients with functional single ventricle, the Fontan procedure, by which systemic venous blood flow returns directly into the pulmonary circulation, is the final stage of operation. Prior to undergoing the Fontan operation, patients with functional univentricular hearts usually have bidirectional caval pulmonary shunt (BCPS) status, in which the superior vena cava is connected with the pulmonary artery, thereby relieving ventricular volume loading [1, 2]. In pediatric patients planned to undergo the Fontan procedure or patients with Fontan circulation, accurate measurement of atrial and pulmonary arterial pressures is critical for making a clinically important decision [3].

Proper placement of the reference transducer level may be the first step to obtain accurate pressure. Pulmonary circulation is dependent on the pressure gradient between the atrium and the pulmonary artery. To eliminate the influence of hydrostatic pressure, the reference transducer level should be placed at the uppermost fluid level in the chamber in which pressure is being measured [4-6]. Accordingly, in patients with a BCPS or Fontan circulation, the transducer for pulmonary artery pressure should be at the level of the pulmonary artery [1], whereas for the measurement of atrial pressure, the reference transducer level should be placed at the uppermost fluid level of the atrium.

In the clinical condition, patients can be placed in various positions such as the supine, sitting, and semi-sitting positions. Traditionally, the central venous pressure (CVP) transducer is placed at the midpoint of the anteroposterior (AP) diameter [7, 8] in the supine position and at the junction of the fourth intercostal space (ICS) in the sitting position[9, 10]. However, this traditional reference level is not validated in the context of the concept of the uppermost fluid level. Furthermore, no reference has been established regarding the transducer position for patients with functional single ventricle, and the heterotaxy syndrome.

The purpose of this study was to determine the optimal transducer level for the measurement of pulmonary arterial and atrial pressures in the supine and sitting positions before and after the Fontan procedure, and to examine whether the different isomerism makes a significant difference in the aforementioned parameters.

MATERIALS AND METHODS

This study was approved by the institutional review board of Seoul National University Hospital Seoul (IRB Number 1501-092-642), South Korea, and patient informed consent was waived.

Computed tomographic (CT) data obtained from patients who underwent either BCPS placement or the Fontan procedure were reviewed. All contrast-enhanced chest CT images with a thickness of 1–5 mm were reviewed by a single interventionist. The following data were recorded from transverse-section images: CT image thickness, AP diameter of the thorax, uppermost blood levels of the atrium, and the confluence of pulmonary artery in the supine position; the most cephalad blood levels of the atrium and pulmonary artery for the sitting position; and the mid-sternoclavicular and xiphisternal joint levels. Demographic information, including age, height, weight, sex, and diagnosis, were also collected.

For the supine position, distances between the skin of the back and the uppermost blood level of the atrium, and the confluence of the pulmonary artery were calculated and expressed as A_{supine} and PA_{supine}, respectively. The largest AP diameter of the thorax was measured from the skin on the back to the anterior chest. We calculated the ratios of A_{supine} and PA_{supine} to the largest AP diameter of the thorax, which were expressed as A_{supine}/AP and PA_{supine}/AP, respectively (Figures 1 and 2).

Fig. 1. Transverse sections of chest computed tomography showing the uppermost level of the atrium and the pulmonary artery in the patients with BCPS in the supine position

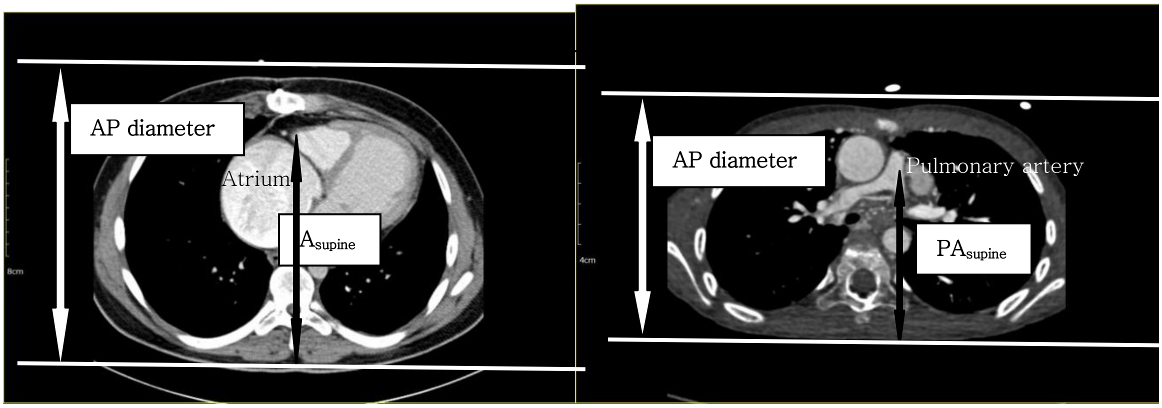

Fig. 1. BCPS: bidirectional carvopulmonary shunt; AP diameter: the largest anteroposterior diameter of the thorax; A_{supine}: the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of the confluence of pulmonary artery in supine position.

Fig. 2. Transverse sections of chest computed tomography showing the uppermost level of the atrium and the pulmonary artery in the patients with the Fontan circulation in the supine position

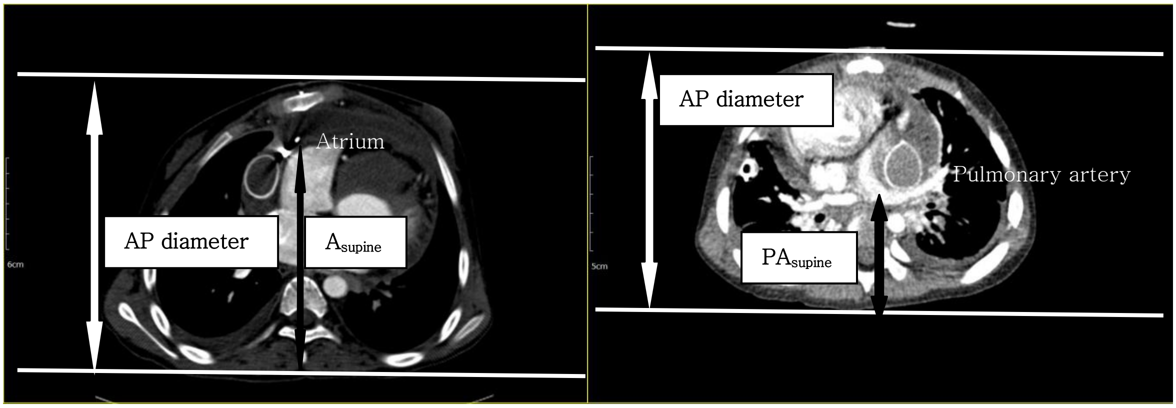

Fig. 2. AP diameter: the largest anteroposterior diameter of the thorax; A_{supine}: the vertical distance from the skin on the back to the most anterior part of the atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of the pulmonary artery in supine position.

Similarly, distances between the sternoclavicular joint and the most cephalad blood levels of the atrium and pulmonary artery were measured and expressed as $A_{sitting}$ and $PA_{sitting}$, respectively. The distance between the sternoclavicular and xiphisternal joints was also measured to obtain sternal length. Then, the ratios of both $A_{sitting}$ and $PA_{sitting}$ to the sternal length were calculated and expressed as $A_{sitting}$/sternum and $PA_{sitting}$/sternum, respectively. To determine the reference levels, the levels of the CT images for the uppermost and most cephalad levels of the atrium and pulmonary artery were marked with regard to the corresponding rib or intercostal space on the parasternal border.

After obtaining data, the patients who underwent BCPS placement were classified into 4 groups according to age as follows: 1–12 months, 1–5 years, 5–15 years, and 15 years or older. The patients who underwent the Fontan procedure were divided into three groups also according to age as follows: 1–5 years, 5–15 years, and 15 years or older.

One-way analysis of variance was used to compare A_{supine}/AP or PA_{supine}/AP, $A_{sitting}$/sternum, and $PA_{sitting}$/sternum between the age groups. Paired *t* test was used to assess the change from before to after the Fontan procedure. Simple linear regression analysis was used to evaluate the relationship between the measured parameters and age. All data were expressed as mean ± standard deviation unless otherwise specified. *P* value less than 0.05 was considered statistically significant. Statistical analysis was performed by using IBM SPSS Statistics 21 (SPSS Inc., IBM Corporation, Armonk, NY, USA).

RESULTS

Contrast-enhanced chest CT images from 108 patients (BCPS group, n = 59 and Fontan group, n = 49) were analyzed. The demographic data of each group are shown in Tables 1-3.

Table 1. The Characteristics of the Patients after BCPS

	1-12mo *n*=16	1-5yr *n*=26	5-15yr *n*=7	>15yr *n*=10	Total *n*=59
Sex (M/F)	12/4	16/10	5/2	6/4	39/20
Age	5.8±4	2.5±0.9	8.5±3.4	28.2±70	7.2±10.4
Weight (kg)	6.9±1.7	12.2±2.0	23.2±7.7	57.7±17.5	19.8±19.4
Height (cm)	70.1±20.1	86.9±9.5	123.8±16.7	159.5±24.0	99.0±35.6
AP Diameter of Thorax (mm)	110.9±6.5	126.5±12.9	149.0±14.4	190.0±42.7	138.6±36.4
Sternal Length (mm)	89.7±37.4	104.1±31.3	157.6±39.3	190.1±42.7	121.1±51.1

Values are expressed as number of patients or mean ± standard deviation.

BCPS: bidirectional carvopulmonary shunt, AP diameter: the largest AP diameter of the thorax.

Sternal Length: the distance between the sternoclavicular joint and the xiphisternal junction.

Table 2. The Characteristics of the Patients after the Fontan Procedure.

	1-5yr *n*=7	5-15yr *n*=24	>15yr *n*=18	Total *n*=49
Sex (M/F)	4/3	12/12	12/6	28/21
Age (yr)	2.6±0.7	8.2±2.2	24.9±5.6	13.5±9.7
Weight (kg)	12.4±1.8	24.6±28.7	59.8±7.6	35.8±20.4
Height (cm)	89.8±6.5	122.8±18.3	168.3±6.7	134.8±31.1
AP Diameter of Thorax (mm)	138.0±5.9	157.0±18.6	203.4±16.5	171.3±30.3
Sternal Length (mm)	122.2±32.5	164.0±39.4	225.3±69.4	180.6±63.0

Values are expressed as number of patients or mean ± standard deviation.

AP diameter: the largest anteroposterior diameter of the thorax.

Sternal Length: the distance between the sternoclavicular joint and the xiphisternal junction.

Table 3. Diagnosis of Patients after BCPS and after Fontan Procedure

	After BCPS	After Fontan Procedure
Heterotaxy syndrome	15	14
Tricuspid Atresia	9	13
Hypoplastic Left Heart Syndrome	6	4
Functional Single Ventricle	25	14
Double Inlet Left Ventricle	3	1
Double Inlet Right Ventricle	1	3
Total	59	49

BCPS: bidirectional cavopulmonary shunt

Supine Position

In the BCPS group, mean A_{supine} was 104.5±25.8 mm, whereas that in the Fontan group was 136.4 ± 31.9 mm. Mean PA_{supine} of BCPS patients was 78.1 ± 22.0 mm whereas that in the Fontan group was 100.1 ± 21.8 mm.

In the BCPS group, the uppermost blood level of the atrium was located mostly at the third ICS and the uppermost pulmonary artery was located primarily at the second ICS (Figure 3). For the Fontan group, the uppermost blood level of the atrium was located at the third ICS and the uppermost level of the pulmonary artery was located at the second ICS (Figure 4).

Fig. 3. Distribution of the rib or intercostal space level corresponding to the uppermost atrium and pulmonary artery of patients after BCPS in supine position.

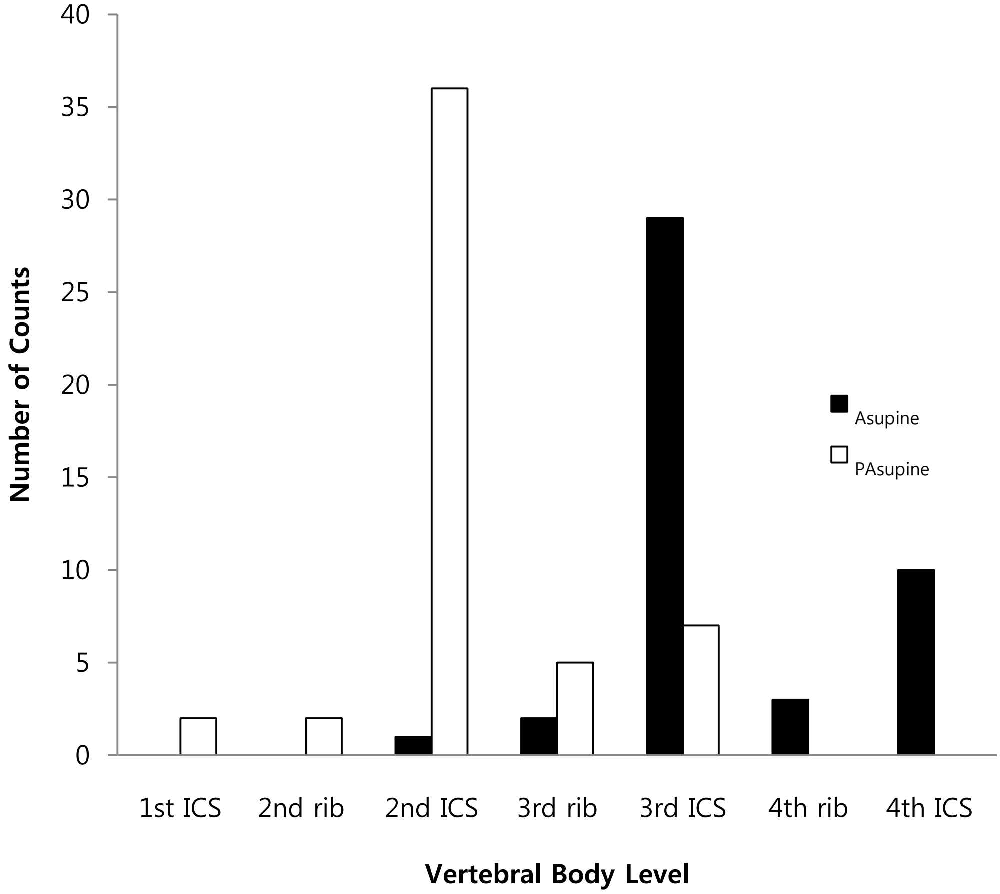

Fig. 3. For BCPS patients in supine position, the uppermost blood level of the atrium was located mostly at the 3rd ICS, whereas the uppermost blood level of the pulmonary artery ranged primarily at the 2nd ICS respectively. BCPS: bidirectional cavopulmonary shunt A_{supine}: the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position

Fig. 4. Distribution of the rib or intercostal space level corresponding to the uppermost atrium and pulmonary artery of patients after Fontan procedure in supine position.

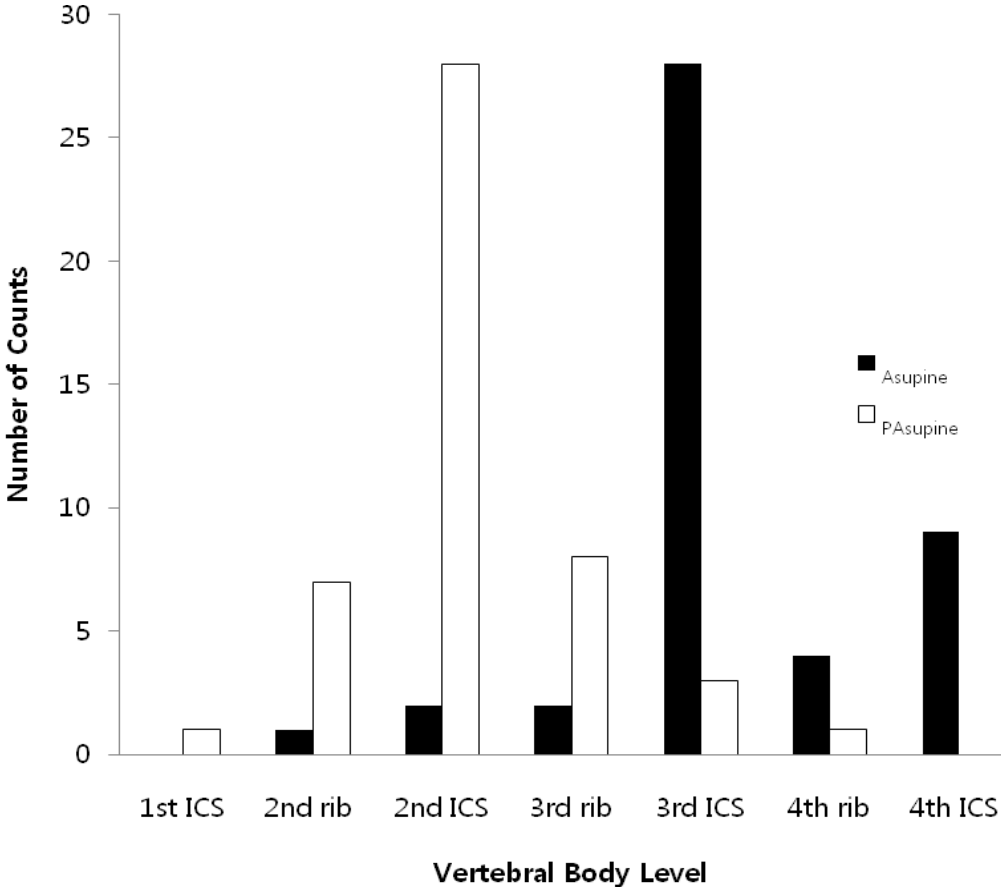

Fig. 4. For Fontan patients, the uppermost blood level of the atrium was located mostly at the 3^{rd} ICS, whereas the uppermost blood level of the pulmonary artery ranged primarily at the 2nd ICS respectively; ICS: intercostal space; A_{supine}: the vertical distance from the skin on the back to the most anterior part of the atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of the pulmonary artery in supine position.

The mean A_{supine}/AP of BCPS patients was 76.0 ± 8.1 %, and that in the Fontan group was 79.3 ± 10.0 %. The mean PA_{supine}/AP of BCPS patients was 56.3 ± 5.5 %, and that in the Fontan group was 58.3 ± 5.8 %. (Table 4 and Table 5, Figure 5 and Figure 6).

Table 4. Parameters of Atrium and Pulmonary Artery of Patients after BCPS.

	1-12mo *n*=16	1-5yr *n*=7	5-15yr *n*=24	≧15yr *n*=18	Total *n=65*
A_{supine}/AP (%) (*P=0.30*)	75.0±7.5	78.4±8.0	76.2±10.7	71.4±5.7	76.0±8.1
PA_{supine}/AP (%) (*P=0.60*)	54.1±5.3	56.7±6.2	60.4±3.3	56.1±3.5	56.3±5.5
D (A_{supine}- PA_{supine}) (mm)	23.1±8.0	27.3±9.8	24.2±18.3	31.2±15.0	26.4±11.6
$A_{sitting}$/Sternum (%) (*P=0.19*)	50.3±11.1	50.4±10.1	50.7±11.3	56.6±14.1	51.4±11.2
$PA_{sitting}$/Sternum (%) (*P*=0.06)	41.5±4.8	41.1±7.5	39.6±10.3	48.1±10.4	42.2±8.1
D($A_{sitting}$- $PA_{sitting}$) (mm)	7.2±5.7	10.49±8.1	25.5±17.7	19.8±17.6	13.0±12.7

Values are expressed as mean ± standard deviation.

BCPS: bidirectional carvopulmonary shunt

A_{supine}: the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery; A_{supine}/AP: ratio of the A_{supine} to the largest anteroposterior diameter of the thorax in supine position; PA_{supine}/AP: ratio of PA_{supine} to the largest anteroposterior diameter of the thorax in supine position; D (A_{supine}-PA_{supine}): distance between the uppermost atrium and the uppermost pulmonary artery in supine position; $A_{sitting}$/Sternum: ratio of $A_{sitting}$ to the length of sternum; $PA_{sitting}$/Sternum: ratio of $PA_{sitting}$ to the length of sternum

Table 5. Parameters of Atrium and Pulmonary Artery of Patients after Fontan Procedure

	1-12mo *n*=7	1-5yr *n*=24	5-15yr *n*=18	Total *n*=49
A_{supine}/AP (%) (***P=0.66)***	67.9±10.2	80.5±9.2	82.2±8.4	79.3±10.0
PA_{supine}/AP (%) (***P=0.052)***	56.1±4.2	56.4±3.8	61.7±7.0	58.3±5.8
D (A_{supine}- PA_{supine}) (mm)	17.9±16.4	38.73±11.7	42.0±22.5	37.0±18.5
$A_{sitting}$/Sternum (%) (***P=0.06)***	54.0±7.2	52.3±8.8	52.7±9.1	52.7±8.6
$PA_{sitting}$/Sternum (%) (***P=0.77)***	39.4±6.4	41.8±6.7	41.6±8.2	41.4±7.1
D($A_{sitting}$- $PA_{sitting}$) (mm)	16.7±9.9	18.9±14.2	23.1±14.7	20.15±13.8

Values are expressed as mean ± standard deviation.

A_{supine}: the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery; A_{supine}/AP: ratio of the A_{supine} to the largest anteroposterior diameter of the thorax in supine position; PA_{supine}/AP: ratio of PA_{supine} to the largest anteroposterior diameter of the thorax in supine position; D (A_{supine}-PA_{supine}): distance between the uppermost atrium and the uppermost pulmonary artery in supine position; $A_{sitting}$/Sternum: ratio of $A_{sitting}$ to the length of sternum; $PA_{sitting}$/Sternum: ratio of $PA_{sitting}$ to the length of sternum

Fig. 5. Correlation between A_{supine}/AP or PA_{supine}/AP and age of patients after BCPS.

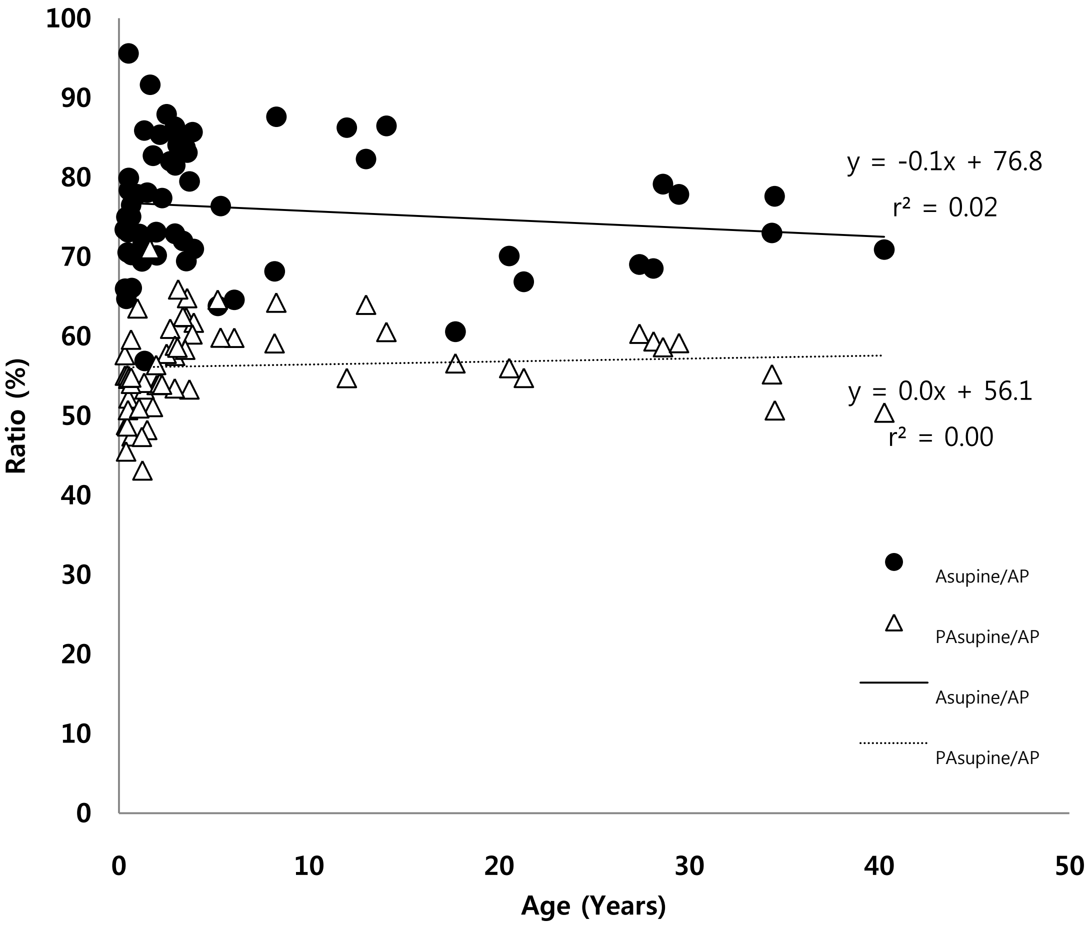

Fig. 5. A_{supine}/AP and PA_{supine}/AP of BCPS patients in supine position did not increase with age; A_{supine}/AP of BCPS $r^2 = 0.02$, P=0.30; PA_{supine}/AP of BCPS $r^2 = 0.01$, P=0.60; A_{supine}/AP: ratio of vertical distance from the skin on the back to the most anterior part of the atrium to the largest AP diameter of the thorax in supine position; PA_{supine}/AP: ratio of vertical distance from the skin on the back to the most anterior part of the pulmonary artery to the largest AP diameter of the thorax in supine position.

Fig. 6. Correlation between A_{supine}/AP or PA_{supine}/AP and Age of Patients after Fontan Procedure.

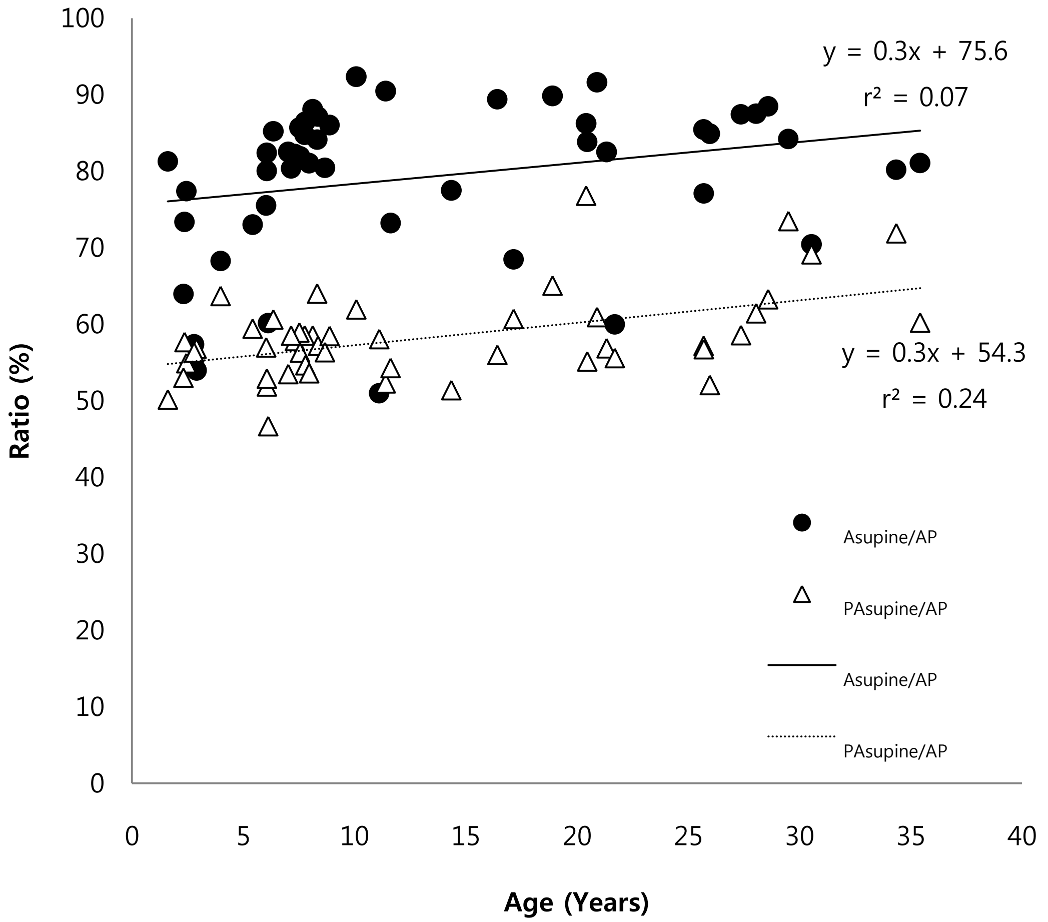

Fig. 6. Neither A_{supine}/AP nor PA_{supine}/AP of Fontan patients increased with age; A_{supine}/AP of Fontan patients $r^2 = 0.07$, P=0.66; PA_{supine}/AP of Fontan patients r^2=0.32, P=0.052

A_{supine}/AP: ratio of vertical distance from the skin on the back to the most anterior part of the atrium to the largest AP diameter of the thorax in supine position; PA_{supine}/AP: ratio of vertical distance from the skin on the back to the most anterior part of the pulmonary artery to the largest AP diameter of the thorax in supine position.

In the supine position, regardless of the procedure patient underwent, A_{supine} and PA_{supine} increased with age. (For BCPS, A_{supine} : r^2=0.624, P<0.001, PA_{supine} : r^2=0.609, P < 0.001; for Fontan patients, A_{supine} : r^2= 0.574, P <0.001, PA_{supine} : r^2=0.32, P< 0.052) However, no significant correlation was found between age and the ratio of vertical distance from the skin on the back to the most anterior portion of the pulmonary artery in the supine position. Analysis of variance showed that A_{supine}/AP and PA_{supine}/AP were similar between the age groups in both the BCPS and Fontan groups. No clinical difference was found in the ratios of A_{supine}/AP and PA_{supine}/AP between the BCPS and Fontan groups.

The distance between A_{supine} and PA_{supine} depending on age was expressed by following equation; For BCPS patients, the equation was: distance between A_{supine} and PA_{supine}(mm)= 24.2 + 0.31 × age (years) (r^2=0.08, P<0.03) and for the Fontan group, distance between A_{supine} and PA_{supine}(mm)=31.1+0.44 × age (years) (r^2=0.05, P <0.11). (Figures 7)

Fig. 7. The distance between A_{supine} and PA_{supine} depending on age for Patients after BCPS and the Fontan Procedure

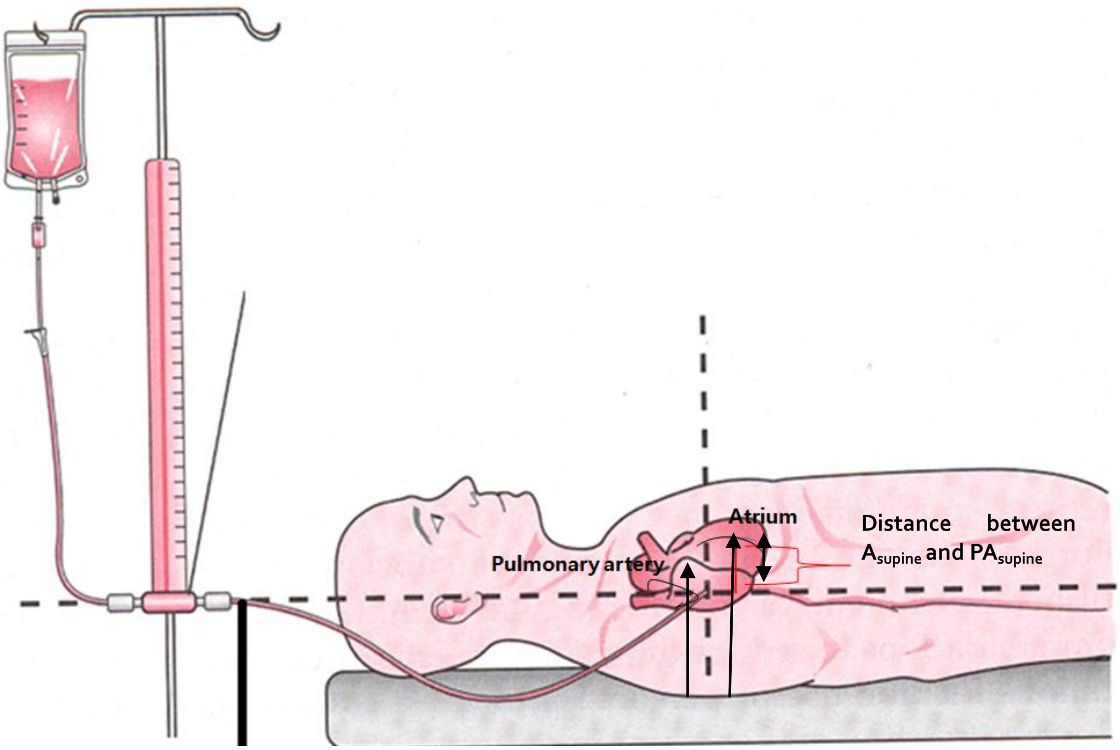

Image from *Bucher, L. & Melander, S. (1999). Critical Care Nursing*

Fig. 7. The distance between A_{supine} and PA_{supine}(mm)= 24.2 + 0.31 × age (years) (r^2=0.08, P<0.03) and for the Fontan group, distance between A_{supine} and PA_{supine}(mm)=31.1+0.44 × age (years) (r^2=0.05, P <0.11). if a transducer is placed at the same level for measuring atrial and pulmonary arterial pressures, atrial pressure would be overestimated or pulmonary artery pressure would be underestimated by approximately 4 mm Hg.

A_{supine}: the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position

Sitting Position

In the BCPS group, the mean $A_{sitting}$ was 62.7±31.3 mm, and in the Fontan group, it was 94.6 ± 36.0 mm. The mean $PA_{sitting}$ of BCPS patients was 51.5±25.1 mm whereas that in the Fontan group was 41.4 ± 7.1mm.

In the sitting position, the most cephalad blood level of the atrium ranged from the first intercostal space to the fourth intercostal space for both the BCPS and Fontan groups. The most cephalad blood level of the pulmonary artery in both groups was located mostly at the second ICS (Figures 8 and 9).

Fig. 8. Distribution of the rib or intercostal space level corresponding to the most cephalad atrium and the pulmonary artery of patients after BCPS in sitting position.

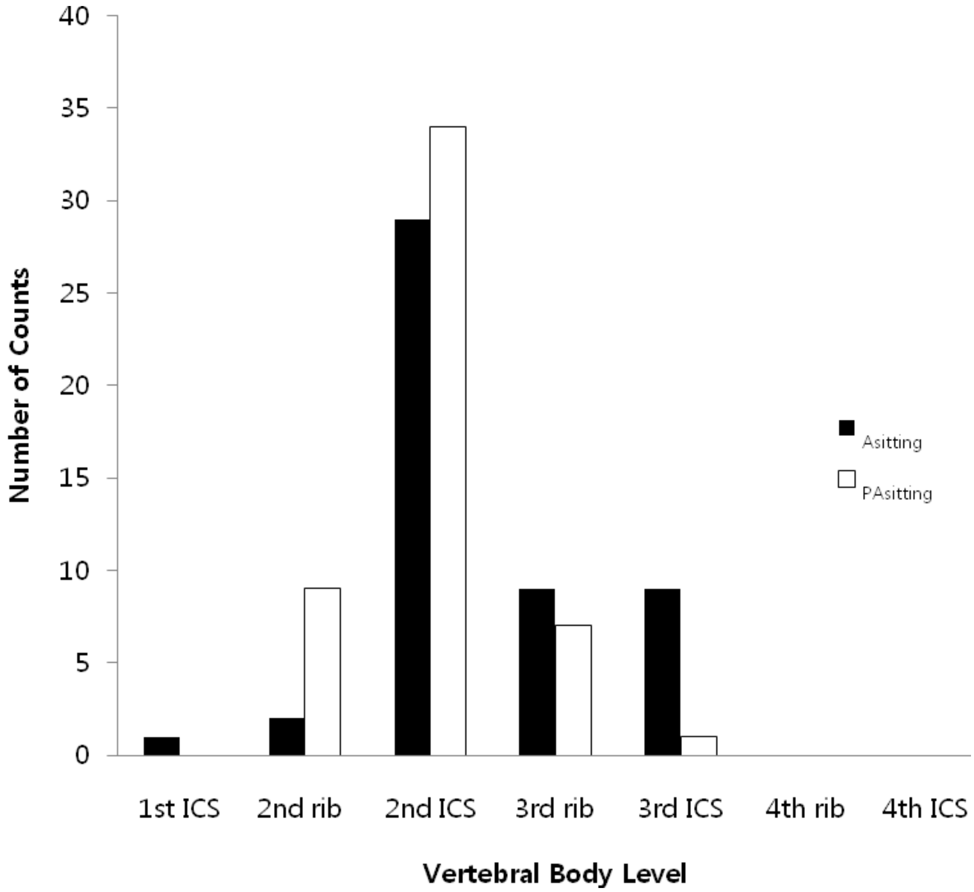

Fig. 8. For BCPS patients in sitting position, the most cephalad blood level of both atrium and pulmonary artery was located mostly at the 2nd ICS respectively; ICS: intercostal space; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery.

Fig. 9. Distribution of the rib or intercostal space level corresponding to the most cephalad atrium and the pulmonary artery of patients after Fontan procedure in sitting position.

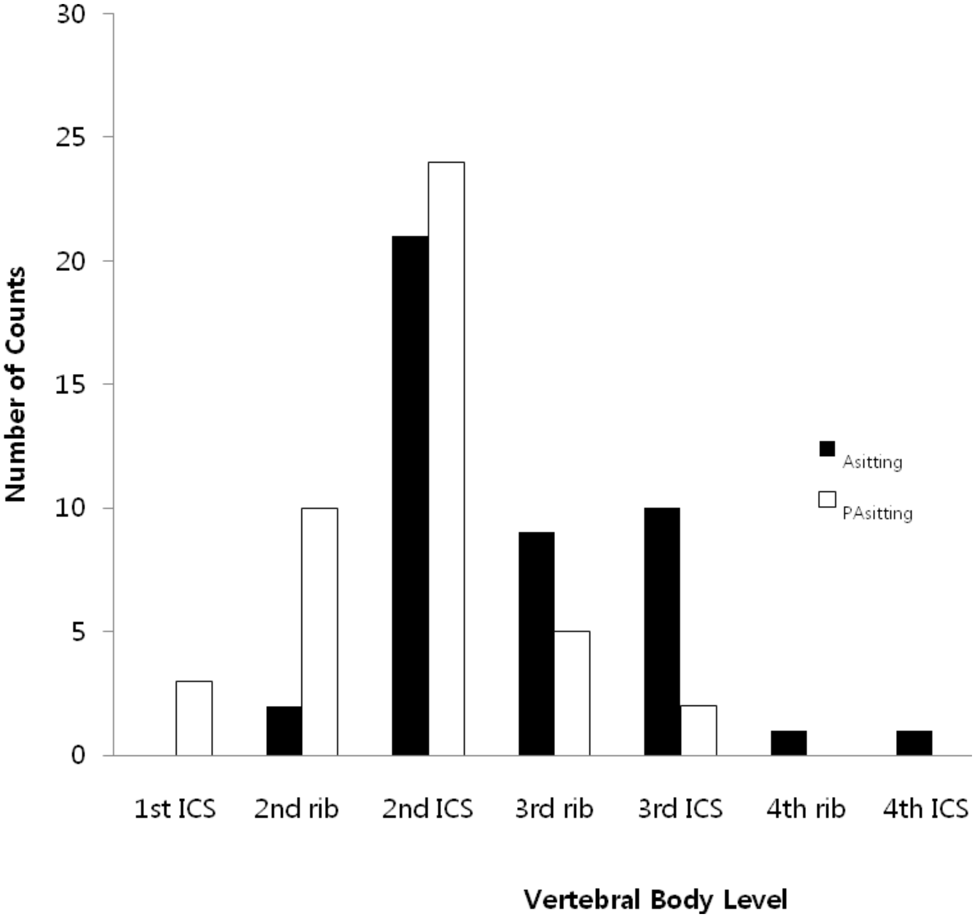

Fig. 9. For Fontan patients in sitting position, the most cephalad blood level of both atrium and pulmonary artery was located mostly at the 2nd ICS respectively. ICS: intercostal space; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery.

In the sitting position, $A_{sitting}$ and $PA_{sitting}$ of both BCPS and Fontan patients were positively correlated with age. ($A_{sitting}$: r^2= 0.41, $P < 0.001$, for PA_{sittin}g: r^2=0.50, $P < 0.001$; for Fontan patients, $A_{sitting}$: r^2= 0.21, $P < 0.001$, $PA_{sitting}$: r^2=0.18, $P < 0.001$)

The mean $A_{sitting}$ /sternum and $PA_{sitting}$/sternum were respectively 51.4 ± 11.2 % and 42.2±8.1% in the BCPS group and 52.7 ± 8.6 % and 41.4 ± 7.1 % in the Fontan group (Table4 and Table 5, Figure 10 and Figure 11). No significant differences in $A_{sitting}$/sternum and $PA_{sitting}$/sternum were found between the BCPS and Fontan groups, and between age groups.

Fig. 10. Correlation between $A_{sitting}$ /Sternum or $PA_{sitting}$ /Sternum and Age of Patients after BCPS.

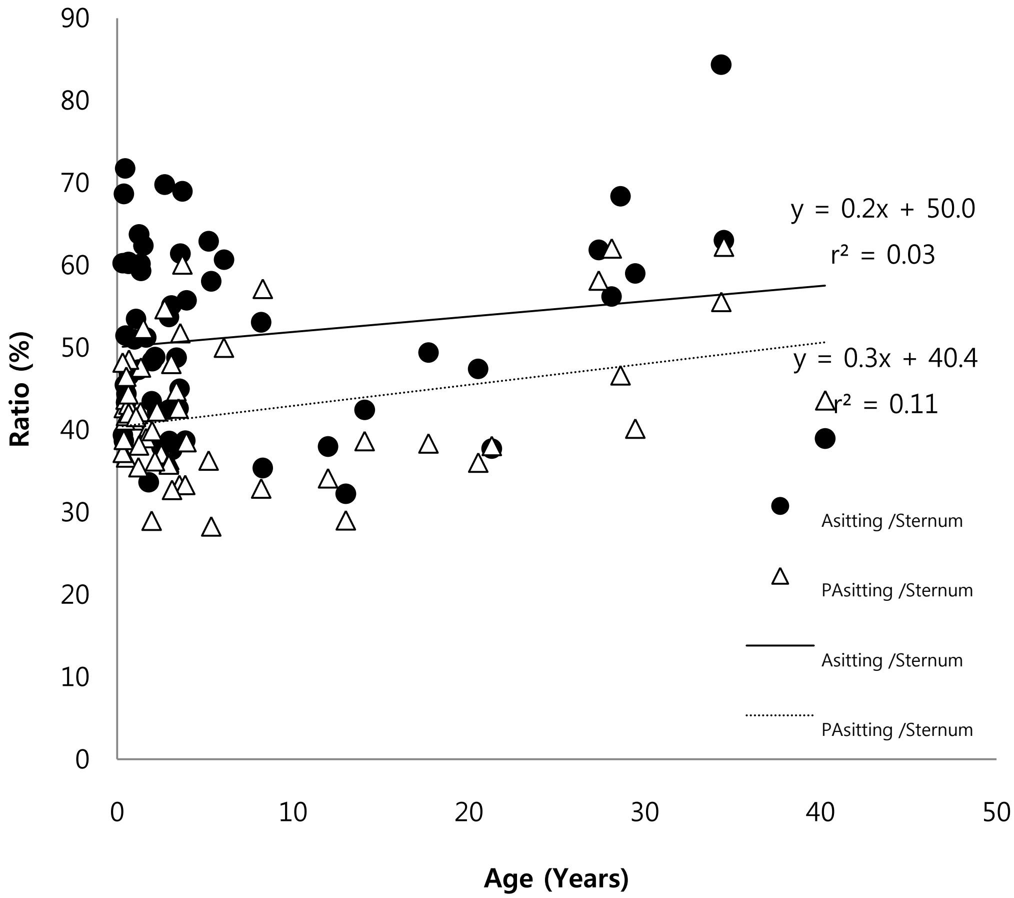

Fig. 10. $A_{sitting}$/Sternum and $PA_{sitting}$/Sternum of BCPS patients in sitting position did not increase with age; $A_{sitting}$/Sternum of BCPS patients $r^2 = 0.03$, P=0.19; PA/Sternum of BCPS patients $r^2 = 0.11$, P=0.06;

$A_{sitting}$/Sternum: ratio of the distance from the sternoclavicular junction to the most cephalad level of atrium to the length of sternum; $PA_{sitting}$/Sternum: ratio of the distance from the sternoclavicular junction to the most cephalad level of pulmonary artery to the length of sternum.

Fig. 11. Correlation between A $_{sitting}$ /Sternum or PA $_{sitting}$ /Sternum and Age of Patients after Fontan Procedure.

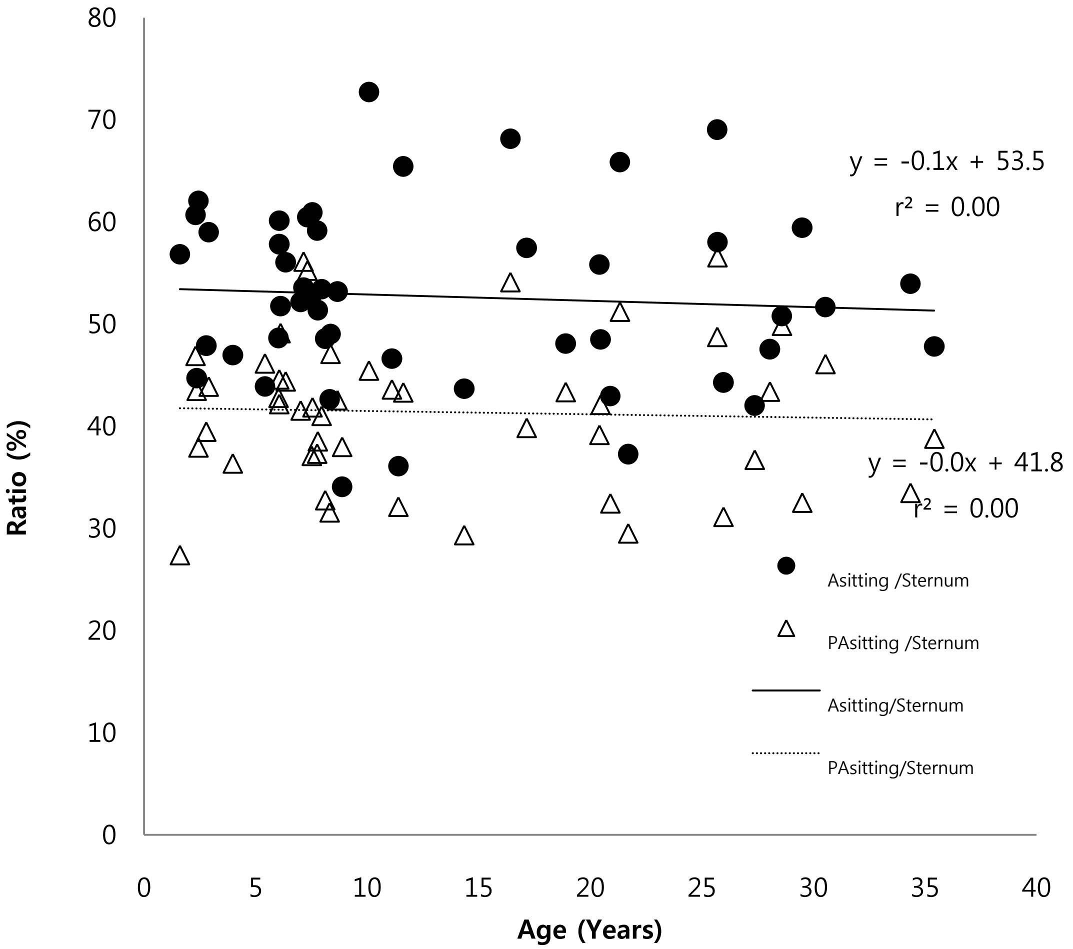

Fig. 11. $A_{sitting}$/Sternum and $PA_{sitting}$/Sternum of Fontan patients did not increase with age; $A_{sitting}$/Sternum of Fontan patients $r^2 = 0.00$, P=0.63; $PA_{sitting}$/Sternum of Fontan patients $r^2 = 0.00$, P=0.77;

$A_{sitting}$/Sternum: ratio of the distance from the sternoclavicular junction to the most cephalad level of atrium to the length of sternum; $PA_{sitting}$/Sternum: ratio of the distance from the sternoclavicular junction to the most cephalad level of pulmonary artery to the length of sternum.

Heterotaxy Syndrome vs. Nonheterotaxy Syndrome

The mean A_{supine}/AP in the heterotaxy group was 77.2 ± 9.0 %, and that in the non-heterotaxy group was 77.6 ± 9.2 %. The mean PA_{supine}/AP in the heterotaxy group was 57.6 ± 6.9 %, compared to 57.3 ± 5.3 % in the non-heterotaxy group. The mean $A_{sitting}$/sternum and $PA_{sitting}$/sternum were respectively 52.6 ± 10.7% and 41.5±7.7% in the heterotaxy group and 51.8± 9.9 % and 42.0± 7.7 % in the non-heterotaxy group. (Table 6). No statistical difference in A_{supine}/AP (*P*=0.83), PA_{supine}/AP(*P*=0.72) , $A_{sitting}$/sternum (*P*=0.72) and $PA_{sitting}$/sternum (*P*=0.77) were found between the groups.

Within the heterotaxy syndrome group, no statistical difference found between the right isomerism group and the left isomerism group. (Table 7)

Table 6. Comparison of the Patients with the Heterotaxy syndrome vs. Non-heterotaxy syndrome

	Heterotaxy syndrome *n=29*	Non-heterotaysyndrome *n=79*
A_{supine}/AP (%)	77.2±9.0	77.6±9.2
(*P=0.83)*		
PA_{supine}/AP (%)	57.6±6.9	57.3±5.3
(*P=0.72)*		
D (A_{supine}- PA_{supine}) (mm)	31.3±17.8	30.9±15.6
$A_{sitting}$/Sternum (%)	52.6±10.7	51.8±9.9
(*P=0.72)*		
$PA_{sitting}$/Sternum (%)	41.5±7.7	42.0±7.7
(*P=0.77)*		
D($A_{sitting}$- $PA_{sitting}$) (mm)	19.3±15.5	15.1±12.8

Values are expressed as mean ± standard deviation.

A_{supine} : the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine} : the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery; A_{supine}/AP : ratio of the A_{supine} to the largest anteroposterior diameter of the thorax in supine position; PA_{supine}/AP : ratio of PA_{supine} to the largest anteroposterior diameter of the thorax in supine position; D (A_{supine}-PA_{supine}) : distance between the uppermost atrium and the uppermost pulmonary artery in supine position; $A_{sitting}$/Sternum: ratio of $A_{sitting}$ to the length of sternum; $PA_{sitting}$/Sternum : ratio of $PA_{sitting}$ to the length of sternum.

Table 7. Comparison of the Patients with the Right Isomerism vs. Left Isomerism

	Right Isomerism *n=16*	**Left Isomerism** ***n*=13**
A_{supine}/AP (%) **(*P=0.33)***	74.9±9.2	79.9±8.0
PA_{supine}/AP (%) **(*P=-0.85)***	57.1±6.9	58.2±7.2
D (A_{supine}- PA_{supine}) (mm)	28.6±14.1	37.1±19.8
$A_{sitting}$/Sternum (%) **(*P=0.75)***	51.4±11.3	53.9±10.2
$PA_{sitting}$/Sternum (%) **(*P=0.96)***	41.5±6.8	41.4±9.0
D($A_{sitting}$- $PA_{sitting}$) (mm)	17.5±12.7	16.2±13.7

Values are expressed as mean ± standard deviation.

A_{supine} : the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine} : the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery; A_{supine}/AP : ratio of the A_{supine} to the largest anteroposterior diameter of the thorax in supine position; PA_{supine}/AP : ratio of PA_{supine} to the largest anteroposterior diameter of the thorax in supine position; D (A_{supine}-PA_{supine}) : distance between the uppermost atrium and the uppermost pulmonary artery in supine position; $A_{sitting}$/Sternum: ratio of $A_{sitting}$ to the length of sternum; $PA_{sitting}$/Sternum : ratio of $PA_{sitting}$ to the length of sternum.

Lt superior vena cava (SVC). vs. Rt superior vena cava (SVC)

The mean A_{supine}/AP in the left SVC group was 71.6 ± 8.4 %, and that in the right SVC group was 78.3 ± 8.7 %. The mean PA_{supine}/AP were 54.2 ± 5.0 %, and 56.9± 5.2 % respectively. The mean $A_{sitting}$/sternum and $PA_{sitting}$/sternum were respectively 54.3 ± 8.8% and 43.3±18.1% in the left SVC group, and 51.2± 10.3 % and 42.0± 7.5 % in the right SVC group. (Table 7). A statistical difference was found in A_{supine}/AP(P=0.02) , but not in PA_{supine}/AP(P=0.13) , $A_{sitting}$/sternum (P=0.36) and $PA_{sitting}$/sternum (P=0.60) between the groups.

Table 8. Parameters of patients with left superior vena cava vs. Parameters of Patients with right superior vena cava.

	Lt. SVC *n=29 (Bilateral: 11)*	**Rt. SVC** *n=79*
A_{supine}/AP (%)	71.6±8.4	78.3±8.7
(*P=0.02*)		
PA_{supine}/AP (%)	54.2±5.0	56.9±5.2
(*P=0.13*)		
D (A_{supine}- PA_{supine}) (mm)	27.3±20.5	32.5±14.9
$A_{sitting}$/Sternum (%)	54.3±8.8	51.2±10.3
(*P=0.36*)		
$PA_{sitting}$/Sternum (%)	43.3±18.1	42.0±7.5
(*P=0.60*)		
D($A_{sitting}$- $PA_{sitting}$) (mm)	17.3±13.5	14.6±12.9

Values are expressed as mean ± standard deviation.

A_{supine}: the vertical distance from the skin on the back to the most anterior part of atrium in supine position; PA_{supine}: the vertical distance from the skin on the back to the most anterior part of pulmonary artery in supine position; $A_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of atrium; $PA_{sitting}$: the distance from sternoclavicular junction to the most cephalad level of pulmonary artery; A_{supine}/AP: ratio of the A_{supine} to the largest anteroposterior diameter of the thorax in supine position; PA_{supine}/AP: ratio of PA_{supine} to the largest anteroposterior diameter of the thorax in supine position; D (A_{supine}-PA_{supine}): distance between the uppermost atrium and the uppermost pulmonary artery in supine position; $A_{sitting}$/Sternum: ratio of $A_{sitting}$ to the length of sternum; $PA_{sitting}$/Sternum: ratio of $PA_{sitting}$ to the length of sternum.

Before and after the Fontan procedure

15 patients had undergone both BCPS and the Fontan procedure, and their data were analyzed to explore the influence of procedure on the ratio of the atrium and the pulmonary artery to the anteroposterior diameter and the sternal length in the supine and sitting position. T-paired test revealed that there is no statistically significant change before and after the Fontan procedure. A_{supine}/AP (*P=0.96)*, PA_{supine}/AP (*P=0.10)*, $A_{sitting}$/sternum (*P=0.09)* and $PA_{sitting}$/sternum (*P=0.19)* were observed from before and after the Fontan procedure. (before the Fontan, mean A_{supine}/AP = 74.2% vs. after the Fontan procedure, mean A_{supine}/AP = 77.6%; before the Fontan procedure, mean PA_{supine}/AP=54.4% vs. after the Fontan procedure, mean PA_{supine}/AP= 57.3%; before the Fontan procedure, mean $A_{sitting}$/sternum= 55.3% vs. after the Fontan procedure, mean $A_{sitting}$/sternum= 52.4%; before the Fontan procedure, mean $PA_{sitting}$/sternum = 44.8% vs. after the Fontan procedure, , mean $PA_{sitting}$/sternum = 41.6%)

DISCUSSION

This study was conducted to determine the most appropriate level of the reference transducer for measuring atrial and pulmonary arterial pressures in patients with functional single ventricle, according to the patient's position. When measuring atrial pressure in the supine position, the reference transducer should be placed approximately 75–80% of the AP diameter of the thorax. For monitoring pulmonary arterial pressure, the transducer should be placed at 55–60% of the AP diameter of the thorax. In the sitting position, the optimal transducer level for measuring both pulmonary arterial and atrial pressures should be placed at the second ICS.

Pulmonary hypertension is the critical determinant of perioperative outcome in patients with functional single ventricle. Despite the importance of the reference transducer level in the diagnosis and classification of the severity of pulmonary hypertension, a zero reference level is lacking even during cardiac catheterization [11]. For adults, various reference transducer levels have been suggested as setting in the supine position, such as 5 cm below the anterior thorax surface, at one third of the thoracic diameter below the anterior thorax surface, and at the mid thoracic level or 10 cm above table level [7, 8, 11]. To date, no study has been conducted to determine the adequate placement of a transducer for pediatric patients with cardiac problems.

Inaccurate calibration or baseline drift is a source of measurement error. Even a small transducer position error can have significant impact on the measurement of venous pressure and pulmonary vascular resistance, which are major factors in determining the feasibility of heart transplantation and perioperative prognosis in BCPS placement and the

Fontan procedure. A pulmonary vascular resistance of <2.5 Wood units is considered a relative contraindication for the BCPS procedure [1]. Growing evidence indicates that a mean pulmonary artery pressure of >15 mm Hg may be associated with both early and late mortality after the Fontan procedure [2]. The relationship of preoperative pulmonary hemodynamics to early and late morbidity remains to be defined [12].

Before we started this study, we expected that age and stage of surgical procedure would influence the level of the atrium and pulmonary artery at some extent. However, according to our data, the transducer position for monitoring arterial and pulmonary arterial pressures was not affected by age or surgery in both the supine and sitting positions.

It is also worthy of notice that even a complicated cardiac anomaly other than functional single ventricle such as heterotaxy syndrome, a disorder resulting in certain organs to form on the opposite side of the body, that leads to significant differences in anomalous systemic venous connections, [13] and variable shapes of the atrium between the right and the left isomerism[14]. No statistical difference in atrial and pulmonary arterial pressures found in the left versus the right isomerism as well as in the heterotaxy versus the non-heterotaxy group reveals that our finding can be applied in various situations with wide range of subjects.

We found a significant difference between the height of the atrium and that of the pulmonary artery. The mean difference between the uppermost atrium and the uppermost pulmonary artery was approximately 2.6 cm in the BCPS group and 3.8 cm in the Fontan group, which yields a hydrostatic difference of approximately 3.5–5.2 mm Hg. Therefore, if a transducer is placed at the same level for measuring atrial and pulmonary arterial pressures, atrial pressure would be overestimated or pulmonary artery pressure would be underestimated by approximately 4 mm Hg.

In the sitting position, for atrial and pulmonary arterial measurements in the BCPS group, the reference transducer should be placed at approximately 50% and 40% of the sternum, respectively. This was about the same for the Fontan group. The differences between the most cephalad atrium and pulmonary artery was 1.3 and 2 cm for the Fontan group. Compared with that in the supine position, the transducer level in the sitting position showed a larger ratio variability. We suggested the second ICS as the transducer position for atrial and pulmonary arterial pressure monitoring in the sitting position from a practical point of view.

This retrospective study had several limitations. First, the results did not reflect the potential changes caused by the downward movement of the heart from the supine to the sitting position. Second, as the accumulated chest tomographic data used in this study were solely obtained in the inspiratory phase, it did not take into account differences in atrial and pulmonary arterial heights between the inspiratory and expiratory phases, although previous literature reported no significant difference in atrial height between the inspiratory and expiratory phases [8, 15]. Third, the age of the patients greatly varied, as we divided the patients according to procedure.

In conclusion, the optimal transducer levels for measuring pulmonary arterial and atrial pressures in patients with functional single ventricle are respectively at 55–60% and 75% of the AP diameter of the thorax in the supine position. In the sitting position, we recommend the second ICS as the transducer position for measuring atrial and pulmonary arterial pressures in patients who had undergone BCP S placement or the Fontan procedure.

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국문 초록

서론: 선천선 심장 질환을 가진 환자에서 정확한 혈역학 데이터를 획득하는 것은 환자의 마취 관리를 위한 올바른 결정을 하는 첫 단계라고 할 수 있다. 본 연구는 기능적 단심실 환자들의 앙와위 및 좌위에서 심방 및 폐 동맥 압력 측정 시 최적의 변환기 위치를 알아보기 위해 실시하였다.

방법: 양측성 대정맥폐동맥 문합술 또는 폰탄 수술을 받은 108 명의 환자의 조영제로 강화된 흉부 컴퓨터 단층 촬영 영상을 후향적으로 분석하였다. 횡단면 영상에서 환자의 가장 큰 흉부 전후 직경을 측정하고, 등부터 심방 혹은 폐동맥까지의 거리를 얻어 흉부 전후 직경에 대한 각각의 비율을 구했다. 좌위에서는 총 흉골 길이에 대한 흉쇄관절과 심방 혹은 폐동맥까지의 거리 비율을 계산 하였다. 또한 각각의 레벨에 해당되는 늑골 또는 늑간이 어디 있는 지 측정 하였다.

결과: 앙와위에서 양측성 대정맥폐동맥 문합술 환자의 경우 심방 및 폐동맥의 최상위 레벨과 환자의 흉부 직경의 비율은 각각 76.0 ± 8.1 %, 및 56.3 ± 5.5 %였다. 폰탄 수술을 받은 환자의 경우는, 각각 79.3 ± 10.0 % 및 58.3 ± 5.8 % 이었다. 좌위에서 가장 머리 쪽에 위치한 심방과 폐동맥은 양측성 대정맥폐동맥 문합술 환자의 경우, 각각 흉골길이의 51.4 ± 11.2 % 및 42.2 ± 8.1 %에 위치해 있었다. 폰

탄 수술을 받은 환자는 각각, 흉골길이의 52.7 ± 8.6 % 각각 41.4 ± 7.1 % 였다. 앉아 있을 때, 가장 머리 쪽에 위치한 심방과 폐동맥은 모두 제 2 늑간에 위치해 있었다.

결론: 단심실 환자에서 심방 압력과 폐동맥의 압력을 측정하기 위한 최적의 변환기 위치는 앙와위 자세에서는 전 흉곽 길이의 각각 75~80% 및 55~60%에 있었다. 반면 좌위에서는, 심방과 폐 동맥 모두 제 2 늑간에 위치해 있었다.

주요어 : 중심 정맥 압력; 앙와위; 좌위; 선천성 심장 질환
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