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Vascular Pedicle Width on Chest Radiograph as a Measure of Volume Overload: Meta-Analysis

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Introduction: Vascular pedicle width (VPW), a measurement obtained from a chest radiograph (CR), is thought to be an indicator of circulating blood volume. To date there are only a handful of studies that demonstrate a correlation between high VPW and volume overload, each utilizing different VPW values and CR techniques. Our objective was to determine a mean VPW measurement from erect and supine CRs and to determine whether VPW correlates with volume overload.

Methods: MEDLINE database, Web of Science, and the Cochrane Central Register of Controlled Trials were searched electronically for relevant articles. References from the original and review publications selected electronically were manually searched for additional relevant articles. Two investigators independently reviewed relevant articles for inclusion criteria and data extraction. Mean VPW measurements from both supine and erect CRs and their correlation with volume overload were calculated.

Results: Data from 8 studies with a total of 363 subjects were included, resulting in mean VPW measurements of 71 mm (95% confidence interval [CI] 64.9–77.3) and 62 mm (95% CI 49.3–75.1) for supine and erect CRs, respectively. The correlation coefficients for volume overload and VPW were 0.81 (95% CI 0.74–0.86) for both CR techniques and 0.81 (95% CI 0.72–0.87) for supine CR and 0.80 (95% CI 0.69–0.87) for erect CR, respectively.

Conclusion: There is a clinical and statistical correlation between VPW and volume overload. VPW may be used to evaluate the volume status of a patient regardless of the CR technique used. [West J Emerg Med. 2011;12(4):426–432.]

INTRODUCTION

Rapid identification of patients with severe volume overload is important in the diagnosis and management of critically ill emergency department (ED) patients. While patients with volume overload typically present with difficulty breathing, clinical diagnosis can often be challenging.^{1–3} Patients with a delayed diagnosis of volume overload may experience significant morbidities, prolonged hospitalization, and increased length of intensive care stay, or possibly even

death.^{4,5} Yet as significant as volume overload is to clinical practice and patient outcomes, no reliable, robust method for quantifying volume status or volume overload exists.

Chest radiographs (CR) are routinely used in the ED to evaluate for cardiopulmonary abnormalities. CRs are quick, easy to obtain, and noninvasive. Several CR characteristics, such as prominent pulmonary vasculature in the lung fields, blunted costophrenic angles, loculated fissure effusions, hazy interstitial markings, and a butterfly edema pattern, are

routinely used for the evaluation of volume overload.^{6–10} However, these radiographic signs are subjective and clinician dependent, and the correlation with volume overload is qualitative at best, as well as quantitatively ill-defined.

In 1984, Milne and colleagues¹¹ measured the vascular pedicle width (VPW) on CR to estimate the intravascular volume status. VPW is the distance, measured in millimeters, from a perpendicular line at the takeoff point of the left subclavian artery off the aorta to the point at which the superior vena cava crosses the right main bronchus (Figure 1). Numerous studies^{12–20} report that VPW measurement is significantly larger in patients with volume overload and that increased VPW measurement correlates with volume overload as well. Measuring the VPW is relatively easy, accurate, and objective. (Please see Figure 2 for comparison of VPW measurement in a patient with volume overload vs a patient with normal volume status.)

Studies^{12–24} published to date have used different VPW values to illustrate the significance of volume overload. Some studies have measured VPW on erect CRs and others have used supine views. The number of subjects in prior studies has been limited. Therefore, a systemic meta-analysis was conducted to determine the different VPW values using different CR techniques and whether they correlate with volume overload.

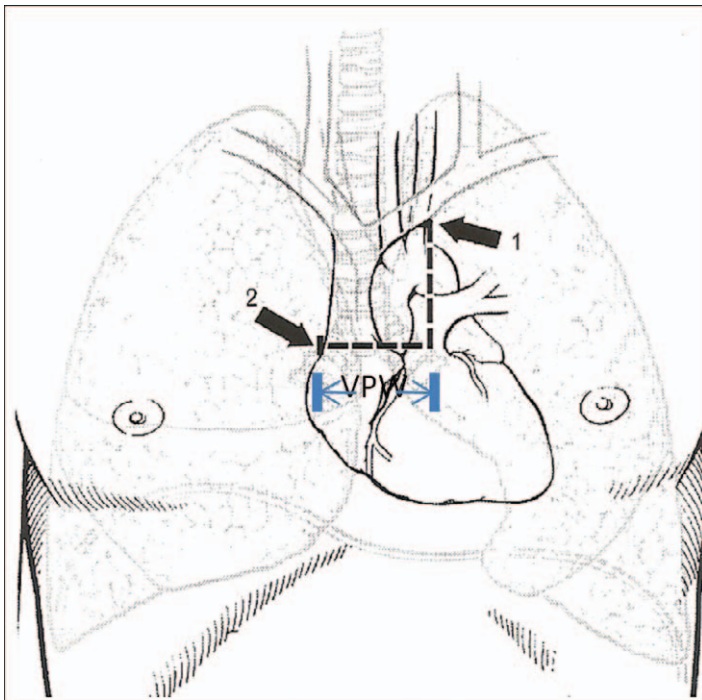


Figure 1. The vascular pedicle width is measured by 1, dropping a perpendicular line from the point at which the left subclavian artery exists the aortic arch and 2, measuring across to the point at which the superior vena cava crosses the right mainstem bronchus. Produced with permission from Ely et al.²⁰

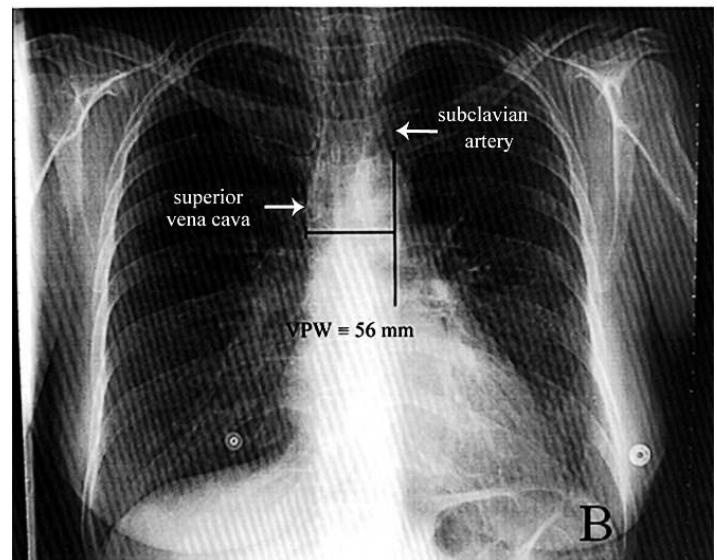
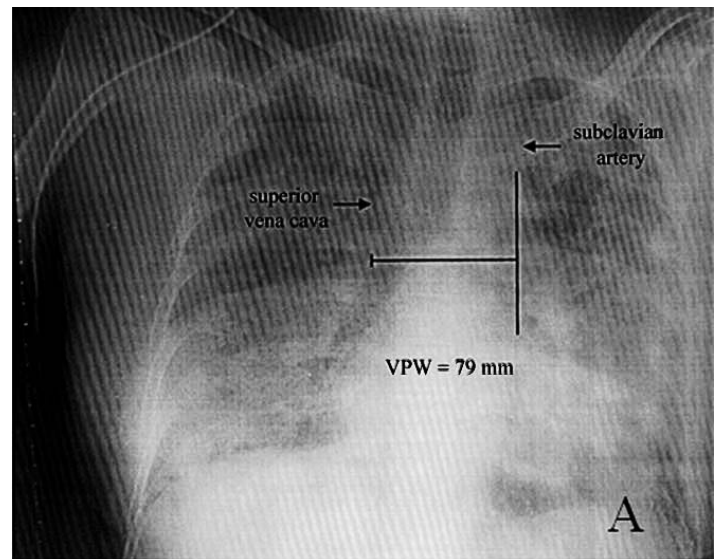


Figure 2. A, A portable chest radiograph (CR) of a 52-year-old woman with pulmonary edema who has a vascular pedicle width (VPW) measured at 79 mm. B, The same patient after having 10,900 mL net fluid removed 10 days later. Portable CR showed a VPW of 56 mm. Figure adapted and produced with permission from Ely and Haponik.³⁴

METHODS

An electronic search of the MEDLINE database (1966–December 2009), Web of Science (1900–December 2009), and the Cochrane Central Register of Controlled Trials (1900–December 2009) for English-language articles that had the keywords, text words, or MESH headings of “vascular pedicle width” or “VPW” in combination with “volume status” or “volume overload” or “pulmonary edema” or “intravascular volume” was performed. A manual search of cited references was reviewed. Two investigators independently reviewed all articles. Discrepancies were resolved by consensus, with a third reviewer available if necessary.

Articles were selected if VPW was measured on CR in patients in either erect or supine positions and if volume overload had been evaluated by invasive and/or noninvasive techniques, including pulmonary artery occlusion pressure (PAOP), global end diastolic volume, intrathoracic blood volume index, left atrial emptying fraction (LAEF), or total blood volume. Studies that did not report a mean value or standard deviation (SD) were excluded. Two reviewers also independently assessed each included study and evaluated the quality of each article using the Jadad score.²⁵

The mean VPW, SD, correlation coefficient, and sample size were obtained from each study. Comprehensive meta-analysis software 2.2 and Stata 11 (College Station, Texas) were used for data analysis.²⁶ The summary effect of mean VPW (weighted mean) was estimated by assigning weight as the inverse of its variance method in the fixed effects of meta-analysis.²⁷ A random effect model, utilizing the DerSimonian and Laird method, estimated the summary effect of mean VPW.²⁸ Similarly, fixed and random effects were estimated for cardiothoracic ratio (CTR) as well as correlation coefficient. Two subgroups, erect and supine, were analyzed for VPW values. The Q-test, which is a chi-square method, was used for comparison between these 2 groups based on Cochran method.²⁹ A P value less than 0.05 was considered a statistically significant difference between groups.

RESULTS

Eight studies (2 retrospective and 6 prospective) with 363 subjects were included in the meta-analysis (Table 1). With the exception of 2 studies that did not mention who measured

VPW, in most studies, VPW was measured by radiologists.^{15,18} Volume overload and/or pulmonary edema were evaluated using either invasive or noninvasive methods, as mentioned above. Only VPWs measured in volume overload and/or pulmonary edema patients are included in this meta-analysis. Seven studies were excluded because they either belonged to review papers or contained a lack of reportable data^{6,11,20-24} (refer to Figure 3 for flow diagram of selection).

The meta-analysis results of VPW measurement in patients with volume overload are shown in Table 2. VPW measurements from 2 CR groups were compared: those with erect and supine views. The mean VPW value was 62.2 mm (95% confidence interval [CI] 49.3–75.1 mm) in the erect group and 71.1 mm (95% CI 64.9–77.3 mm) in the supine group. VPW measurements between the erect and supine CR groups were statistically significant (Q value = 77.3, P < 0.001). Regardless of CR technique, the larger the VPW value measured, the higher the change in the patient’s volume overload (r = 0.81, Q = 0.06, P = 0.80) (Table 3).

Only 3 studies¹⁴⁻¹⁶ investigated the CTR and its correlation with volume status. CTR is the maximum transverse diameter of the heart (determined by CR) divided by the greatest internal diameter of the thoracic cage (from inside of rib to inside of rib). It is used initially to help determine enlargement of the heart. Data analysis from these studies supports prior conclusions that CTR correlates poorly with volume status.

LIMITATIONS

A limited number of studies with small sample populations using different CR techniques and various methods to measure

Table 1. Studies included in this meta-analysis.

Study	Study design			Measured VPW			Methods to measure the volume		
	Jadad Score	Year	Patients	Method	Mean (mm)	SD (mm)	CTR	r	Status
Pistolesi et al ¹²	Prospective, blinded (2)	1984	61	Erect				0.80	TBV
Haponik et al ¹⁷	Retrospective (0)	1986	42	Erect	69.0	12.0			CR
Cascade et al ¹⁶	Retrospective (0)	1993	8	Supine	67.0	11.5	0.550		CR
Thomason et al ¹³	Prospective, randomized, blinded (3)	1998	33	Supine				0.45	PAOP
Martin et al ¹⁴	Prospective, randomized, blinded (3)	2002	37	Supine	62.9	12.9	0.535		PAOP
Iqbal et al ¹⁵	Prospective (0)	2006	32	Erect	55.8	10.2	0.540		LAEF
Aloizos et al ¹⁸	Prospective (0)	2007	100	Supine	75.1	3.9		0.71	GEDI/ITBI
Salahuddin et al ¹⁹	Prospective, blinded (2)	2007	50	Supine	77.6	12.6		0.89	PAOP
Total			363						

Jadad score, measures of study design and reporting quality (0 being weakest and 5 being strongest); VPW, vascular pedicle width; CTR, cardiothoracic ratio; volume status, methods used to evaluate volume status/pulmonary edema, including both invasive and noninvasive procedures; r, correlation coefficient with volume overload; SD, standard deviation; TBV, total blood volume; CR, other chest radiograph findings consistent with volume overload/pulmonary edema; PAOP, pulmonary artery occlusion pressure; LAEF, left atrial emptying fraction; GEDI, global end diastolic index; ITBI, intrathoracic blood volume index.

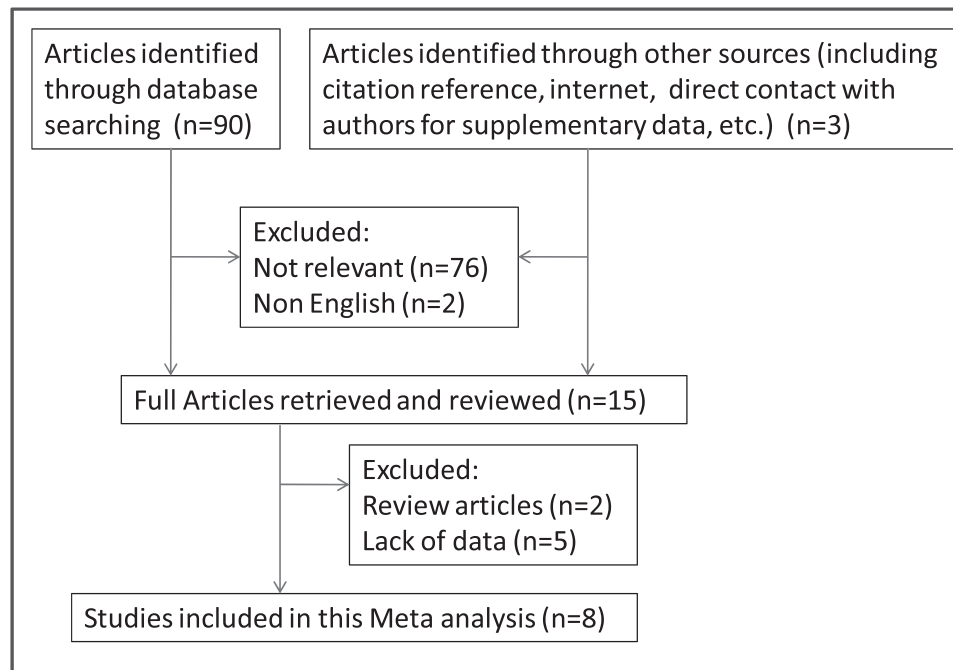


Figure 3. Flow diagram of search results for meta-analysis.

volume overload contribute to a relatively high interstudy variability, lowered power, and statistical effect. Additionally, there was no consistent gold standard to which volume overload was measured, making this study extremely hard to analyze quantitatively when compared to VPW values.

A funnel plot is designed to check the existence of publication bias in meta-analysis. Studies with publication bias usually obtain an asymmetric funnel plot.³⁰ We did funnel plots on both erect and supine mean VPW (data not shown). Our results showed that the supine VPW measurement has less publication bias than did the erect VPW measurement. However, publication bias is only one of the possible explanations for funnel plot asymmetry. Factors that can affect the funnel plot asymmetry include but are not limited to language bias, citation bias, the size of effect differing according to study size, and poor methodological design of small studies, etc.^{31,32} As a result of the limited data, this meta-analysis included both prospective and retrospective studies. In the erect VPW group, there are only 2 small studies included, which could significantly affect the results and cause an asymmetric funnel plot.

Studies that reported only cut-off VPW values chosen from receiver operating characteristic curves are not included in this meta-analysis as a result of lack of VPW mean and SD values.^{11,20–24} This could result in eschewed data and poor meta-analysis due to incomplete enrollment of all studies. In addition, although bigger VPW values correlated with higher PAOP, wider inferior vena cava (IVC) diameter, higher LAEF, and worsening total circulating blood volume, because of the limited numbers of subjects enrolled, no large validation studies were performed individually.^{33–51}

DISCUSSION

The data from this meta-analysis report VPW values from both erect and supine CR techniques that support the correlation between volume overload and increased VPW measurements.^{11,12,33–35} Prior studies were limited by small sample size, varying VPW measurements, and CR technique (supine and erect). VPW was initially described using 72-inch erect periapical radiographs. However, supine CRs are commonly performed in critically ill patients using a portable radiograph machine. Thus, it is critical to address the difference in VPW values based on the position of the patient for CR. VPW measured¹¹ on supine CRs in normal volunteers increased by 17% as a result of gravity. In addition, VPW values can be altered by respiratory effects or by subjects' previous medical problems, especially cardiovascular diseases.¹¹ For these reasons, the accuracy of VPW measurements on supine CR and its correlation with volume status has been questioned.

Four studies included in this meta-analysis used the supine CR technique for VPW measurements on subjects in the intensive care unit setting. Mean VPW values on supine CRs were significantly larger than in erect CRs (62 mm vs 71 mm, $Q = 77.3$, $P < 0.001$). Analysis of statistical heterogeneity is done using the Q statistic, which is a measure of the variability among studies related to the outcome variable. We chose the results from the random effect model on VPW value since the heterogeneity is presented ($P < 0.001$). In contrast, results of correlation coefficient from fixed-effects model are used because no statistically significant difference was found between studies ($Q = 0.06$, $P > 0.05$). Our results indicate that different VPW cut-off values need to be considered when using

Table 2. Meta-analysis of vascular pedicle width measurement in patients with volume overload.

Model	Study	Method	Statistics for each study			
			Mean (mm)	Standard error	95% confidence interval	
Fixed	Haponik et al ¹⁷	Erect	69.00	2.83	63.46	74.54
	Iqbal et al ¹⁵	Erect	55.81	1.80	52.28	59.34
Random		Erect	59.62	1.52	56.64	62.60
Fixed	Cascade et al ¹⁶	Supine	67.00	4.70	57.80	76.20
	Martin et al ¹⁴	Supine	62.99	2.12	58.83	67.15
	Aloizos et al ¹⁸	Supine	75.14	0.75	73.67	76.61
	Salahuddin et al ¹⁹	Supine	77.60	1.78	74.11	81.09
		Supine	74.17	0.65	72.89	75.45
Random		Supine	71.18	3.16	64.98	77.38
Fixed		Overall	71.91	0.60	70.74	73.09
Random		Overall	69.51	2.85	63.92	75.10

different CR techniques. However, regardless of the CR techniques used to measure the VPW value, they both correlate with volume overload (0.81 vs 0.80, $P > 0.05$), indicating the reliability of using VPW to evaluate the volume status.

Various invasive and noninvasive methods were used to measure volume overload, including pulmonary artery catheterization, ultrasound of the IVC, echocardiogram for LAEF, and direct measurement of total circulating blood volume.³⁶⁻⁵¹ Invasive procedures require skillful operators, are time consuming, and result in more severe complications.³⁶⁻³⁹ Recently there has been an effort to replace invasive procedures with noninvasive alternatives. Subjects undergoing direct measurement of total circulating blood volume receive high radiation exposure, and this method is contraindicated in patients with a dye allergy or renal failure and is not repeatable on a daily basis.⁴⁰⁻⁴³

Bedside ultrasound is used to assess the volume status, including the measurement of IVC and LAEF. However, different percentage of IVC collapse during respiration obtained at different locations (such as at the level of the diaphragm, the hepatic vein inlet, or the left renal vein) indicates relatively higher variability.⁵¹ Echocardiogram to measure LAEF requires more specific training and is unreliable in inexperienced hands. Overall, to date there is no gold standard by which to determine whether subjects have volume overload and how severe it is.

CRs are commonly used in the ED to evaluate cardiovascular pathology. However, some radiographic signs for cardiovascular pathology are considered subjective, with higher variability among different readers. Using VPW to evaluate volume status is relatively objective. In addition, some studies also investigated the consistency of VPW

Table 3. Meta-analysis of correlation coefficient of vascular pedicle width and volume overload in patients with erect or supine chest radiograph.

Model	Study	Method	Statistics for each study		
			Correlation	95% confidence interval	
Fixed	Pistolesi et al ¹²	Erect	0.80	0.69	0.87
		Erect	0.80	0.69	0.87
		Erect	0.80	0.69	0.87
Random	Thamason et al ¹³	Supine	0.45	-0.11	0.79
		Supine	0.71	0.45	0.86
		Supine	0.89	0.81	0.94
		Supine	0.81	0.72	0.87
Fixed		Supine	0.75	0.43	0.90
Random		Supine	0.75	0.43	0.90
Fixed		Overall	0.81	0.74	0.86
Random		Overall	0.79	0.69	0.86

measurement interpreted by the same radiologist at different time points (second reading approximately 3 months later to reduce recall bias; this is considered intrareader variability) or interpreted by different radiologists (interreader variability). The mean average percent variation on VPW measurement among different readers was only 2%.¹¹ The intrareader correlation coefficient for VPW is 0.82, and the interreader correlation coefficient is 0.84.²⁰ These studies indicate that measuring VPW on CR has relatively high consistency and low variability.

The data from this meta-analysis demonstrate that VPW correlates with volume overload. The higher the VPW value, the greater the correlation with volume overload and/or pulmonary edema. However, it may not be accurate to measure VPW in subjects with recent cardiothoracic surgery or severe rotation on CR or in subjects with mediastinal pathologies. Taken together, VPW measurements may be used as a diagnostic tool to evaluate volume status in selected patients. VPW measurement may be of particular value to emergency physicians, since it represents an easy, quick, and noninvasive method that can be applied in daily practice.

Few studies with limited data have also reported that the “delta” VPW, which is the difference between VPW measurements before and after treatment, highly correlates with intravascular volume status.^{14,22} Serial VPW measurements and the “delta” VPW may be useful to monitor the volume status change of a patient receiving medical management. However, we are unable to do any meta-analysis on delta VPW as a result of lack of clinical data at this time. To further determine the role of VPW in the evaluation of volume overload requires multicentered, prospective studies involving large numbers of patient and detailed information.

CONCLUSION

VPW value measured in supine and erect positions may be useful for evaluating patient volume status, as it appears to vary in a similar fashion with other prevailing measures of volume overload, none of which provides a gold standard for defining volume overload. In addition, a different cut-off VPW value needs to be considered related to the different CR techniques.

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funding sources, and financial or management relationships that could be perceived as potential sources of bias. The authors disclosed none.

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