

Aortic Valve Areas: Gorlin or Hakki?

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Over the last several months, I've been taking our cardiology fellows and lab staff through the fundamentals and some of the advanced concepts of hemodynamics in the cath lab. We've been using our *Hemodynamic Rounds 4th edition* as our source book. These "Hemodynamic Rounds Live" are 30-minute recorded zoom talks. Some have been archived on *CLD's* website under "Grand Rounds with Morton Kern, MD".^{1,2}

In the presentations this month, we covered atrial septal defects (ASDs), ventricular septal defects (VSDs), and hypertrophic cardiomyopathy in two parts. As a natural extension of our learning program, we revisited the calculations essential to quantitating the results of our pressure tracings and in particular, valve area calculations. In the spirit of full disclosure, a confession. I went into cardiology so I would not have to do math and not deal with hematology. I was wrong on both counts. Cath lab math has always been a struggle for most of us, but with some patience and applied diligence, we can overcome this barrier. With this in mind, I thought I'd talk about how one of the most common and most important hemodynamic formulas, the Gorlin formula, evolved into a simplified, practical method, the Hakki formula. Having said that, we, those of us working in the cath lab, should know how to calculate the important hemodynamic derivative values, but, let's face it, we live in the era of the internet and smart phone apps, so that most formulas and results can be easily obtained by looking at your phone. Nonetheless, real heart people (mostly fellows) have to work through the numbers (particularly just before your board exams).

Starting Point: Cardiac Output Methods

Cardiac output (CO) is a key measure in all valve calculations and a determination of the severity of heart failure and shock and several other conditions, including shunts. There are several ways to obtain CO: the Fick method, thermodilution, radionuclide imaging, echocardiographic stroke volume calculations, or angiographically-derived stroke volumes. We no longer think about or use angiographic CO unless you're in a research center.

Outside the cath lab, the most common methods would include the stroke volume (SV) measured from the echocardiogram x the heart rate. For example:

- Stroke volume = left ventricular end diastolic volume – left ventricular end systolic volume (SV = LVEDV – LVESV);
- e.g., from the echo images, SV = 140 – 80 ml, SV = 60 ml;

- Cardiac output (CO) = HR (heart rate, beats/min) x SV = 70 bpm x 60 ml = 4,200 ml/min = 4.2 liters/minute.

In the ICU or CCU, patients in shock may have a right heart catheter placed and CO can be determined by thermodilution technique (see below). Table 1 provides some useful common hemodynamic parameters.

The Fick Method of Computing CO

Inside the cath lab, the 2 most common methods for CO measurements are the Fick or thermodilution techniques. In 1870, Adolf Eugen Fick, a German-born physician and physiologist (1829-1901) was working on diffusion physics. Based on this work, he was the first to compute CO by measuring blood oxygen changes in different locations. His method says that if you know the beginning and ending concentrations of a circulating substance (like oxygen in the blood) across a circuit, and you know the initial total amount substance available to be diluted in the flow stream, the difference between the starting-ending concentrations can be used to compute the transit or flow rate (volume/unit time or ml/min, etc).

In other words, the rate of flow across the circulation (say, starting from the aorta and ending in the right atrium) can be determined by the amount of total oxygen consumed (available), divided by the difference between the ends of the circuit; that is, the arterial oxygenated blood and the right atrial mixed venous blood oxygen (Figure 1). Formally, the Fick CO is calculated as:

Oxygen (O₂) consumption divided by the arteriovenous [O₂] difference (in milliliters of O₂).

NB: Remember for O₂ saturation percentages used for shunt calculations, the percents are converted

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Table 1. Basic Hemodynamic Formulas.

•	Mean arterial pressure = 1/3 (systolic blood pressure) + 2/3 (diastolic blood pressure); MAP = 1/3 [SBP] + 2/3 [DBP]
•	Pulse pressure = SBP – DBP
•	Stroke volume = left ventricular end diastolic volume – left ventricular end systolic volume; SV = LVEDV – LVESV
	For example, SV = 148 – 84 ml, SV = 64 ml
•	Cardiac output = heart rate x stroke volume; CO = HR x SV
	For example, CO = 80 bpm x 64 ml = 5120 ml/min = 5.12 L/min
Resistances	
•	Pulmonary vascular resistance = 80*(pulmonary artery pressure – pulmonary capillary wedge pressure)/CO, normal 100-200 dyn·s/cm ⁵ (called hybrid units = 80* Wood units) PVR = 80*(PAP – PCWP)/CO
•	Systemic vascular resistance (SVR) = 80*(MAP – central venous pressure [CVP])/CO, normal 900-1200 dyn·s/cm ⁵ .

Table 2. Three Formulas for Calculating Oxygen Consumption in the Cath Lab.

70 yo patient, 70 kg, BSA 1.7	O ₂ consumption, ml O ₂	Assuming AVO ₂ , diff of 5 mL O ₂ , CO (L/min)
1. LaFarge: a) Males: O ₂ cons = [138.1 – (11.49 x log pt age) + (0.378 x HR)] x BSA b) Females: O ₂ cons = [138.1 – (17.04 x log pt age) + (0.378 x HR)] x BSA	243	4.41
2. O ₂ cons = 125 ml/min x BSA [Dehmer]	212	4.2
O ₂ cons = 3 ml O ₂ x weight (kg)	210	4.2

BSA = body surface area, m²; AV = aortic valve; CO = cardiac output; cons = consumption; pt = patient; HR = heart rate

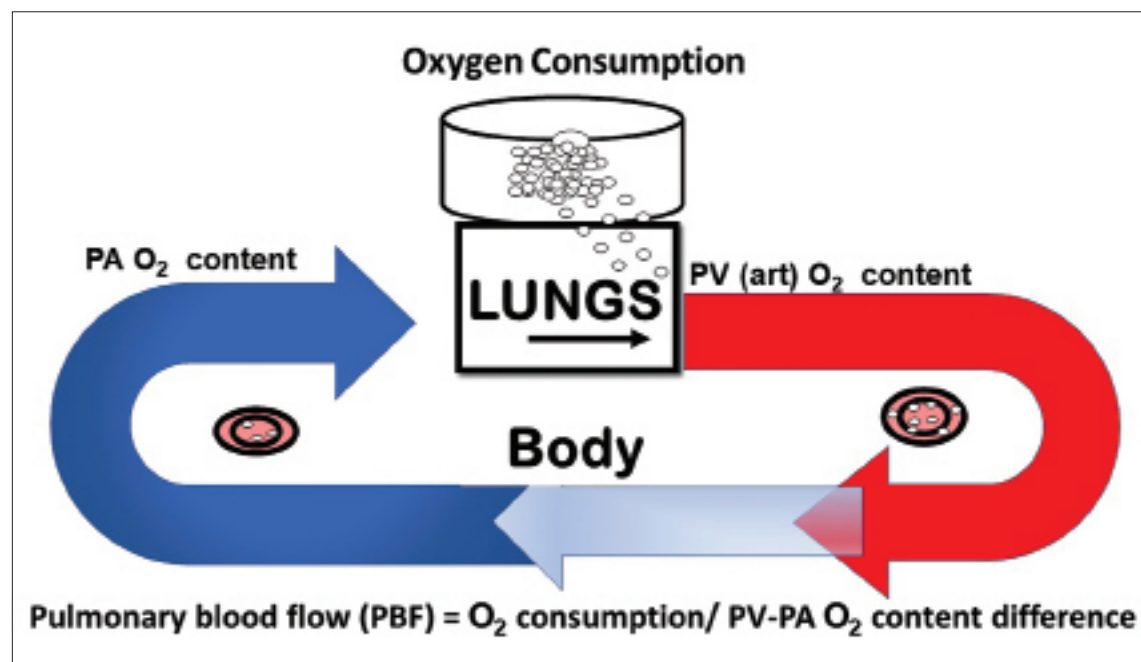


FIGURE 1. Cardiac output: Fick principle. In absence of shunt, pulmonary blood flow (PBF) = systemic blood flow (SBF) = the cardiac output (L/min). NOTE: Oxygen content = Hb x 1.36 x oxygen saturation (%). Hb = hemoglobin; PA = pulmonary artery; PV = pulmonary vein. In absence of shunt, mixed venous sat = PA sat; with intra-cardiac shunt, use MV = 3 x SVC + IVc/4.

TD CO Errors

- ✓ Not accurate in severe tricuspid regurgitation and low output syndromes
- ❄️ PA temp changes are greater for cold injectant
- 🌡️ Low flow, low CO may cause warming of injectant
- ✗ Empirical correction factor of 0.825 may be inadequate for derivation of true injectate temp

Inject 10 cc of saline in prox port

Temp change is detected at distal tip in PA

Change in temp is plotted on a curve. Area under curve = CO

FIGURE 2. Method of thermodilution cardiac output and common errors.

to amount (or content) of O₂ using the following formula: content = [1.36 x hemoglobin x O₂ saturation x 10 (a correction factor)]. A full discussion of shunts will be a future CLD Editor's Corner page.

The most variable part of the Fick formula is the determination of oxygen consumption. Several formulas have been proposed to use an approximated O₂ consumption (Table 2). The simplest is the formula 3 ml/kg x weight (kg) = ml O₂ consumption.

Estimating CO From PA O₂ Saturations

A quick way to estimate whether CO is either high or low is to look at the pulmonary artery (PA) O₂ saturation. The slower the blood flow moves around the circuit, the more time there

is for the extraction of the indicator (oxygen) to be taken out of the circulation and the lower the PA O₂ saturation will be. The faster the flow rate, the less time to extract oxygen, and the higher the PA O₂ sat. Normally, PA saturation values range from 65-75%. PA O₂ sats <60% suggest low CO, and PA sats >75 or 80% are associated with high CO (or shunts, as we will see). Figure 1 describes the Fick calculations for pulmonary and systemic blood flow (ie, CO).

Thermodilution CO

Another method of measuring cardiac output is by thermodilution, involving a multi-lumen right heart catheter positioned in the PA. Using

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2 thermistors to measure the temperature of the injected saline in the right atrium and the time-temperature curve as the saline/blood mix travels over the distal thermistor in the PA, the area under the thermodilution (TD) curve produces the CO value. Requirements for accurate measurements include a bolus injection, and a correction or calibration factor for the catheter (Figure 2). TD CO is better than Fick CO for high CO states. The TD method is less accurate in patients with tricuspid regurgitation, arrhythmias, and low CO conditions. Alnasser et al present an excellent review of cath lab math for a more detailed discussion.³

Valve Areas: Gorlin or Hakki?

In 1951, Gorlin and Gorlin (his father, a mechanical engineer who designed hydraulic systems for gasoline engines at the beginning of the 20th century) published their formula for calculating human valve areas.⁴ As might be expected at that time, the formula was complicated. Valve area (cm²) = flow across the valve (ml/sec) divided by and square root of pressure difference across the valve x 2 constants; the discharge coefficient is an empirical constant of 1 for the aortic valve and 0.7 for the mitral valve (these were assigned arbitrarily to improve data fit). The second constant is 44.5, which is a blood acceleration factor (square root of 2x gravity acceleration factor, 980 cm/sec/sec). Only the flow across the valve during valve opening is used. For aortic stenosis, flow = CO (ml/min) divided by HR (beats/min) x the systolic ejection period (SEP, point of aortic valve opening on left ventricular [LV] curve to the dichotic notch of aortic valve closure). For mitral stenosis, CO (ml/min) divided the HR x the diastolic filling period (DFP, point on the LV curve where mitral valve opens to end of the 'a' before isometric contraction [sec/beat]) (Figure 3). In 1972, Cohen and Gorlin revised the original formula and suggested the use of 0.85 for the mitral valve (instead of 0.7) as the discharge coefficient.⁵ The modern formula is:

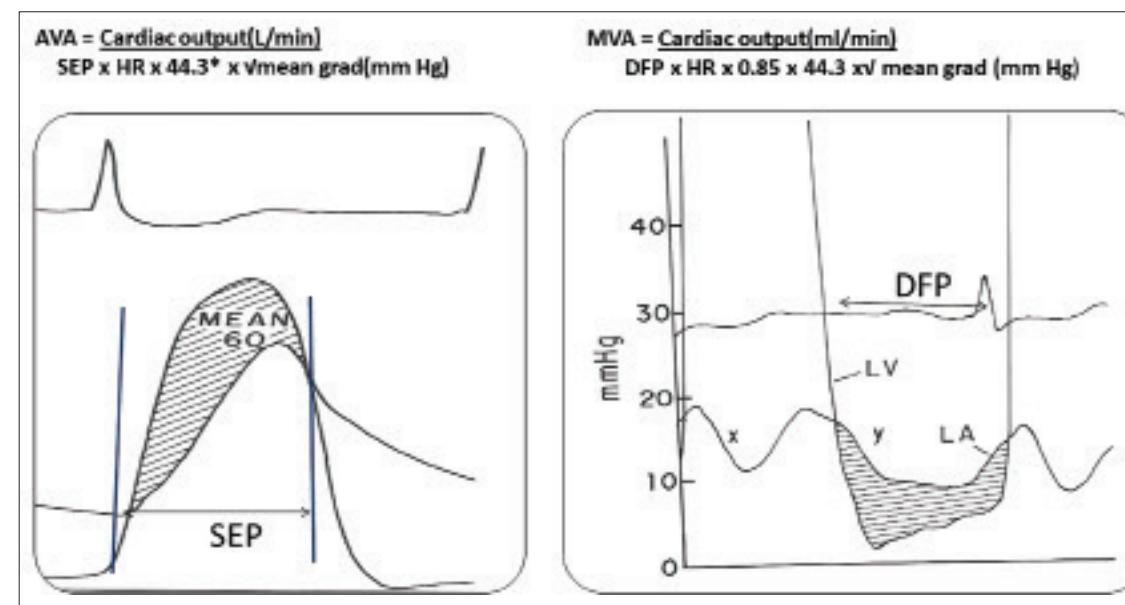


FIGURE 3. Aortic (left) and mitral (right) valve area calculations by the Gorlin formula. SEP = systolic ejection time/beat; HR = heart rate; SEP x HR = aortic valve flow during systole; DFP = diastolic flow period. *44.5 = the square root of twice the gravity acceleration factor (980 cm/sec/sec). 0.85 is correction factor for mitral valve coefficient.



FIGURE 4. Mechanical hand planimeter, circa 1965, used for calculating planar areas on paper tracings. The numbered wheels at the top move as the arm traces the area, adding positive values in one direction and reducing them as the arm moves back, producing a net area in square centimeters. A standard circle with known area was originally provided for calibration, but has been lost. Technology replaced hand planimetry about 40 years ago.

Today, everyone who works in the cath lab should know about the Hakki formula as an alternative and simplified Gorlin formula:

$$AVA_{Hakki} \text{ or } MVA_{Hakki} = \frac{CO}{\sqrt{\text{Peak-Peak (LV-AO) or mean (mitral) gradient}}}$$

$$Aortic \text{ Valve Area, } AVA_{Gorlin} = \frac{CO \text{ (milliliters)}}{[SEP \times HR \times 44.3 \times \sqrt{\text{Mean Gradient}}]}$$

$$Mitral \text{ Valve Area} = \frac{CO \text{ (milliliters)}}{[DFP \times HR \times 0.85 \times 44.3 \times \sqrt{\text{Mean Gradient}}]}$$

(Side note about Dr. Gorlin: I was a medical student at Mt. Sinai School of Medicine in New York City in 1974. Dr. Gorlin left the Peter Bent Brigham Hospital in Boston to become chief of medicine at the Mount Sinai Hospital. In 1976, after being one of his students and residents, I said to Dr. Gorlin that I was interested in staying and working with him for my cardiology fellowship. Smiling, he said I should go to Boston to get trained, then come back to work with him. Funny, that's what they said when I finished my fellowship in Boston at the Brigham and Women's. I then went to UT San Antonio, then on to St. Louis University, but I never forgot the great things that Dr. Gorlin had done for me. I wish I knew in my early training years what a genius he was and what he had done for all of us in providing the valve area calculation we still use today. Dr. Gorlin died in 1997.)

Hakki and the Simplified Gorlin Formula

Today, everyone who works in the cath lab should know about the Hakki formula as an alternative and simplified Gorlin formula:

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However, few know who Dr. Hakki is and how this formula came about. After looking up the 1981 publication,⁶ I realized that Drs. Gary Mintz and Ami Iskandrian were co-authors on the paper. I spoke to them and they related their story of Dr. Hamid Hakki (actually, A-Hamid Hakki).⁷ Dr. Hakki was a fellow at Hahnemann when Dr. Mintz was a cath lab and echo lab attending. Dr. Hakki was from Iraq, as was Dr. Ami Iskandrian. Hakki was very meticulous. All of our [Drs. Mintz and Iskandrian's] aortic stenosis cases involved measuring CO. At that time, CO was measured with indicator dilution method using indocyanine green [predating thermodilution - MK] coupled with simultaneous measurement of LV and aortic (Ao) pressures. The fellows would planimeter (Figure 4) the gradients by hand and calculate valve areas using the Gorlin formula. Hamid Hakki came into the lab one day and announced that the Gorlin formula should be simplified, because (if I [Dr. Mintz] remember correctly), HR x SEP x 44.3 (the Gorlin constant) was always "1." (Dr. Mintz sent a photo [Figure 5] of Dr. Hakki.)

Dr. Iskandrian told us that the 1981 *Circulation* paper⁶ "was the only paper that I [Dr. Iskandrian] ever had accepted without revisions." After

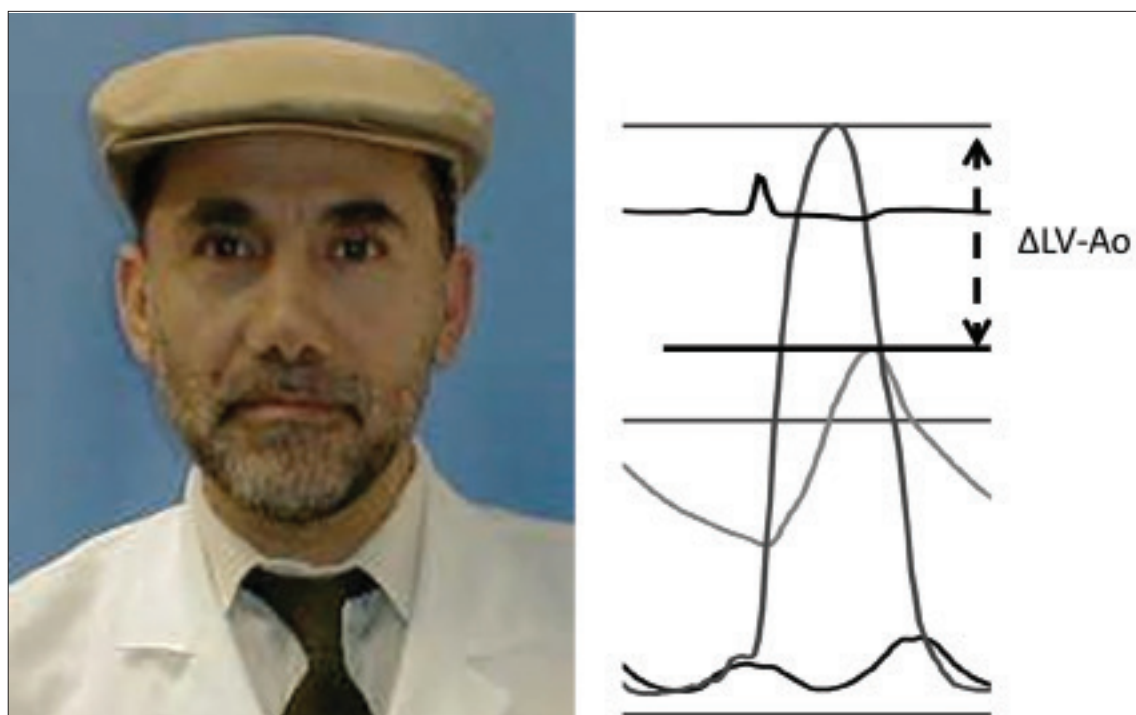


FIGURE 5. Dr. A-Hamid Hakki. Courtesy of Gary Mintz, MD. Right panel, $\Delta LV-Ao$, peak LV minus peak Ao pressures. LV = left ventricle; Ao = aortic. Double-headed arrow denotes the peak to peak LV and Ao systolic pressures.

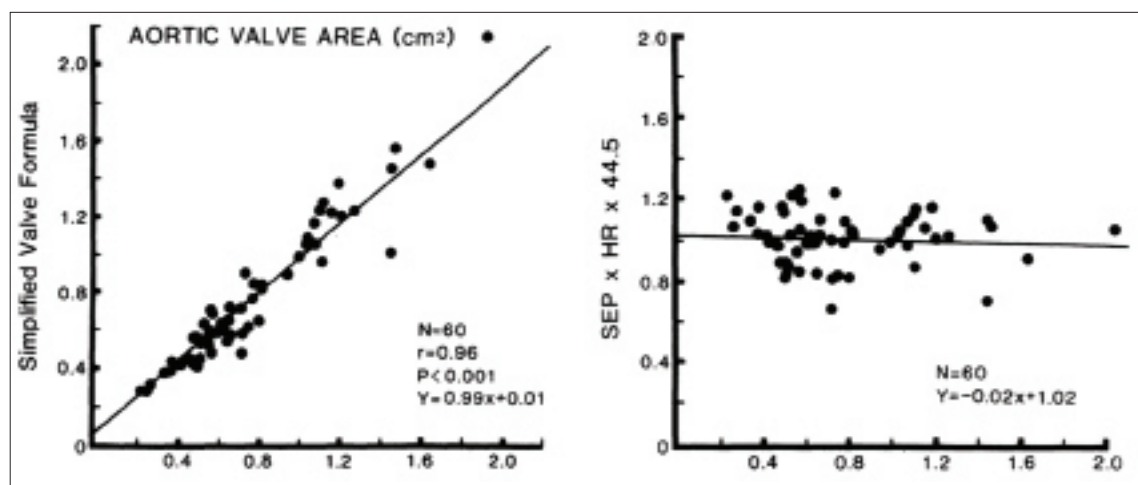


FIGURE 6. Left, correlation between aortic (Ao) valve area by original Gorlin formula and simplified valve formula. Mean pressure difference was used in both formulas. Right, correlation between the product of system ejection period (SEP) x HR x 44.5 and aortic valve area as measured by the original Gorlin formula. The $SEP \times HR \times 44.5$ is close to 1. Reprinted with permission from Hakki AH, Iskandrian AS, Bemis CE, Kimbiris D, Mintz GS, Segal BL, Brice C. A simplified valve formula for the calculation of stenotic cardiac valve areas. *Circulation*. 1981;63(5):1050-1055. doi:10.1161/01.cir.63.5.1050

fellowship, Dr. Hakki worked with Dr. Iskandrian for a time in the in nuclear lab, and later went to Florida to practice general cardiology and imaging.

The Hakki formula correlated very closely with the Gorlin aortic valve area (AVA) (Figure 6) with a few caveats related to reduced accuracy in bradycardia (HR <60 bpm) and tachycardia (HR >100 bpm).

The Bottom Line

An accurate cardiac output is pivotal to many critical hemodynamic conditions, especially for the calculations of valve areas and subsequent clinical decisions. The answer to the question, “Gorlin or Hakki?” is yes; that is, the results are the nearly

same and selection of the better formula depends on the clinical variables of the specific patient. The stories of how valve areas were derived are unique and pertinent to today’s invasive practice. I hope that these explanations and personal vignettes will help us remember what to do in the lab and on our exams. ■

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Disclosures: Dr. Morton Kern reports he is a consultant for Abiomed, Abbott Vascular, Philips Volcano, ACIST Medical, and Opsens Inc.

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