ORIGINAL ARTICLES

Noninvasive, Indirect Measurement of Pulmonary Artery Pressure

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Objective: The gold standard for measuring pulmonary artery pressure (PAP) is right heart catheterization. However, the usefulness of this technique is limited in patients with lung disease because of a poor acoustic window. The aim of this study was to assess PAP in a group of healthy persons using a noninvasive, indirect measurement procedure derived from the venous return flow velocity wave.

Material and methods: Twenty-three healthy volunteers with a mean (SD) age of 34 (9) years were evaluated. Measurements were made with a Hitachi EUB 5000 ultrasound device (3.5 MHz wave). The subject was placed in supine decubitus with neck hyperextended and head turned to one side. B-mode images were used to locate the point in the internal jugular vein 1 cm higher than its union with the subclavian vein. A color flow image was obtained of the vessel and a pulsed wave was then used to measure velocities. After 5 identical cycles, an estimate of PAP was derived from the ratio of maximum diastolic and systolic flow rates.

Results: On the right side, the mean (SD) ratio between flow rates was 0.50 (0.08), corresponding to a mean PAP of 15 (2.4) mm Hg. On the left side, the ratio was 0.55 (0.09), corresponding to a mean PAP of 16 (2.8) mm Hg. The nonsignificant difference between mean PAP values on the right and left was 1.3 (3.1) mm Hg, and higher values were on the left.

Conclusions: Mean PAP values obtained with the described procedure are within the normal range for a healthy population. Transcutaneous venous Doppler ultrasound is useful for estimating PAP in healthy individuals

Key words: *Pulmonary arterial pressure. Transcutaneous Doppler ultrasound. Reference values.*

Determinación indirecta y no invasiva de la presión arterial pulmonar

Objetivo: El procedimiento de referencia para determinar la presión arterial pulmonar (PAP) es el cateterismo derecho. Clínicamente se usa la ecocardiografía, que presenta limitaciones en pacientes con neumopatía, por mala ventana ecográfica. El objetivo del presente estudio ha sido determinar la PAP en un grupo de personas sanas mediante un procedimiento indirecto e incruento que se basa en la curva de velocidad del retorno venoso.

Material y métodos: Se evaluó a 23 voluntarios sanos, con una edad media ± desviación estándar de 34 ± 9 años. Las medidas se realizaron con un ecógrafo Hitachi EUB 5000 (sonda de 3,5 MHz). El procedimiento consiste en situar al sujeto en decúbito supino con el cuello hiperextendido y lateralizado. Se localiza en modo B la vena yugular interna 1 cm por encima de la unión con la subclavia. Con la Doppler color se sigue dicho trayecto y con la Doppler de onda pulsada se obtienen las curvas de velocidades. Tras 5 ciclos idénticos se procede a estimar la PAP a través de la relación de velocidades máximas diastólica y sistólica.

Resultados: En el lado derecho, el valor medio de la relación de velocidades fue de 0,50 ± 0,08, que equivale a una PAP media de 15 ± 2,4 mmHg. En el lado izquierdo la relación de velocidades fue de 0,55 ± 0,09, con una PAP media de 16 ± 2,8 mmHg. La diferencia entre las PAP medias derecha e izquierda fue de 1,3 ± 3,1 mmHg, y los valores, más elevados en el lado izquierdo (p no significativo).

Conclusiones: Los valores medios de PAP obtenidos con el procedimiento descrito están en el margen de referencia para la población sana. La ecografía Doppler venosa y transcutánea es un procedimiento útil para obtener los valores de PAP en personas sanas.

Palabras clave: *Presión arterial pulmonar. Ecografía Doppler transcutánea. Valores de referencia.*

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Introduction

Indirect measurement of pulmonary arterial pressure (PAP) is among the diagnostic procedures that make it possible to monitor various cardiac, respiratory, or systemic diseases. There are 2 ways to measure PAP: the first is invasive and direct, by way of catheterization of the artery, and the other is noninvasive and indirect, by ultrasound imaging.[1] A considerable number of respiratory diseases that cause chronic hypoxemia lead to consistently elevated PAP and with time this situation can lead to heart failure.[2-6] Chronic obstructive pulmonary disease (COPD) is among the most common causes of pulmonary hypertension, estimated to be present in 40% of COPD patients.[7] Pulmonary hypertension is a clear indicator of poor prognosis in COPD patients and for that reason it is important to diagnose this complication early.

A diagnosis of pulmonary hypertension is defined by a PAP in excess of 25 mm Hg at rest or 30 mm Hg during exercise.[8] Even though invasive measurement is not the usual way to obtain reference values for cardiopulmonary circulation, those available for our practice setting were determined by arterial catheterization in a sample of 57 healthy volunteers; mean (SD) PAP was found to be 12.3 (3.6) mm Hg by that method.[9] Echocardiography is also available to assess pulmonary hypertension based on tricuspid valve regurgitation, but it is not very useful when the underlying cause is respiratory disease because air trapping diminishes the quality of the acoustic window.[10,11]

Ranganathan and Sivaciyan[12] proposed an indirect, noninvasive method for estimating PAP based on jugular venous blood flow visualized by transcutaneous Doppler ultrasound. Later, Matsuyama et al[13] and Burgess and Bright-Thomas[14] used the method to assess pulmonary hypertension in patients with COPD. The procedure is simple and noninvasive and the equipment is portable. In theory it is within the technical range of teams with little training, although it should be validated in each hospital and by each group of practitioners given that there is a substantial subjective component in interpreting ultrasound images.

The aim of this study was to validate this procedure in our practice setting by analyzing the venous return flow velocity wave corresponding to the right brachiocephalic vein in a group of healthy volunteers and then to apply the technique to determine PAP in patients with chronic respiratory disease. We also sought to evaluate the feasibility of the method for use by trained pneumologists in an outpatient clinic.

Materials and Methods

Twenty-three healthy individuals of both sexes (6 men, 17 women) aged between 20 and 50 years were recruited. The subjects were considered healthy if their medical history was unremarkable, they were not taking vasoactive medication, and an electrocardiogram, spirometry, and a chest x-ray were normal. Pregnant women were excluded because of changes in systemic and pulmonary circulation during pregnancy. Smokers were not excluded.

To determine PAP, venous circulation was examined by Doppler ultrasound at the side of the neck with the subject lying down and breathing room air. Measurement variability was assessed by taking measurements on both sides of the neck. A pneumologist carried out the procedures after completing training that lasted approximately 15 days in a course that required no prior technical knowledge.

The apparatus used was a Hitachi EUB 5000 Plus High Vision ultrasound device (Tokyo, Japan), which produced a 3.5 MHz wave (Model L54-M). The examination took place with the subject in supine decubitus with neck hyperextended and head turned to one side to give optimal exposure to the jugular vein and the supraclavicular fossa on the side being examined. With the patient in the described position, the right internal jugular vein was located in B mode and followed to a point 1 cm above its junction with the right subclavian vein in the right brachiocephalic trunk. The left subclavian vein was located in the same manner. In a cross-sectional transverse image, the internal jugular vein is the outermost vessel just above the common carotid artery and both structures are adjacent to the thyroid glands. Both vessels (the deeper artery and the vein closer to the surface) should always be identified using the features typical of their flow velocity waves. The point of interest is located in a transverse image from the supraclavicular fossa midway between the insertions of the sternocleidomastoid muscle and with the probe pointed toward the contralateral shoulder. The internal jugular vein is followed with color flow imaging until the point of interest is located in relation to the right brachiocephalic vein; on the left, the path of the jugular is traced in relation to left subclavian vein. In pulsed wave Doppler ultrasound, the sample volume is designated at the center of the vessel and the beam angle is kept to a minimum to ensure optimal resolution of the flow velocity curve. Signals are collected from an angle near 60º and gain is set low so that the wave can be viewed without noise or double images. The subject is asked not to breathe for short periods so as to obtain flow rates that are as similar as possible. Then, the subject is asked to take a deep breath and hold it, so that at least 5 morphologically identical cycles can be recorded. The caliper is situated to measure the maximum systolic venous flow velocity curve (sf) and the maximum diastolic flow curve (df). The df/sf ratio is calculated, and PAP is then derived from the relation between the 2 flow rates.

Table 1 shows both right and left systolic and diastolic venous flow rates as measured and their ratios. Anthropometric data and smoking habits are also recorded. The following equation was applied to derive PAP: mean PAP = 0.06 + [(df/sf) / 0.034], deduced from data published by Matsuyama et al.[13] The values for each subject in Table 1 are means of 3 technically satisfactory measurements with variation of less than 3 mm Hg.

Analysis of variance was performed for comparisons (by sides, gender, and smoking habit) of results for the 2 groups.

Results

The flow velocity ratios were 0.51 (0.08) and 0.55 (0.09) for the right and left sides, respectively. From those ratios a mean PAP of 15 (2.4) mm Hg was derived for the right side and 16 (2.8) mm Hg for the left. Measurements ranged from 8 to 18 mm Hg on the right and from 11 to 21 mm Hg on the left. Table 1 shows the PAP estimates for all volunteers as means (SD) for both the right and left sides. The mean difference between right and left PAP was 1.3 (3.1) mm Hg (P=.10).

It was possible to draw the curves correctly according to the described technique in all but 1 person, in whom PAP could be estimated only for the right side.

For smokers, the mean right PAP was 14 (2.5) mm Hg, with a range of 9 to 17 mm Hg; left PAP was 16 (2.8) mm Hg and ranged from 11 to 19 mm Hg. PAP for nonsmokers was 15 (2.4) mm Hg on the right, with values ranging from 8 to 18 mm Hg, and 16 (2.9) mm Hg on the left, ranging from 11 to 21 mm Hg (Table 2). The differences between smokers and nonsmokers were not statistically significant (P=.31).

TABLE 1
Patient Characteristics, Venous Return Flow Rates, and Pulmonary Artery Pressures*

Case	Sex	Age, y	Right Side			Left Side			Right mPAP, mm Hg	Left mPAP, mm Hg
			sf	df	df/sf	sf	df	df/sf		
1	F	49	44.1	26.3	0.6	49.3	31.8	0.65	18	19
2	F	25	57.4	33.7	0.59	70.3	36.8	0.52	17	15
3	F	36	72.3	35.1	0.49	58.5	41.4	0.71	14	21
4	M	31	39.5	18.1	0.46	38.1	14.7	0.39	13	11
5	F	52	42.7	24.1	0.56	53.5	33	0.62	17	18
6	F	50	37.4	19.8	0.53	53.5	24.2	0.45	16	13
7	M	38	106	52.4	0.49	45	23	0.51	15	15
8	M	45	1.71	0.51	0.3	1.82	1.01	0.55	9	16
9	F	31	78.1	38.2	0.49	78.1	45.3	0.58	14	17
10	M	28	48.5	17.7	0.36	71.9	47.9	0.67	11	20
11	M	40	50.6	31.5	0.62	56.5	31.5	0.56	18	16
12	F	29	65	35.3	0.54	49.1	28.6	0.58	16	17
13	F	29	59.8	27.9	0.47	59.8	27.9	0.47	13	14
14	F	27	55.7	33.2	0.6	75.9	53.9	0.71	18	21
15	F	29	58.3	30.5	0.52	40.6	20.7	0.51	15	15
16	F	23	56.1	32.8	0.58	86.5	57.5	0.66	17	20
17	F	27	83.2	42.6	0.51	48.5	18.2	0.38	15	11
18	F	32	34.2	16.6	0.49	38.6	21	0.54	14	16
19	F	48	71.1	23.9	0.34	48.7	19.2	0.39	10	12
20	F	32	122	63.8	0.52	51.8	29.8	0.58	15	17
21	F	25	27.5	15	0.55	20.2	12.1	0.6	16	18
22	F	31	101	51.4	0.51	58.3	34.6	0.59	15	17
23	M	26	59.8	32	0.54	63.9	29.1	0.46	16	13
Mean (SD)		34 ± 9			0.51 ± 0.08			0.55 ± 0.1	15 ± 2.41	16 ± 2.86
Left-right difference									1.31	

*df indicates maximum diastolic jugular flow rate; sf, maximum systolic jugular flow rate; mPAP, mean pulmonary artery pressure; F, female; M, male.

For men, the mean PAP was 14 (3.4) mm Hg on the right (range, 9-18 mm Hg) and 15 (2.8) mm Hg on the left (range, 11-20 mm Hg). For women, the mean PAP was 15 (1.8) mm Hg on the right (range, 10-18 mm Hg) and 17 (2.9) mm Hg on the left (range, 11-21 mm Hg). The differences were not statistically significant (P=.12).

Discussion

The main contribution of this study was to enable the noninvasive estimation of PAP in healthy individuals. The data collected and the comparison with reference values for our practice setting obtained by invasive methods allow us to assume we will be able to extend use of this procedure for assessing PAP to patients with chronic respiratory diseases.

PAP can be measured invasively by right heart catheterization or estimated noninvasively by transthoracic echocardiography of tricuspid valve regurgitation. The main problem with the first method is that inserting a catheter through the venous system as far as the pulmonary artery is invasive and not devoid of complications.[15-17] The second method, on the other hand, is problematic in patients with COPD because the hyperinflation caused by their underlying disease diminishes the transthoracic acoustic window.[10,11] Recent studies of transcutaneous Doppler ultrasound imaging, however, led to its proposal as a candidate to replace both the aforementioned methods and according to several authors its correlation with the gold standard (heart catheterization) is good.[12-14,18-20]

TABLE 2
Mean Right and Left Pulmonary Artery Pressures, by Smoking Status and Sex*

	mPAP, mm Hg, Right Side	mPAP, mm Hg, Left Side
All volunteers (right, n=23; left, N=22)	15	16
Smoking habit		
Smokers	14	16
Nonsmokers	15	16
Sex		
Male	14	15
Female	15	17

*Differences were not statistically significant. mPAP indicates mean pulmonary artery pressure.

Transcutaneous Doppler ultrasound as a noninvasive alternative offers such advantages as avoiding the introduction of catheters in contexts in which cardiac arrhythmias, pneumothorax, or other complications might develop.[15-17,21] It is also an easy-to-learn technique. It is intuitive, unlike echocardiography, which is technically difficult, particularly so in patients with respiratory diseases and others in whom tricuspid regurgitation cannot be observed.

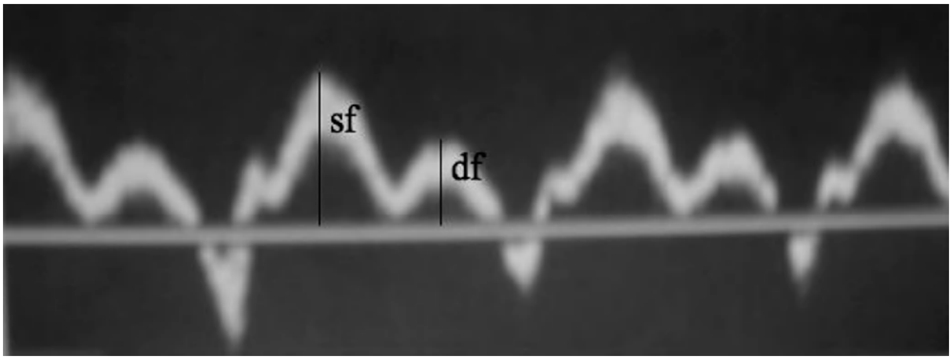

Figure 1. Jugular venous return flow velocity waves; sf indicates maximum systolic flow rate; df, maximum diastolic flow rate.

PAP estimation can be derived from a jugular venous flow velocity curve with 2 peaks for systolic and diastolic flow. Systolic jugular flow starts at the end of atrial relaxation (X descent) but is sustained mainly by the descent of flow with the ventricular systole (X' descent), in which ventricular contraction brings about a fall in atrial pressure; diastolic jugular flow comes as the tricuspid valve opens. The systolic peak is generally higher in healthy subjects (figure) and corresponds to the X' descent of the right atrial pressure pulse. Diastolic flow velocity corresponds to the flow from the right atrium to the right ventricle through the tricuspid valve (Y descent); PAP can be derived from the ratio of the 2 flow peaks.

The method is easy to apply and estimates both right and left pressures. However, because the arrangement of vessels in the neck differs between the left and right, where the brachiocephalic trunk is located, it is easier to locate the point of interest and visualize the flow velocity curves on the right. As right-left pressure differences were not found to be significantly different, PAP can be estimated by making observations only on the right side, measuring flow on the left only if the right side were to present some anatomical anomaly. The only problem that developed during our study was in attempting determinations on the left for 1 subject.

Considering that PAP in healthy individuals in our setting has been measured by right heart catheterization and found to be a mean of 12.3 mm Hg, with a range of 10 to 15 mm Hg, the mean PAP estimated with the described noninvasive procedure (15 mm Hg) falls within the confidence interval for the healthy population, suggesting that the method offers an appropriate approach to PAP estimation. However, as we were unable to evaluate sensitivity, specificity, or statistical agreement with PAP values measured directly in the healthy volunteers in this study, observation should be extended to demonstrate the diagnostic capability of this technique in patients with pulmonary hypertension.

Smoking is known to affect the vascular epithelium.[22] We therefore compared the estimated PAP values between smokers and nonsmokers. In our sample of volunteers classified as healthy, the differences between them were not statistically significant, possibly due to the low number of smokers we included. Nor did we find differences in PAP between males and females; likewise, there was no significant correlation between amount of smoking or gender and PAP.

Transcutaneous Doppler ultrasound is easy to perform and can be considered a viable alternative to the previously mentioned measurement methods. However, its limitations should be taken into account to minimize or avoid errors. First, results should be questioned if tachycardia or arrhythmia is present, as either will make venous pressure unstable. Second, systolic and diastolic jugular flow velocities are similar in patients with moderate pulmonary hypertension (25-35 mm Hg) and the ratio of velocities is subject to greater variability in this context. As the clinical role for this technique is still in the stages of being established, it is also necessary to prepare a meticulous protocol for taking measurements and eliciting patient cooperation. The ease of use and noninvasive nature of the technique makes it an attractive choice for assessing vascular reactivity in clinical trials of inhaled, oral, or intravenous vasodilators[23-25] that might be useful for the treatment of pulmonary hypertension as it will permit the efficacy of treatment to be monitored over the long term.

In conclusion, the simplicity of the transcutaneous Doppler ultrasound procedures and device means that this noninvasive method for estimating PAP can be used during a pneumologist's examination of the patient. It circumvents problems that make ultrasound imaging difficult in COPD patients because of the poor transthoracic window caused by air trapping and it promises to provide an alternative to other examination techniques.

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