ISSN 0025-7680

ORIGINAL ARTICLE MEDICINA (Buenos Aires) 2004; 64: 31-35

OVERESTIMATION OF THORACIC GAS VOLUME DURING THE AIRWAY RESISTANCE MANEUVER

A POTENTIAL ERROR IN THE DIAGNOSIS OF AIR TRAPPING

CARLOS A. NIGRO, EDUARDO DIBUR, SANDRA LIMA, SANTIAGO GIAVEDONI, ERNESTO J. PRIETO, EDGARDO E. RHODIUS

Laboratorio Pulmonar, Servicio de Neumonología, Hospital Alemán, Buenos Aires

Abstract There are no data published about the agreement between the measurement of thoracic gas volume (TGV) during the airway resistance (TGV-Raw) and the conventional technique described by Dubois. The aim of this study was to establish the agreement between both methods to measure TGV. We studied eighty consecutive subjects. Only sixty-six performed acceptable plethysmography maneuvers. The patients were measured with a constant volume plethysmograph (*Medical Graphics 1085 DL*). TGV was performed in the same patient with two techniques: 1) during the airway resistance (Raw) measurement (TGV-Raw) and 2) during quiet breathing at the end of expiration (TGV). The panting frequency was 1 to 2 Hz with both maneuvers. The differences between both techniques were expressed in percentage (ΔTGV %) and absolute values (ΔTGV). The TGV-Raw of the whole group was higher than TGV (3.69 ± 1.08l vs 3.28 ± 1.05l, p < 0.001). Similarly, the subgroups of patients had a greater TGV-Raw than TGV (Normal: 3.44 ± 0.77l vs 2.98 ± 0.72l, p < 0.001; Obstructive: 4.08 ± 1.19l vs 3.71 ± 1.15l, p < 0.001; Restrictive: 2.62 ± 0.49l vs 2.25 ± 0.51l, p < 0.01). There was a considerable lack of agreement between the TGV-Raw and TGV, with discrepancies of up to +0.95l or +34%. The ΔTGV % was similar between the patients' subgroups and between the subjects with different degree of airflow obstruction (Normal: 16.5 ± 10%, Obstructive: 10.8 ± 9.4%, Restrictive: 18 ± 14.3%, p NS; mild obstruction: 10.7 ± 11%, moderate obstruction: 12.3 ± 5.7, severe obstruction: 10.1± 6.6, p NS). In conclusion, TGV-Raw was larger than TGV. This was because the patients generally panted at a volume above FRC when performing the TGV-Raw maneuver. TGV-Raw should not be used to estimate FRC because FRC would be overestimated and the diagnosis of air trapping may be erroneous.

Key words: static lung volume, thoracic gas volume, body plethysmography

Resumen ***Sobreestimación del volumen de gas torácico durante la maniobra de resistencia de la vía aérea. Un error potencial en el diagnóstico de atrapamiento aéreo.*** No hay datos publicados sobre el acuerdo entre la medición del volumen de gas torácico (VGT) durante la maniobra de resistencia de la vía aérea (Raw) y la técnica de medición convencional del VGT descripta por Dubois. El objetivo del estudio fue establecer el grado de acuerdo entre ambos métodos para medir VGT. Se estudiaron 80 sujetos consecutivos que concurrieron al laboratorio pulmonar para hacerse un examen funcional respiratorio. Solo 66 individuos realizaron maniobras pletismográficas adecuadas. Los pacientes fueron medidos con un pletismógrafo de volumen constante (*MG 1085 DL*). El VGT fue realizado en el mismo paciente con dos técnicas: 1) Durante la maniobra de la *Raw (VGT-Raw)*; 2) Durante la respiración tranquila al final de la espiración (VGT). Las diferencias entre ambas técnicas se expresaron en porcentaje (ΔTGV %) y en valores absolutos (ΔTGV). El *VGT-Raw* del grupo total fue mayor que el VGT (3.69 ± 1.08l vs 3.28 ± 1.05l, p < 0.001). Del mismo modo el *VGT-Raw* de los diferentes subgrupos fue mayor que el VGT (Normal: 3.44 ± 0.77l vs 2.98 ± 0.72l, p < 0.001; Obstructivo: 4.08 ± 1.19l vs 3.71 ± 1.15l, p < 0.001; Restrictivo: 2.62 ± 0.49L vs 2.25 ± 0.51l, p < 0.01). Se observó falta de acuerdo entre el *VGT-Raw* y el VGT con diferencias de hasta +0.95L o +34% entre ambos métodos. El ΔTGV % fue similar entre los subgrupos y con los diferentes grados de obstrucción al flujo aéreo (Normal: 16.5 ± 10%, Obstructivo: 10.8 ± 9.4%, Restrictivo: 18 ± 14.3%, p NS; obstrucción leve: 10.7 ± 11%, obstrucción moderada: 12.3 ± 5.7, obstrucción grave: 10.1± 6.6, p NS). El *VGT-Raw* fue sistemáticamente mayor que el VGT. Esto se debió a que los pacientes generalmente jadearon a un volumen pulmonar por arriba de FRC cuando realizaron la maniobra de *Raw*. No debería usarse el *VGT-Raw* para estimar FRC ya que la misma puede sobreestimarse y el diagnóstico de atrapamiento aéreo puede ser erróneo.

Palabras clave: volúmenes pulmonares estáticos, volumen de gas torácico, pletismografía corporal

The use of body plethysmography for the measurement of thoracic gas volume (TGV) is widely accepted in both physiological and clinical pulmonary function laboratories[1,2]. In the standard procedure, the patient breathes normally and the shutter is closed at the end of a normal tidal expiration. The subject is asked to pant quietly against the closed shutter[1,2]. In this situation, the TGV is equal to functional residual capacity (FRC). Computerized plethysmographs allow airway resistance (Raw) and static

Received: 1-VII-2004 Accepted: 9-IX-2004

Postal address: Dr. Carlos Nigro, Cachimayo 333, 1424 Buenos Aires, Argentina
Fax: (54-11) 4827-7000 e-mail:cnigro@intramed.net

lung volumes (TGV, RV and TLC) to be measured from a combined maneuver at the same time. The TGV in this maneuver (TGV-Raw) is not equal to the TGV measured with the conventional technique because the shutter is closed at a different volume from the FRC. We have observed that most individuals, when performing the airway resistance maneuver, usually pant above their FRC. As a result, their TGV should be greater. These observations are in accordance with previous reports[3]. However, the degree of agreement between these two techniques (i.e.: TGV-Raw vs. TGV) has not been investigated in the literature. We assumed that if the TGV was overestimated during the airway resistance maneuver, then the diagnosis of air trapping (i.e.: FRC > 120% of the predicted) would be misleading. The objective of this investigation was to compare both techniques to measure TGV and to establish whether they sufficiently agree that the TGV-Raw could replace the conventional technique to measure TGV.

Material and Methods

Patients

We consecutively study eighty subjects who concurred to the pulmonary laboratory to undergo a body plethysmography. Fourteen patients were excluded due to unacceptable maneuvers of lung volume or airway resistance. Sixty six patients were included in the study. Twenty seven patients had a normal spirometry; thirty three showed an obstructive pattern and the remainder six patients had a restrictive abnormality. The subgroup with airflow limitation was classified in mild, moderate and severe airway obstruction (forced expiratory volume in one second - FEV1: 60%-79%, 40%-59% and < 40% of the predicted) in accordance with the American Thoracic Society (ATS)[4].

Pulmonary function tests

The patients were measured with a constant volume plethysmograph (*Medical Graphics 1085 DL*). The pulmonary function tests performed in each patient were: slow vital capacity (SVC), spirometry (flow volume loop), airway resistance and thoracic gas volume (TGV). We used the American Thoracic Society and American Association for Respiratory Care acceptability criteria for the spirometry[5] and body plethysmography (airway resistance and static lung volume)[1, 2]. We measured the TGV in the same patient with two techniques: 1) During the Raw measurement (TGV-Raw) 2) During quiet breathing at end of expiration (TGV) as described Dubois[10]. The panting frequency was 1 to 2 Hz in both procedures. The *MG 1085DL* automatically measured the slope of the curve resulting from plotting mouth pressure against box pressure (P_{MOUTH}/P_{BOX}) for both methods (TGV-Raw and TGV). Two independent and blind observers manually corrected the tangents for both maneuvers. The reported values of TGV-Raw and TGV were the mean of three reproducible measurements (i.e.: agree within 10%).

Statistical analysis

The patients' characteristics were reported using mean values and SDs (mean ± SD). The differences between both techniques of measuring (ΔTGV) were calculated according to: 1) ΔTGV (%) = (TGV-Raw – TGV) / (TGV) × 100; 2) ΔTGV (liters, l) = TGV-Raw – TGV.

The paired *t* test was used to compare TGV-Raw vs TGV and the panting frequency between the two methods of TGV measurements. One-way analysis of variance (ANOVA) was performed to evaluate the differences between the ΔTGV (L) of the subgroups (normal, obstructive and restrictive). A p value at the 0.05 level was considered significant. The agreement between TGV-Raw and TGV was evaluated by the method of Bland and Altman[6].

Results

The characteristics of the study group and the subgroups are shown in Table 1. In the obstructive subgroup, there were 7 patients with severe obstruction, 6 with moderate obstruction and 20 with mild obstruction (Table 2). The panting frequency with the TGV-Raw maneuver was greater than panting frequency during the measurement of TGV (TGV-Raw: 1.50 ± 0.35Hz, vs TGV: 1.37 ± 0.25Hz, $p < 0.01$). The TGV-Raw of the whole group was higher than TGV (3.69 ± 1.08 l – 95%CI 3.42 – 3.95 vs 3.28 ± 1.05 l - 95%CI 3.02 – 3.54l, $p < 0.001$). Similarly, the

TABLE 1.– *Characteristics of study group*

Total group (n = 66, F 33 / M 33)	
Age (years)	51.4 ± 17.7
Height (cm)	166.2 ± 19.9
Weight (kg)	71.0 ± 14.9
FVC (% predicted)	89.5 ± 21.1
FEV1 (% predicted)	77.5 ± 25.8
FEV1/FVC (%)	0.7 ± 0.11
Normal subgroup (27, F 13 / M 14)	
Age (years)	40.6 ± 15.3
Height (cm)	167.4 ± 10.6
Weight (kg)	72.2 ± 13.1
FVC (% predicted)	104.5 ± 13.5
FEV1 (% predicted)	99.2 ± 14.1
FEV1/FVC (%)	0.8 ± 0.04
Obstructive subgroup (n = 33, F 18 / M 15)	
Age (years)	52.4 ± 16.4
Height (cm)	164.0 ± 8.5
Weight (kg)	67.2 ± 14.7
FVC (% predicted)	81.8 ± 18.9
FEV1 (% predicted)	61.8 ± 21.4
FEV1/FVC (%)	0.6 ± 0.12
Restrictive subgroup (n = 6, F 2 / M 4)	
Age (years)	61.0 ± 8.0
Height (cm)	173.2 ± 11.7
Weight (kg)	86.5 ± 16.0
FVC (% predicted)	66.3 ± 18.3
FEV1 (% predicted)	65.7 ± 18.0
FEV1/FVC (%)	0.79 ± 0.03

Values are mean and SD. F = female, M = male

TABLE 2.– *Severity of airflow limitation in obstructive subgroup*

Severe obstruction (n = 7)	
FVC l (% predicted)	1.62 ± 0.34 (52 ± 8.2)*
FEV1 l (% predicted))	0.75 ± 0.27 (29 ± 9.3)
FEV1/FVC (%)	45 ± 9
Moderate obstruction (n = 6)	
FVC l (% predicted)	2.60 ± 0.43 (81 ± 8.2)
FEV1 l (% predicted))	1.33 ± 0.21(51 ± 2.9)
FEV1/FVC (%)	51 ± 5
Mild obstruction (n = 20)	
FVC l (% predicted)	3.23 ± 1.17 (92 ± 11)
FEV1 l (% predicted))	2.12 ± 0.72 (76 ± 10)
FEV1/FVC (%)	67 ± 6

** Values are the mean and SD; l: liters*

TABLE 3.– *Thoracic lung volume measured with the two techniques*

TGV-Raw (l)	TGV (l)	ΔTGV (l)	p
Total group			
3.69 ± 1.08 (3.42-3.95)*	3.28 ± 1.05 (3.02-3.54)	0.41 ± 0.27 (0.34-0.47) Range: -0.28 to 0.95	< 0.001
Normal group			
3.44 ± 0.77 (3.14-3.75)	2.98 ± 0.72 (2.69-3.27)	0.46 ± 0.26 (0.36-0.57) Range: -0.12 to 0.95	< 0.001
Obstructive group			
4.08 ± 1.19 (3.66-4.50)	3.71 ± 1.15 (3.30-4.12)	0.37 ± 0.28 (0.27-0.47) Range: -0.28 to 0.95	< 0.001
Restrictive group			
2.62 ± 0.49 (2.10-3.14)	2.25 ± 0.51 (1.72-2.78)	0.37 ± 0.22 (0.14-0.60) Range: 0.11 to 0.71	< 0.01

**Values are the mean and SD. Data between parentheses are the 95%CI; l: liters*

TABLE 4.– *ΔTGV (l) and ΔTGV (%) of the subgroups*

Normal	Obstructive	Restrictive	P
0.46 ± 0.26l (0.36-0.57l)* Range: -0.12 to 0.95l	0.37 ± 0.28l (0.27-0.47l) Range: -0.28 to 0.95l	0.37 ± 0.22l (0.17-0.6l) Range: 0.11 to 0.6l	NS
16.5 ± 10% (13-20.4%) Range: -3.6 to 35.6%	10.8 ± 9.4% (7.5-14.2%) Range: -8.1 to 43.4%	18 ± 114.3% (2.9-33%) Range: 5.3 to 45.2%	NS

ΔTGV (%) = (TGV-Raw – TGV) / TGV × 100. ΔTGV (l) = TGV-Raw - TGV; l: liters
**Values are the mean and SD. Data between parentheses are the 95%CI.*

different subgroups of patients had a greater TGV-Raw than TGV (Normal: 3.44 ± 0.77 l vs 2.98 ± 0.72 l, p < 0.001; Obstructive: 4.08 ± 1.19 l vs 3.71 ± 1.15 l, p < 0.001; Restrictive: 2.62 ± 0.49 l vs 2.25 ± 0.51 l, p < 0.01) (Table 3). The ΔTGV (%) in the whole group was 14 ± 10.4% - 95%CI 11.2-16.4% - range: -8.1 to 45.2%). The ΔTGV (l) was similar between the patients' subgroups and between the different degree of airflow obstruction (Nor-

TABLE 5.– *ΔTGV (l) and ΔTGV (%) in patients with different degree of obstruction*

Mild obstruction	Moderate obstruction	Severe obstruction	P
0.31 ± 0.3 l (0.17-0.45 l)*	0.56 ± 0.25 l (0.3-0.82 l)	0.37 ± 0.22 l (0.17-0.57 l)	NS
Range: -0.28 to 0.72 l	Range: 0.21 to 0.95 l	Range: 0.02 to 0.67 l	
10.7 ± 11.2 (5.4 -15.9%)	12.3 ± 5.7 (6.3-18.2%)	10.1 ± 6.6 (3.9-6.2%)	NS
Range: -8.1 to 43.4%	Range. 5.1 to 22.1%	Range: 0.3 to 19.2%	

ΔTGV (%) = (TGV-Raw – TGV) / TGV × 100. ΔTGV (l) = TGV-Raw - TGV; l: liters
**Values are the mean and SD. Data between parentheses are the 95%CI.*

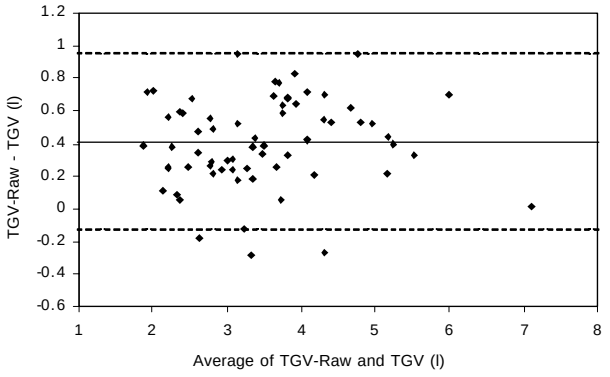

Fig. 1.– Bland Altman plot illustrating the agreement in TGV with the two manoeuvres (TGV-Raw and TGV). The mean of the difference (bias) in TGV was +0.41 l (thin line). The difference between the two tests results will fall within 0.54l (2 SD) of this mean difference 95% of the time (dashed line, limits of agreement).

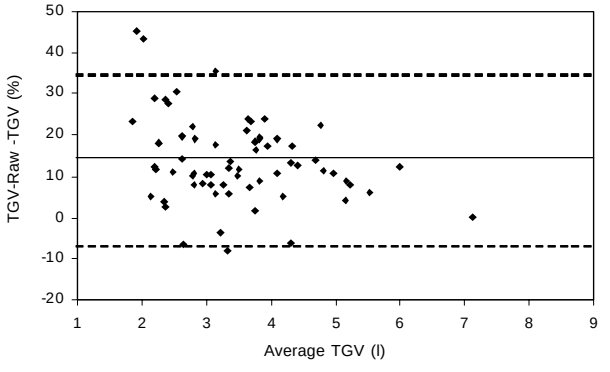

Fig. 2.– Bland Altman plot illustrating the agreement in TGV with the two manoeuvres (TGV-Raw and TGV). The mean of the difference (bias) in TGV was +14% (thin line). The difference between the two tests results will fall within 21% (2 SD) of this mean difference 95% of the time (dashed line, limits of agreement).

mal: 0.46±0.26 l, Obstructive: 0.37±0.28 l, Restrictive: 0.37±0.22 l, p NS; mild obstruction: 0.31 ± 0.3 l, moderate obstruction: 0.56 ± 0.25 l, severe obstruction: 0.37 ± 0.22 l, p NS) (Tables 4 and 5). There was substantial lack of agreement between the TGV-Raw and TGV with discrepancies of up to +0.95 l (Fig 1) or +34 (Fig 2).

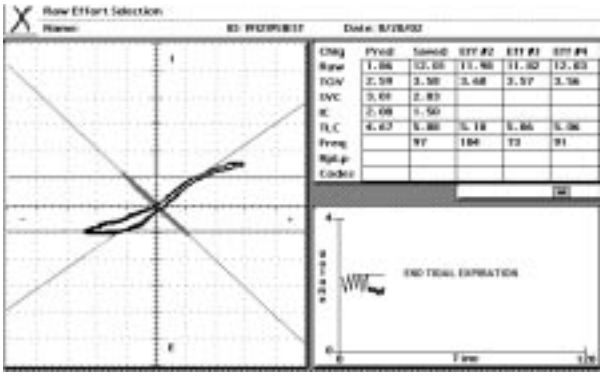

Fig. 3.– Typical tracing of TGV-Raw. The patient pants at a volume higher than FRC.

Discussion

The main finding of this study was that the TGV measured simultaneously with the Raw maneuver (TGV-Raw) produced a consistent overestimation of the thoracic gas volume comparing it with the TGV measured with conventional technique (TGV). This was proved in each subgroup of patients (normal, obstructive and restrictive pattern) and in those with different degrees of airflow limitation. Only four patients had a negative value of ΔTGV%. The rest of the patients systematically showed a positive ΔTGV% ranging from 1% to 43%.

We can summarise the lack of agreement between the two methods to measure TGV by calculating the bias, estimated by the mean difference of TGV and the standard deviation of the differences (Fig. 1 and 2). The measurement of TGV with the maneuver of Raw produced an absolute systematic error. Thus, the TGV-Raw may be up +0.95 l above the TGV, which would be unacceptable for clinical purposes. The discrepancy between the results of TGV with both techniques is related to the fact

that the patients pant above their end tidal expiration near the total lung capacity when they perform the combined maneuver (TGV and Raw), so the TGV measured with this method is usually greater (Fig 3).

The ΔTGV (%) in the subgroup with airflow obstruction had an average value of +11% (Table 4). Begin and coworkers[7] found a mild positive panting frequency dependence of TGV in patients with COPD. They observed that TGV increased up to 5.4%/Hz (0.8±2.3%/Hz) when panting frequency increased from 0.8 to 2.5 Hz. In the subgroup with obstructive pattern, the panting frequency in the TGV-Raw was higher than TGV maneuver (1.53±0.23Hz vs 1.32±0.25Hz, $p < 0.01$). This difference in the panting frequency explains only approximately the 1% of overestimation in TGV observed with TGV-Raw's maneuver. Another reason to explain the difference between both techniques could be a different panting technique. A panting primarily with intercostals muscles could result in a substantially overestimation of TGV than panting with abdominal muscle alone[8]. We cannot discard that the patients used different pattern of panting during the maneuvers, but it is highly improbable that the pant was systematically performed by using the only the intercostals muscles with the TGV-Raw. Furthermore, the subjects were instructed to pant quietly against the shutter in a natural fashion with both maneuvers.

The diagnosis of air trapping is performed when the FRC (i.e.: TGV at the end of tidal expiration) is greater than 120% of the predicted[11]. Air trapping may result from emphysematous changes or from airway obstruction caused by asthma or chronic bronchitis. If we use the TGV-Raw to estimate the FRC, it will be erroneously overestimated. When the FRC is overestimated the diagnosis of air trapping may be misleading. In fact, we observed that twenty nine patients with airway obstruction had a TGV-Raw greater than 120% of the predicted but only twenty of them had a diagnosis of air trapping (i.e.: TGV > 120%).

In summary, we have demonstrated the existence of a large potential error in the measurement of TGV when is performed simultaneously with the airway resistance (Raw) maneuver. This was due to the fact that the patients generally panted at a volume above FRC. The TGV-Raw should not be used to estimate the FRC because the FRC would be overestimated and the diagnosis of air trapping may be erroneous.

Acknowledgements: The authors are grateful to Dr. Daniel Rodenstein for his valuable observations of this manuscript.

References

1. American Association for Respiratory Care: Clinical practice guidelines: body plethysmoghy. *Respir Care* 1993; 39: 1184-90.
2. American Association for Respiratory Care: Clinical practice guidelines: static lung volume. *Respir Care* 1993; 39: 830-6.
3. Ruppel L G. Spirometry and related tests. In Russel J (ed.). Manual of pulmonary function test, 7th ed. St Louis, Missouri: Mosby, 1998, p 27-68.
4. Evaluation of impairment/disability secondary to respiratory disorders. American Thoracic Society. *Am Rev Respir Dis* 1986; 133 :1205-9.
5. American Thoracic Society: Standardization of spirometry: 1994 update, *Am J Respir Crit Care Med* 1995; 152: 1107-36.
6. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; 1**:** 307-10.
7. Begin P, Peslin R. Influence of panting frequency on thoracic gas volume measurements in chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1984; 130: 121-3.
8. Habib MP, Engel LA. Influence of the panting technique on the pletysmographic measurement of thoracic gas volume. *Am Rev Respir Dis* 1978; 117: 265-71.
9. Ruppel L G. Lung volume and gas distributiion tests. In Russel J (ed) Manual of pulmonary function test, 7th ed. St Louis, Missouri: Mosby, 1998; p 69-94.
10. Dubois AB, Botelho SY, Bedell GN, Marshall R, Comroe jr. JH. A rapid plethysmographic method for measuring thoracic gas volume: a comparison with a nitrogen washout method for measuring functional residual capacity in normal subjects. *J Clin Invest* 1956; 35: 322-6.
11. Ruppel L G. Lung volumes and gas distribution tests. In Russel J (ed.). Manual of pulmonary function test, 7th ed. St Louis, Missouri: Mosby, 1998, p 69-94.
12. Figueroa-Casas JB, Diez AR, Rondelli MP, Figueroa-Casas MP, Figueroa-Casas JC. Assessment of bronchodilator response through changes in lung volumes in chronic airflow obstruction. *Medicina (Buenos Aires)* 2003; 63: 377-82.

- - - -

Un gran libro como la Divina Comedia no es el aislado y azaroso capricho de un individuo; muchos hombres y muchas generaciones tendieron hacia él. Investigar sus precursores no es incurrir en una miserable tarea de carácter jurídico o policial; es indagar los movimientos, tanteos, las aventuras, los vislumbres y las premoniciones del espíritu humano.

Jorge Luis Borges (1899-1986)

Nueve ensayos dantescos. El verdugo piadoso. Madrid: Espasa Calpe, 1982, p. 134