In Search of Maximum Inspiratory and Expiratory Pressure Reference Equations

Respiratory muscle weakness can occur in neuromuscular diseases as well as in pulmonary disease. For example, in chronic obstructive pulmonary disease, patients' muscles may become weakened from hyperinflation, which causes the diaphragm to function at a poor mechanical advantage, or in patients on steroids that can result in myopathies. Pulmonary function tests are used to determine diagnosis, prognosis, and, when available, the effect of treatment. While vital capacity decreases in muscle weakness, and hypercapnia can be present, these measurements are both non-specific and occur after muscle strength is decreased by as much as half. In fact, we need to be able to differentiate limitations caused by parenchymal and airway diseases from those attributable to the respiratory muscle weakness.

While there are other specific tests to measure respiratory muscle strength, determination of maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) can be performed routinely in a pulmonary function laboratory, requiring only the minimum of equipment. These tests measure the overall muscle function and are carried out while the mouthpiece is closed so that the patient cannot inhale or exhale; lung volumes remain unchanged, so the performance of the muscles can be separated from the performance of the lung. A small leak prevents pressure from being generated by cheek muscles.

However, pulmonary function tests must be standardized to be reliable, and any test result is only as good as the available reference values and lower limit of normal (LLN) values. Reference equations for MIP and MEP have been limited, and their use hampered by the variation in the techniques used.

The 2002 American Thoracic Society/European Respiratory Society (ATS/ERS) Statement on Respiratory Muscle Testing[1] has standardized the measurement, and lists reference normal ranges for the 2 types of mouthpieces generally used, straight tube and flanged, from several authors. For clinical use they recommend flanged mouthpieces even though they result in somewhat lower values, because with them it is easier for patients to perform the test. The 2004 ATS Pulmonary Function Laboratory Management and Procedure Manual[2] also provides normal ranges, but this list is not totally overlapping with that of their statement. Many laboratories use the equations from Black and Hyatt,[3] even when flanged mouthpieces are used, although Black and Hyatt used straight tubes.

Two papers in this issue of RESPIRATORY CARE aim at helping pulmonary function laboratories further standardize their procedures and update their predictive equations, while approaching the problem in totally different ways.

The article by Evans and Whitelaw[4] very ambitiously reviews the literature, adds to the standardization of the methodology recommended by the American Thoracic Society,[1] and derives reference equations with LLN values by what the authors call "amalgamated results." In this amalgamation they use only studies with flanged mouthpieces, because of the ATS recommendation.

SEE THE ORIGINAL STUDY ON PAGE 1321 AND THE REVIEW ON PAGE 1348

The reference equations by Evans and Whitelaw[4] are for MIP and MEP and the LLN values for adult males and females as a simple function of age, up to "approximately" age 70. Other independent variables are not included in each equation, because the contributions of these other variables, such as height and body mass index, are smaller than the variation of the measurement. They also found no consistent differences with race, and whatever differences there may be are well within the variation of the measurement. The equations are listed in Table 2 of their paper and can also be found in the abstract. Nice graphical displays in their Figures 2 through 5 help us see how the derived equations and LLN values compare with the studies used to derive them.

However, because the equations are a composite and not measured directly, and because of the limitations inherent in the measurements themselves, there are some important caveats that the authors point out. First of all, the pressures are generated by muscles that are used for more than just respiration; thus, strength could decrease below the LLN, and normal breathing at rest could still be possible. Alternatively, a value below the LLN doesn't necessarily mean an abnormality, as there is substantial patient effort required, and significant variations in results among personnel performing the test have been reported. These tests, even more so than others, must be used in conjunction with the clinical picture, and are best when a previous result is used for comparison. Finally, the results may not be linear as the patients get older;

therefore, the age limit of these equations is reported by the authors as "approximately" 70 years. For these reasons, the article provides a guide for the interpretation of results that should be useful to clinicians.

Equations by amalgamation may prove to be useful, but are no substitute for direct measurement, which the paper by Sachs and co-workers[5] seeks to do. The authors derive reference equations for MIP for men and women, using data from the Multi-Ethnic Study of Atherosclerosis (MESA), which includes whites, African Americans, Hispanics, and Chinese Americans age 45–84 years old, from 6 cities in the United States. Recruiting the various ethnic/race groups from all of the sites ensures that the variation among staff performing the tests does not influence a specific group more than the others. The measurements have a resolution of 5 cm H_2O, using a straight tube mouthpiece; the quality goal of repeatability of 10 cm H_2O in 5 maneuvers was achieved in 83% of the participants. Reproducibility was ensured by repeating the measurements on 5% of the quality tests, chosen randomly. They found no differences among the race/ethic groups, so the 2 reference equations, for males and females, appear in Table 5; the LLN values are 40 cm H_2O and 36 cm H_2O for men and women, respectively. Unfortunately, only MIP equations are available, as MEP was not measured in the MESA.

How will these studies change the practice of measuring these variables in our pulmonary function laboratory? Certainly, direct equations are preferable, but most pulmonary function test laboratories that measure MIP also use MEP and need equivalent equations. The amalgamation offers both and it provides reasonable results, but our population is aging, and reliable reference equations are needed for patients older than 70. The equations for MIP and MEP previously derived by Enright and co-workers[6] from the Cardiovascular Health Study, and those from the Minnesota study,[7] are for the 65–85 years age range; however, weight is one of the predictors in the reference equations. Since the weights in their 2 studies were in the normal range for both males and females, the usefulness of the equations is limited in obese patients, which, unfortunately, are now in the majority in our laboratory. For example, the reference value for an obese patient (body mass index > 30 kg/m^2) could increase above the variability of the measurement, when compared to his or her non-obese counterpart. It's doubtful that obese patients can generate more pressure from their obesity alone, and the equations were not reported to address this problem.

Table 1. Reference Values for Maximal Inspiratory Pressure for Men and Women for 2 Age Groups

Age	MIP (LLN) for Males (cm H_2O)		MIP (LLN) for Females (cm H_2O)	
	Evans[4]	Sachs[5]	Evans[4]	Sachs[5]
50	−100 (−55)	−119 (−79)	−78 (−37)	−86 (−50)
65	−93 (−52)	−99 (−59)	−68 (−30)	−80 (−44)

MIP = maximal inspiratory pressure
LLN = lower limit of normal

There is some overlap in what the 2 current studies offer, and they can be compared. Table 1 lists the reference values for MIP for men and women for 2 age groups, 50 and 65, which the 2 sets of equations include.

The 2 sets of equations agree within 10% variation of the measurement for age 50, but at age 65, only the equations for males are that close. This is perhaps because age 65 is close to "approximately 70" and thus the equations by Evans and Whitelaw[4] have more variability. The LLN values don't agree very well, but Evans and Whitelaw[4] report that theirs are "vague LLN values."

Despite some advances, we are still short of having the final answer. This confusion, and the fact that currently measuring maximal pressures does not have appropriate billing codes, cause some laboratories to be reluctant to offer the measurement.

Marcy F Petrini PhD
Demondes Haynes MD
Pulmonary, Critical Care, and Sleep Medicine
University of Mississippi Medical Center
Jackson, Mississippi

The authors have disclosed no conflicts of interest.

Correspondence: Marcy F Petrini PhD, Pulmonary, Critical Care, and Sleep Medicine, University of Mississippi Medical Center, 2500 North State Street, Jackson MS 39216-4505. E-mail: mpetrini@medicine.umsmed.edu.

REFERENCES

1. American Thoracic Society, European Respiratory Society. ATS/ERS statement on respiratory muscle testing. Am J Respir Crit Care Med 2002;166(4):518-624.
2. American Thoracic Society. ATS pulmonary function laboratory management and procedure manual, 2nd edition. 2004.
3. Black LF, Hyatt RE. Maximal respiratory pressures: normal values and relationship to age and sex. Am Rev Respir Dis 1969;99(5):696-702.
4. Evans JA, Whitelaw WA. The assessment of maximal respiratory mouth pressures in adults. Respir Care 2009;54(10):1348-1359.
5. Sachs MC, Enright PL, Stukovsky KDH, Jiang R, Barr RG. Performance of maximum inspiratory pressure tests and maximum inspiratory pressure reference equations for 4 race/ethnic groups. Respir Care 2009;54(10):1321-1328.
6. Enright PL, Kronmal RA, Manolino TA, Schenker MB, Hyatt RE. Respiratory muscle strength in the elderly: correlates and reference values. Am J Respir Crit Care Med 1994;149(2):430-438.
7. Enright PL, Adams AB, Boyle PJ, Sherrill DL. Spirometry and maximal respiratory pressure references from healthy Minnesota 65-85 year old women and men. Chest 1995;108(3):663-669.