Pulmonary Artery Wedge Pressure Formula Using Echocardiography Finding

Lukman H. Makmun[1], Telly Kamelia[2], Prasandhya Astagiri Yusuf[3]*

[1]Division of Cardioloy, Department of Internal Medicine, Faculty of Medicine Universitas Indonesia - Cipto Mangunkusumo Hospital, Jakarta, Indonesia.
[2]Division of Respirology and Critical Care Medicine, Department of Internal Medicine, Faculty of Medicine Universitas Indonesia - Cipto Mangunkusumo Hospital, Jakarta, Indonesia.
[3]Department of Medical Physics, Faculty of Medicine Universitas Indonesia, Jakarta, Indonesia.

***Corresponding Author:**
Telly Kamelia, MD., PhD. Division of Respirology and Critical Care Medicine, Department of Internal Medicine, Faculty of Medicine Universitas Indonesia - Cipto Mangunkusumo Hospital. Jl. Diponegoro no. 71, Jakarta 10430, Indonesia. Email: tellykamelia99@gmail.com.

ABSTRACT

This study aims to introduce a new formula for pulmonary artery wedge pressure (PAWP) derived from the pathophysiology of Velocity A (V_A) waves. The current formula is the the Nagueh formula. Left ventricular (LV) filling is described as a velocity A (VA) wave. The VA wave represents the filling rate of the end-diastolic blood phase from the left atrium (LA) to the LV which can be determined on echocardiography. Left ventricular end diastolic pressure (LVEDP) is equivalent to LA pressure and is also equivalent to PAWP. The gold standard method for obtaining PAWP values is right heart catheterization. By measuring the VA waves in the bloodstream, a new PAWP formula is obtained, and the PAWP examination can be validated in research and can be compared with several other PAWP formulas that are currently the world's standard formula for calculating pulmonary artery wedge pressure (PAWP).

The new PAWP formula is obtained from the conversion of the VA wave. This formula could be validated further in research and used in clinical practice.

Keywords: *Velocity A wave (VA wave), pulmonary artery wedge pressure (PAWP) formula.*

INTRODUCTION

Pulmonary arterial wedge pressure (PAWP) is between 4 to 12 mmHg. It is used to asses for severity of mitral stenosis (MS), to differentiate between cardiogenic and non-cardiogenic pulmonary edema, and to confirm the diagnosis of pulmonary hypertension (PH).[1] PAWP is a critical component of the hemodynamic evaluation, as the sole parameter to define precapillary PH (PCPH) from PH due to left heart disease.[2]

The gold standard method to assess the functionality of the pulmonary circulation is by right heart catheterization (RHC), which measures pulmonary vascular pressures using fluid-filled Swan-Ganz catheter and pulmonary flow thermodilution or the Fick principle. PAWP is acceptable as estimate of left atrial pressure (LAP) or left ventricular end diastolic pressure (LVEDP).[3]

The current formula to calculate PAWP is the Nagueh formula. It uses the measurements of E wave velocity and early diastolic velocity of mitral annulus (E_a) during Doppler tissue imaging. These velocities reflect the shortening and lengthening of the myocardial fibers along a longitudinal plane, with each corner of the annulus being influenced more by the adjacent left ventricle (LV) wall. It demonstrated that the ratio of the transmitral E velocity to E_a (i.e., the E/E_a ratio) is related significantly with PAWP.[4]

On Doppler echocardiographic examination, LV filling is described as a velocity A (V_A) wave. The V_A wave represents the filling rate of the end-diastolic blood phase from the LA to the LV, and is also equivalent to PAWP. By measuring the V_A waves in the bloodstream, a new PAWP formula is obtained.

CALCULATION OF CONVERSION OF VA VALUE TO PAWP VALUE (PC), EQUIVALENT TO P_{LA}

P_{LA} or pressure on the LA area stereometrically caused by the suppression of the blood volume contained in the LA in the end diastolic phase. The amount of pressure in the LA area is calculated using the formula:

Pressure (P_{LA}) = Force (F) / Area on which the force act (A)

or: $P_{LA} = F / A$……………………..1).

F = Force ……..in N (Newton).

W (Weight) = m x g; W = or F (N).

W = weight (N); m = mass (kg); g = gravitational field strength = 9,8 m/sec^2

1 N = 1 kg. 1 m/sec^2 = 1 kg.m/sec^2

1 Dn (Dyne) = 1 g cm/sec^2

1 N = 10^3.g. 10^2 cm/ sec^2 = 10^5 gcm/sec^2

1 N = 10^5 Dn.

By using the formula for kinetic energy:

E = ½ mv^2 …………………2).

E = Energy; m = mass; v = velocity.

Then combined with this formula:

E = F x d ……………………3)

E = energy; F = Force; d = distance

Thus becoming:

F x d = ½ mv^2

F = ½ mv^2 / d …………4)

F = m x g.

Thus: m x g = ½ mv^2 / d

or d = v^2 / 2 g ………….…5)

Pressure formula:

P_{LA} = F / A …………..1)

= m g / A …………6).

CALCULATION OF LA VOLUME IN THE END DIASTOLIC PHASE:

Referring to the heart on Atlas Netter, mitral cross section > LA Basic Cross Section

h = height from apex, LV peak to LA base

h_1 = distance from apex – mitral cross section

d = distance = distance from LA base – mitral cross section.

R = pseudo "LA basic cross section" radius (look at the image)

r_1 = Mitral cross section radius.

r_2 = "pseudo" cross radius at LA level

Based on the comparison count in the heart image on Atlas of Human Anatomy:

h_1 = 2/3 h; d = 1/3 h; r_1 = 2/3R; R = r_1 + 2 r_2

or: r_2 = ½ (R – r_1)

= ½ (R – 2/3R)

= 1/6 R.

Based on the comparison calculation in the heart image on Atlas of Human Anatomy, the shape from basic to apex is more like a tube, so the general volume formula is: V = π R^2 h

V (volume) LA = π R^{2}h – π r_1^2 h_1 – 2 (π r_2^2 d)

V = π (R^{2}h – r_1^2 h_1 – 2. r_2^2 d)

V = π (R^{2}h – r_1^2. 2/3 h – 2. r_2^2 1/3h)

= πh (R^2 – 2/3 r_1^2 – 2/3. r_2^2)

= πh {R^2 – 2/3(r_1^2+r_2^2)}

= πh {R^2 – 2/3(4/9R^2+ 1/36R^2)}

= πh (R^2 – 2/3x17/36R^2)

= πh. 37/54 R^2

or = 37/54 πh R^2 ……………7)

Formula: Mass = Volume x Density

m = V x D.

m = mass; V = volume from formula 7);

D = blood density = 1,060 g/cm3.

m = 37/54 πh R^2 x D.

= 37/54 πh R^{2}D gram (cgs unit) …………8)

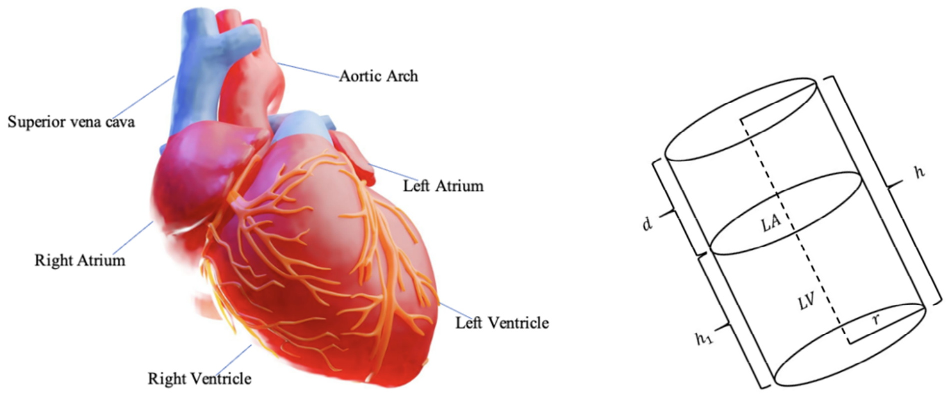

Figure 1. Comparison of anatomical and schematics drawing of a heart.[5]

A = LA space surface area

LA area approximation = the total conical wall area with side length s approximately equal to length h, minus the conical wall area "LV" and minus the area of 2 "pseudo" small cone sections at the base.

Area of 1 full circle with radius = s, is = πs^2

Area of a section with angle α at the center = $\alpha/360\ \pi s^2$

$R/h = tg\ \frac{1}{2}\alpha$.

Based on the calculation of the ratio of R and h on the heart image in Atlas Netter:

R = 6 cm, h = 10 cm → tg ½ α.= 0,6

$tg\ 30^0 = 0{,}58$.

Thus $1/2\ \alpha = 30^0$ or angle $\boldsymbol{\alpha = 60^0}$

LA half area = ½ A

$1/2\ A = \alpha/360\ \pi s^2 - \alpha/360\ \pi\ s_1^{\ 2} - 2 \times (1/2\alpha)/360\ \pi\ s_2^{\ 2}$.

$= \alpha/360\ \pi\ (s^2 - s_1^{\ 2} - s_2^{\ 2})$; length s approximately = h

$= \alpha/360\ \pi\ (h^2 - h_1^{\ 2} - d^2)$

$= \alpha/360\ \pi\ (h^2 - 4/9\ h^2 - 1/9\ h^2)$

$= \pi\ \alpha/360.\ 4/9\ h^2$

The total surface area of LA = A = $2\times\ .\ 4/9\ \pi\ \alpha/360\ h^2$

$= 8/9\ \pi\ 60/360\ h^2$

$= 4/27\ \pi h^2$ cm^2 ……………………9).

Pressure on LA

$P_{LA} = m.\ g / A$ from formula 6)

$= 37/54\ \pi h\ R^2\ D.\ g / 4/27\ \pi h^2$ from formula 8) and 9)

$= 37/8\ D\ R^2 .\ g\ h / h^2$

$= 37/8\ (R/h)^2\ D\ g.\ 3d$;…………..see also formula 5).: h = 3d and $d = v^2/2\ g$

$= 37/8\ (R/h)^2\ D.\ g.\ 3 \times v^2/2\ g$

D = 1,060 g/cm^3, g = gravitational field strength

R/h = tg 1/2 α; $\alpha = 60^0$; $1/2\ \alpha = 30^0$ → $tg\ 30^0 = 0{,}58$.

P_{LA} = $111/16.\ 0{,}58^2 .\ 1{,}060\ .\ \times v^2$.

$\boldsymbol{P_{LA} = 2{,}47\ v^2\ g/cm.sec^2}$ **………………10)**

1 P_a = 1 N/ 1 m^2. (P_a = Pascal)

= 1 kgm/sec^2 / 1 m^2 =1 kg/m sec^2

= 10 g/cm sec^2

1 mmHg = 133,3 P_a atau 1 P_a = 0.0075 mmHg

$\boldsymbol{P_{LA} = 2{,}47\ V_A^{\ 2}\ g/\ cm.sec^2}$

$= 0{,}247.\ V_A^{\ 2}$ Pa (Pascal)

$= 0{,}247\ V_A^{\ 2} \times 0{,}0075$ mmHg

or: $\boldsymbol{P_{LA} = 18{,}525.\ 10^{-4} \times V_A^{\ 2}}$ mmHg cgs → VA units must be in cm/s

$= 18{,}525.\ 10^{-4}.\ 10^4 \times V_A^{\ 2}$ mmHg V_A value in **m/s**

$\boldsymbol{P_{LA} = 18{,}525\ V_A^{\ 2}}$ **mmHg**…….(V_A in **m/s**) …… Formula **11**.

Example: if $V_A = 0{,}7$ m/s

$$P_{LA} = 18{,}525 \times 0{,}7^2 \quad \text{mmHg.}$$
$$= 9{,}1 \text{ mmHg}$$

One of the clinical benefits is in treating acute heart failure, according to the Nohria method with Wet and Cold data, other than cardiac output, PC (Pulmonary Capillary) or PAWP pressure is required.

CONCLUSION

The new PAWP formula has advantages over the Nagueh formula, where the new formula uses blood flow while the Nagueh formula uses tissue imaging. This formula can enrich the knowledge, especially in the field of cardiology. It is recommended that this formula be validated with right heart catheterization using Swan-Ganz catheter, to compare its advantages and disadvantages over the Nagueh formula.

ACKNOWLEDGMENTS

This PAWP formula has been registered to the Indonesian Copyright Service (HAKI) by Lukman H. Makmun (Reg. no.EC00202297063, November 30, 2022).

REFERENCES

1. Nair R, Lamaa N. Pulmonary capillary wedge pressure. StatPearls [Internet]. 2022 Apr 21; Available from: https://www.ncbi.nlm.nih.gov/books/NBK557748/
2. Viray MC, Bonno EL, Gabrielle ND, et al. Role of pulmonary artery wedge pressure saturation during right heart catheterization: A prospective study. Circ Heart Fail [Internet]. 2020;660–2. Available from: https://www.ahajournals.org/doi/abs/10.1161/CIRCHEARTFAILURE.120.007981
3. Naeije R. Physiology of the pulmonary circulation and the right heart. Curr Hypertens Rep. 2013;15(6):623–31.
4. Nagueh SF, Middleton KJ, Kopelen HA, Zoghbi WA, Quiñones MA. Doppler tissue imaging: a noninvasive technique for evaluation of left ventricular relaxation and estimation of filling pressures. J Am Coll Cardiol. 1997;30(6):1527–33.
5. Netter FH. Netter atlas of human anatomy. 7th Edition. Philadelphia, PA: Elsevier Health Sciences; 2019.