# A novel biometric approach to estimating tidal volume

Darragh E O'Brien, Jeffrey KP Kam, Reuben J Slater and Antony E Tobin

Since the publication of the Acute Respiratory Distress Syndrome Network (ARDSNet) article in 2000, low tidal volume ventilation (LTVV) has become the cornerstone of ventilation in patients with acute respiratory distress syndrome (ARDS).[1-3] Mechanical ventilation using lower tidal volumes ($V_T$) of 4–8 mL/kg ideal body weight (IBW) and limitation of plateau pressure to 30 cmH$_2$O have been strongly recommended by the American Thoracic Society, the European Society of Intensive Care Medicine and the Society of Critical Care Medicine in their current clinical practice guidelines.[4] Over the subsequent years, this approach has been broadened to include mechanically ventilated patients without ARDS in the intensive care unit (ICU),[5] mechanically ventilated patients under general anaesthesia,[6] and mechanically ventilated patients in the emergency department.[7]

Despite the evidence, adherence to LTVV is poor,[8] with less than two-thirds of patients in the largest ARDS study to date receiving the recommended $V_T$ < 8 mL/kg IBW and plateau pressure < 30 cmH$_2$0.[4] Many barriers to adherence to LTVV have been identified.[9-11] In order to deliver LTVV, an accurate height measurement is required so as to calculate IBW.[1] The difficulty in calculating the IBW has received some recent attention.[12,13] Indeed, the data suggest that the sickest patients have the most to benefit from LTVV;[12] however, they are often the most difficult to get accurate height measurements.[12,13] A recent 14-year single centre audit revealed that 45% of ventilated patients admitted to the ICU did not have a height or weight recorded during their admission.[14] Therefore, there is a significant group of patients who could benefit from LTVV and who currently do not receive it, including many patients who have no biometric data recorded. A simple and validated biometric approach could lead to a more widespread implementation of LTVV, with potentially improved patient outcomes.

IBW or, more specifically, predictive body weight equations are used when determining

## ABSTRACT

**Background:** Low tidal volume ventilation (LTVV) of 4–8 mL/kg of ideal body weight (IBW) reduces mortality in patients with acute respiratory distress syndrome, and, more recently, it has been recommended as the default therapy for all controlled ventilation. However, adherence to LTVV is poor. Barriers to adherence include not having height measurements taken or IBW calculated during admission. The aim of our project was to develop and validate a simple one step biometric measuring tool to directly estimate tidal volume ($V_T$) in ventilated patients based on their demispan.

**Objectives:** To validate our novel biometric approach for the estimation of $V_T$ in mechanically ventilated patients by demonstrating its accuracy as a simple reliable alternative to IBW derived from measured height.

**Design and setting:** A simple computer program was written based on regression equations for demispan, height and IBW which used simple substitution to produce a vector graphic scale with markings in millilitres of 6 mL/kg IBW $V_T$ printed onto a paper tape. We performed an observational validation study on ventilated patients after cardiac surgery comparing the $V_T$ derived from demispan measurements using our tape with the $V_T$ based on IBW calculated from pre-operative vertical height.

**Main outcome measure:** We compared compliance with a target $V_T \le 6.5$ mL/kg for $V_T$ derived using our demispan method and with $V_T$ based on IBW calculated from vertical height.

**Results:** Eighty-two patients were studied. The mean age was 65.7 years (SD, 11.4) and 61 patients (74%) were male. Mean height was 170.4 cm (SD, 9.5) and mean body mass index for the group was 28.6 kg/m$^2$ (SD, 5.5). The $V_T$ based on 6 mL/kg IBW estimated by traditional height method and using our biometric tape method correlated well ($r = 0.8$) and was not statistically different, with a mean difference of −7.5 mL (SEM, 8.8). Bland–Altman plot showed 95% limits of agreement from −64 mL to 79 mL around the mean difference of 7.5 mL, with 4 points (4.9%) outside the limits of agreement.

Fifty-one of the initial $V_T$ (62%) were compliant, with a target of ≤ 6.5 mL/kg IBW using volumes determined from measured height, while 66 of the tape volumes (80%) would have been compliant at a target of ≤ 6.5 mL/kg IBW.

**Conclusion:** Estimating $V_T$ using of our biometric one step approach based on demispan correlates well with $V_T$ derived from vertical height. The simplicity of its use and accuracy could lead to improved adherence in a large cohort of patients who currently do not receive the recommended $V_T$ restriction.

**Figure 1. Technique for measuring demispan from sternal notch to root of the middle finger**
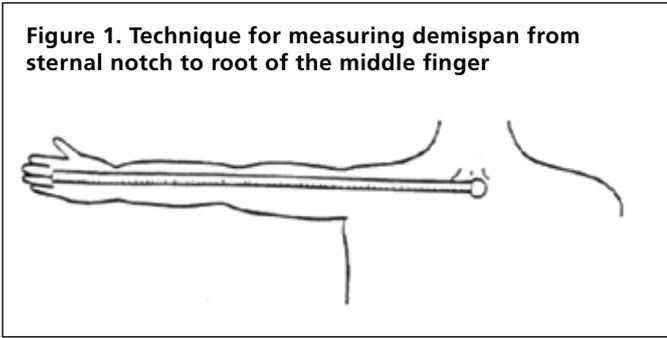
ventilation on a per kilogram basis. IBW is generally calculated from height using the Devine regression equations. When standing height is not available, height can be reasonably estimated from demispan using the Bassey regression equations, giving a demispan estimated height (DEH).[15,16]

Demispan is defined as the distance between the mid-point of the sternal notch and the finger roots with the arm outstretched laterally and abducted to 90 degrees (Figure 1). Therefore, by using simple substitution, IBW can be determined from demispan. The aim of our project was to develop and validate a simple one step biometric approach that directly estimates $V_T$ for ventilated patients based on their demispan, and demonstrate that it is achievable in a real-world clinical setting with minimal instruction.

For a one step biometric approach, we developed a novel tool that measures $V_T$ (mL/kg IBW) directly from a disposable tape (tidal tape) used to measure demispan. To achieve this, IBW and $V_T$ markings were substituted for length on the scale of the measuring tape. The tape itself is gender-specific, with a non-linear vector graphic scale based on the regression equations of Devine and Bassey (Figure 2) (the full tape design is available in Appendix 1, online at cicm.org.au/Resources/Publications/Journal). Only IBW and $V_T$ were printed on the tape so as to avoid unnecessary confusion

for the bedside staff and to make the tape visually less busy. A more complete description of the tape design is presented in the online Appendix 2.

Our hypothesis is that $V_T$ derived from our tape would correlate with $V_T$ derived from the vertical height measurements preformed in clinic prior to cardiac surgery.

## Methods

We conducted our study in the 15-bed ICU of St Vincent's Hospital Melbourne, which is a 450-bed tertiary referral hospital affiliated with the University of Melbourne. The ICU has a clinical information system (IntelliSpace Critical Care and Anesthesia [ICCA], Philips) into which all clinical observations and laboratory data are entered or imported.

We studied patients after cardiac surgery, as this group have height and weight recorded on admission to the hospital and are routinely mechanically ventilated post-operatively in the ICU. All patients after cardiac surgery were initially ventilated in synchronised intermittent mandatory ventilation mode, with a recommendation to set the ventilator to a $V_T$ 6 mL/kg IBW calculated from the measured height recorded on the anaesthetic chart.

When patients arrived in the ICU after cardiac surgery, a nurse not involved in that patient's care did a demispan measurement using the tidal tape (Figure 3). The measuring nurse was blinded to the patient's true height and weight. Instructions on how to conduct the measurement are printed on the tape. Left and right demispans were measured with the respective $V_T$ determined and then recorded onto a card as predicted by the tape. Data were stored in a collection box in the ICU, with the data inputted into a spreadsheet.

All patients in this study were ventilated as per our department recommendation, with tidal tape measurements being recorded for data collection purposes only.

The study was undertaken as a quality assurance project and was approved by the hospital's Human Research Ethics Committee (LRR 126/15).

**Figure 2. Sternal and web root ends of female (A) and male (B) tidal tapes showing instructions and the recommended tidal volumes***
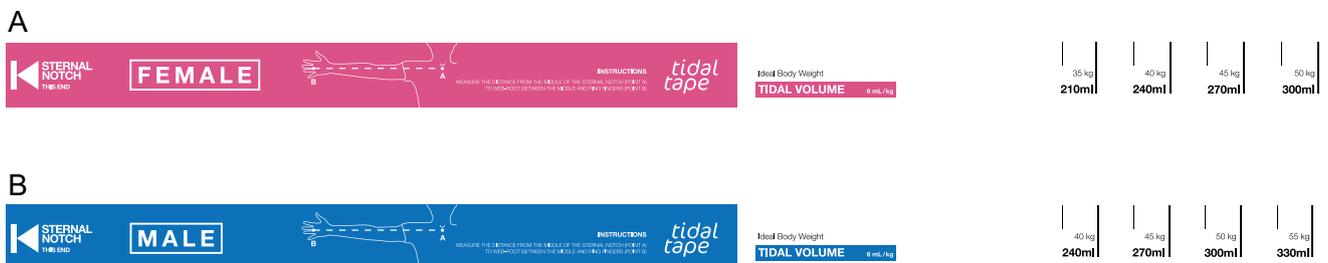


* For the full tape design, please view Appendix 1, online at cicm.org.au/Resources/Publications/Journal.

**Figure 3. Use of the tidal tape to determine 6 mL/kg ideal body weight tidal volumes from demispan**



## Statistical analysis

After determining a lack of statistical difference between the volumes measured on the right and left arms (mean difference, 2.8 mL; standard error of the mean [SEM], 2.0 mL), $V_T$ from measurements of the left and right arm demispan were averaged for the analysis. Categorical variables are reported as frequencies and percentages (%). Continuous data are presented as means and standard deviation (SD). We analysed differences between $V_T$ using the Student $t$ test reporting mean difference and SEM. Linear regression was used to determine the association between $V_T$ based on height and $V_T$ based on the tape. Contingency tables were assessed with the $\chi^2$ or Fischer exact test as appropriate. Bland–Altman plots were used to determine the level of agreement between $V_T$ based on measured height and $V_T$ from the tape. $P < 0.05$ was considered statistically significant. Statistical analysis was performed using Stata/IC 15 (StataCorp).

## Results

Eighty-two patients were recruited for the study. The mean age was 65.7 years (SD, 11.4) and 61 (74%) were male. Mean height was 170.4 cm (SD, 9.5) and mean body mass index (BMI) for the group was 28.6 kg/m² (SD, 5.5). The mean height for men was 174.1 cm (SD, 7.0) and 159.8 cm (SD, 7.9) for women. Mean BMI was 28.7 kg/m² (SD, 5.4) for men and 28.1 kg/m² (SD, 5.8) for women.

The $V_T$ based on 6 mL/kg IBW estimated from vertical height and using our biometric tape method correlated well ($r = 0.8$) and were not statistically different, with a mean difference in $V_T$ of −7.5 mL (SD, 8.8). The Bland–Altman plot of the difference between the tape and ideal volumes based on height versus the average of the two demonstrated 95% limits of agreement, from −64 mL to 79 mL around the mean difference of 7.5 mL, with 4 points (4.9%) outside the limits of agreement. Linear regression of the difference demonstrated overestimation at lower volumes and underestimation at higher volumes (Figure 4).

Initial $V_T$ was considered compliant if $V_T \leq 6.5$ mL/kg IBW.[17] Using $V_T$ determined from measured height, 51 of the initial $V_T$ (62%) were compliant compared with 66 of the recommended tidal tape volumes (80%) ($P < 0.05$). Compliance at $\leq 7$ mL/kg IBW and $\leq 8$ mL/kg IBW was 76% and 89%, respectively, for actual $V_T$, and they would have been 91% and 99%, respectively, for the tidal tape recommended volumes. Actual compliance was greater for males, for patients aged < 65 years and for patients with a height > 159 cm; compliance would have been greater if tidal tape recommendations had been used rather than the actual ventilator settings (Table 2).

## Discussion

The tidal tape estimation of $V_T$ 6 mL/kg IBW provided a reasonable approximation of that determined from actual measured height, with a mean difference of 7.5 mL from the calculated ideal $V_T$, and would have resulted in 80% of individuals in this study receiving a $V_T \leq 6.5$ mL/kg IBW if the measurement had been used to set the ventilator.[17] This is a promising result, considering our study measurements were performed in a real-world setting on mechanically ventilated patients and taken by bedside nursing staff with little or no training in the use of the tape. This result means that a large cohort of patients with no biometric data on admission could potentially benefit from LTVV by using our technique. Moreover, delays in the implementation of LTVV could also be reduced.

The preponderance of available evidence suggests that adherence to LTVV of 4–8 mL/kg IBW has mortality and morbidity benefits in patients with ARDS, and also potentially has a dose-response benefit in all mechanically ventilated patients, with delayed implementation being associated with worse outcomes.[8] Accurate LTVV is important, particularly in patients with severe ARDS, for whom an increase of 1 mL/kg IBW is associated with an increased mortality rate of 18%.[12]

**Figure 4. Bland–Altman plot of the difference between the tidal tape volumes and volumes based on measured height versus their average**
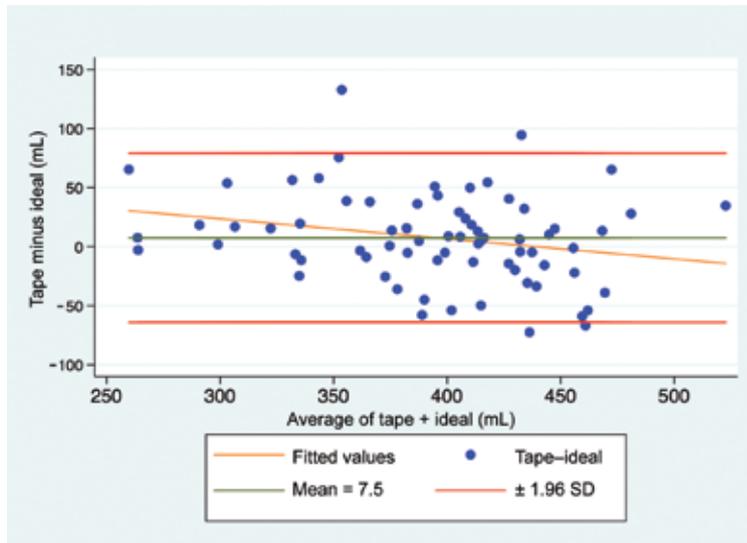
SD = standard deviation.

## Poor adherence to low tidal volume ventilation

The average patient for elective surgery in Victoria, Australia, is 25 kg over their IBW, reflecting high obesity levels.[18] According to a 14-year single centre audit, 45% of mechanically ventilated patients in the ICU did not have their IBW calculated.[14] In patients who had IBW calculated, the LUNG SAFE (Large Observational Study to Understand the Global Impact of Severe Acute Respiratory Failure) study revealed poor compliance with LTVV, with less than two-thirds of patients with ARDS receiving ≤ 8mL/kg IBW. This reflects the experience in multiple institutions, with the barriers to implementation being an area of ongoing research.[4,9]

For patients without a calculated IBW, an initial $V_T$ 450 mL for men and 350 mL for women adjusted for plateau pressure has been suggested.[19] This would have resulted in a compliance with $V_T$ < 6.5 mL/kg IBW of 38% for women and 48% for men in our cohort, substantially less than would have been the case if the tidal tape volumes in our study were adhered to. Previously, DEH has predicted a significantly smaller $V_T$ compared with body weight, the effect being most pronounced in older women.[20]

Our results show worse compliance for short, older and female patients for both the tidal tape and the actual delivered $V_T$. The actual delivered $V_T$

reflects the findings of Fernandez-Bustamante and colleagues[21] who showed that in 429 patients undergoing prolonged abdominal surgery, high $V_T$ (> 10 mL/kg IBW) was more common in women, in patients with BMI > 30 kg/m² and in patients < 165 cm tall.

Reduction in vertical height occurs secondary to flattening of the vertebral bodies and increase in spinal curvature, secondary to senile kyphosis.[22] Loss of height is seen most in post-menopausal women.[23,24] As demispan is stable over time, it has been suggested that it may be more accurate to use demispan when determining nutritional status in older patients.[16,25]

Given this demispan, estimated IBW and $V_T$ may be a more reliable measure in older patients and post-menopausal women. However, if vertical height is used to calculate IBW and $V_T$, age and post-menopausal-related vertical height loss may result in lower IBW and $V_T$ estimations in older and female patients, and this may account for the reduced compliance observed in the tidal tape group for those patients in this study.

Overall, our findings highlight the importance of recording each individual's IBW and the possible role of biometric tools such as the tidal tape in improving compliance to ventilation recommendations.

## Calculation of ideal body weight from height and demispan

Accurate height measurement uses a stadiometer and requires a patient to stand in the Frankfort horizontal plane.[26,27] There are many obvious barriers to this, particularly in the recumbent mechanically ventilated patient.[28] Current practice for recumbent patients is to use head to heel measurement, but this has been shown to greatly overestimate height and there is great variation depending on the health professional preforming the measurement.[29,30]

**Table 1. Patient characteristics**

|  | Total | Men | Women |
|---|---|---|---|
| Number of patients | 82 | 61 (74%) | 21 (26%) |
| Age (years), mean (SD) | 65.7 (11.4) | 64.9 (11.1) | 68.0 (12.2) |
| Height (cm), mean (SD) | 170.4 (9.5) | 174.1 (7.0) | 159.8 (7.9) |
| BMI (kg/m²), mean (SD) | 28.6 (5.5) | 28.7 (5.4) | 28.1 (5.8) |

BMI = body mass index. SD = standard deviation.

**Table 2. Comparison of compliance between actual tidal volumes received and those recommended from the tidal tape**

|  | Actual | Tidal tape | P* |
|---|---|---|---|
| Tidal volume ≤ 6.5 mL/kg | 51/82 (62%) | 66/82 (80%) | < 0.05 |
| Tidal volume ≤ 7.0 mL/kg | 63/82 (77%) | 75/82 (92%) | < 0.05 |
| Tidal volume ≤ 8.0 mL/kg | 73/82 (89%) | 81/82 (99%) | < 0.01 |
| Male | 41/61 (67%) | 54/61 (89%) | < 0.01 |
| Female | 10/21 (48%) | 12/21 (57%) | 0.5 |
| Age < 65 years | 22/32 (69%) | 29/32 (91%) | < 0.05 |
| Age ≥ 65 years | 29/50 (58%) | 37/50 (74%) | 0.09 |
| Height ≥ 160 cm | 46/72 (64%) | 60/72 (83%) | < 0.01 |
| Height < 160 cm | 5/10 (50%) | 6/10 (60%) | 1.0† |

\* Pearson $\chi^2$ was used, unless otherwise stated. † Fisher exact test.

Calculating IBW is an area of controversy in itself. There are several different regression equations that can be used to convert a height measurement into IBW. Each equation gives a different predicted IBW that is clinically significant, particularly at extremes of height.[13]

It has been suggested that the Devine equation, although not necessarily the best, should be chosen as the "industry standard", as it was used in the ARDSNet study and is also the most widely used equation in the literature.[13] It has been postulated that the use of different equations may have played a role in some conflicting data that have arisen, and a single equation would eliminate unwanted variability and produce a more stable dataset.[9,27]

Demispan is an easy and safe measurement to take, with the Bassey equation being gender-specific.[15] This demispan equation was chosen by the Health Survey England group as its surrogate for height in patients for whom it is not possible to obtain an accurate height measurement in the malnutrition screening program of the National Institute for Health and Care Excellence (NICE).[16] Their results show a strong correlation between DEH and measured height for men ($r = 0.71$) and women ($r = 0.72$) aged ≥ 65 years.[16] A study looking at different height estimations and spirometry interpretation found that forced vital capacity calculated using DEH was the best, showing good agreement ($r = 0.88$).[31]

There is ethnic variation in the relationship between demispan and height, as seen when comparing Afro-Caribbean and Asian populations.[25] In addition, due to their shorter stature, there is greater error when using DEH for patients in the Asian population compared with the white population at extremes of short height.[23,32]

A recent Spanish study found that since the original Bassey equation was derived in 1986 and that at present their population was on average 1 cm taller, the Bassey equation was most accurate for the Spanish population aged > 65 years, perhaps due to it being over 30 years old.[33]

### Strenghts and limitations

Our intervention was low risk, simple, affordable and not time consuming for staff. The strong correlation between the tidal tape and the gold standard is clinically valid, as measurements were performed on ventilated patients rather than healthy individuals. There is systematic bias in our data due to the readings being performed on mechanically ventilated patients by ICU nurses who manage ventilation independently in our patient population. To reduce this bias, the measurements were made by a nurse who was not involved in patient care and who was blinded to the recorded height and weight. Other limitations include that our data are single centre and as post-cardiac surgery patients were studied, more men than women were recruited. Patients were not ventilated based on the tidal tape measurement and, therefore, plateau pressure and outcome data were not obtained. Ethnic data were not obtained and standardised equations were used, which may have introduced inaccuracies.

Our results show that our tape tends to overestimate at lower volumes and underestimate at higher volumes. Some of this difference could be attributed to the age profile and, also, to the greater number of men in our study. The mean difference was 7.4 mL, which is small but with considerable overall variation, especially at extremes. It is possible that the results were affected by systemic bias of the observer. However, updated and age- and gender-specific regression equations may produce more accurate results. Regression equations have been found to show greatest variability at extremes of height.[13]

### Recommendations

Our study recorded the tidal tape volumes, not the use of the tape in actual clinical practice. Repeating this study and ventilating patients as per the tidal tape, with recording of plateau pressure and delivered $V_T$ data, would be the next step in the development of the tape. Furthermore, our method may have a role in emergency medicine, operating

theatres and the pre-hospital environment, and studies should be performed in these environments to determine its utility in improving $V_T$ compliance. The specific role of demispan when ventilating patients in the > 65 years age group and different ethnic groups is also an area that requires further investigation.

## Conclusion

Our simple biometric approach to estimation of $V_T$ in ventilated patients demonstrated good agreement with the gold standard of vertical height measurement. It is quick and easy to perform. There is a large population group who could potentially benefit from this technique, with a real potential to reduce morbidity and mortality from mechanical ventilation.

## Competing interests

None declared.

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# Critical Care and Resuscitation

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