

Reference Equations Used to Predict Pulmonary Function*

Survey at Institutions with Respiratory Disease Training Programs in the United States and Canada

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Adult respiratory disease training programs in the United States and Canada were surveyed to determine which reference equations were used to predict normal pulmonary function and how ethnic differences were approached. Replies from 139 of the 180 (77.2 percent) institutions surveyed were received and evaluated. Surprisingly few studies account for most of the equations in use: three studies account for 85 percent of the spirometric equations, two for 83 percent of the lung volume equations and five

for 84 percent of the diffusing capacity equations. Although there are no definite data, the form of many of the replies suggests that equipment default settings may influence the selection process. Of those responding to the ethnic difference question, 53 percent of institutions applied no correction for ethnic differences. There was no consistent pattern to the method of correction among those who did.

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Many linear and nonlinear regression techniques have been used to generate equations to predict "normal values" since Hutchinson's first provided a quantitative index of pulmonary function based on measurements of vital capacity in more than 2,000 healthy men in 1846. The increasing importance of pulmonary function testing in diagnosing and managing lung disease and assessing impairment has required more accurate definitions of normal. Innovations in technology and equipment, standardization of procedures, and changing concepts of normality have stimulated further studies of healthy subjects and there is now a large number of different regression equations from which to choose. In response to a frequently asked question about which equations are actually being used, we surveyed institutions in the

United States and Canada with training programs in adult respiratory disease to determine which equations are used and what attention is paid to ethnic differences.

METHODS

Letters were mailed to the directors of training programs in adult respiratory disease listed by the American Thoracic Society. We requested specific citations for the prediction equations used for spirometry, lung volumes, carbon monoxide diffusing capacity, and airway resistance. We also asked for a description of how they dealt with ethnic differences in pulmonary function. A follow up request was sent to institutions which had not responded to the first inquiry.

RESULTS

One hundred and eighty institutions were surveyed; 96 replies were received after the first mailing, 50 after the second. Seven replies were excluded because they lacked adequate detail. We were able to analyze 139 replies (77.2 percent of those surveyed). The geographic distribution of inquiries and responses is shown in Table 1.

All 139 institutions provided reference equations

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Table 1—Geographic Distribution of Inquiries and Responses

Region	Inquiries	Responses
United States		
Northeast (ME, NH, VT, MA, RI, CT, NY, PA, NJ, DE)	68	48
Midwest (WI, IL, MI, IN, OH, MN, ND, SD, NB, KS, MO, IA)	33	30
West (AK, HI, WA, OR, CA, MT, ID, NV, UT, CO, AZ, NM)	25	22
South (WV, VA, MD, DC, NC, SC, GA, FL, KY, TN, MS, AL, OK, AR, LA, TX)	42	28
Puerto Rico	1	0
Canada	12	11
Total	181	139

Table 2—Summary of Institutions Citing References for Prediction of Spirometry

	FVC or VC		FEV ₁		FEV ₁ /FVC*		FEF25-75%	
	M	F	M	F	M	F	M	F
Morris et al ^{4,5}	65	65	65	65	58	60	69	69
Crapo et al ⁶	27	27	27	27	29	29	24	24
Knudsen et al ⁷	24	24	25	25			25	25
Korn et al ⁸	7		8					
Korn et al ⁹		7		8				
Cherniack and Raber ¹⁰	3	3	4	4			5	5
Miller et al ¹¹	2	2	2	2	2	2	2	2
Other studies†	11	11	8	8	11	9	14	14

*Thirty-nine predicted FEV₁/FVC by dividing predicted FEV₁ by predicted FVC.

†Studies cited only once.

for spirometry. We chose to deal only with standard spirometric indices and have listed only equations cited by more than one institution; equations cited only once are included as "other studies." The responses are summarized in Table 2. Six institutions used reference equations from different studies to predict FVC and FEV₁; six others selected prediction equations from different studies for men and women. Prediction equations for FEV₁/FVC and FEF25-75% came from sources different from those used for FVC and FEV₁ in six and 16 institutions, respectively. Thirty-nine centers predicted normal FEV₁/FVC by dividing predicted FEV₁ by predicted FVC.

One hundred thirty-five (97.2 percent) institutions furnished reference equations for assessing lung volumes (Table 3). Six of the nine institutions using Boren et al¹⁴ to predict lung volumes for men used the Goldman equations for women.

The 138 responses for carbon monoxide diffusing capacity are summarized in Table 4. Two centers predict Dco based on unpublished studies conducted at their institutions.

Sixty-six institutions did not comment on airway resistance and 16 specifically said they did not measure airway resistance. Of the 57 which supplied information on normal values for airway resistance, 48 used reference equations to predict normal values while nine used a numerical range derived from "clinical experience." The equations used to predict airway resistance are summarized in Table 5.

Table 3—Summary of Institutions Citing References for Prediction of Lung Volumes

	TLC		RV		FRC	
	M	F	M	F	M	F
Goldman and Becklake ¹³	84	90	85	91	74	81
Crapo et al ¹³	28	28	28	28	29	29
Boren et al ¹⁴	9		9		9	
Bates et al ¹⁵	3	3	3	3	1	1
Quanjer ⁴	3	3	3	3	3	3
Other studies	8	11	7	10	9	11

Of the 139 replies analyzed, 95 (68.4 percent) responded to the question on ethnic differences. Fifty centers did not apply any ethnic correction and 45 did. Only five centers used population-specific reference equations to deal with ethnic differences.^{20,26-28} The others reduced predicted values for whites by a fixed percentage: 29 institutions by 15 percent; four by "10 to 15 percent;" and seven by 10 percent. The ethnic groups to which corrections were applied usually depended upon the geographic location of the institution and usually included the predominant minorities. Our survey showed ethnic adjustments were made for blacks in all regions of the United States but not in Canada. Adjustments for American Indians were made only in Utah and Alberta, Canada. Corrections for Hispanics were reported only from Texas, for Asian Indians only from New York, and for Asians only from California.

DISCUSSION

Despite the number of reference studies and equations available in the literature, surprisingly few equations are widely used. Three studies accounted for 85 percent of the equations used for standard spirometric indices. It was not uncommon for institutions to use a different reference equation for each spirometric parameter. While we are not aware of studies on the effects of this practice, it seems likely to increase the uncertainty that prediction equations will match the

Table 4—Summary of Institutions Citing References for Prediction of Carbon Monoxide Diffusing Capacity

	M	F
Burrows et al ¹⁶	25	25
Crapo et al ¹⁷	27	26
Miller et al ¹⁸	25	26
Gaensler and Wright ¹⁹	23	23
Cotes ²⁰	16	15
Bates et al ¹⁵	3	2
Salorinne ²¹	3	3
McGrath and Thompson ²²	1	2
Other studies	15	16

clinical population. In general, we recommend reference equations for spirometric indices be selected from a single study which has been matched to the patient population. This should be relatively easy for spirometry, but is more difficult for lung volumes, Dco, and airway resistance because there are few studies available which include complete pulmonary function tests.

Two studies account for 83 percent of the lung volume equations (Table 3) and five for 84 percent of the Dco (Table 4). The greater number of DCO equations in use may reflect the larger interlaboratory differences for Dco than spirometry or lung volumes, though a preliminary study suggests academic centers do not consistently choose reference equations which match the Dco values produced in their laboratories.²⁹ While all reference equations should be demonstrated to show a reasonable match with the individual laboratory's instruments and clientele, this is especially important in Dco where the variability has been demonstrated to be so great. We believe laboratories should assure that prediction equations for DCO match the data produced in their facilities by comparing measurements made on 20 to 30 healthy subjects with predicted values from several different equations.³⁰

Of those who responded to the question on the adjustments made for ethnic differences, roughly half made no adjustment at all while the majority of those who did simply reduced white values by a fixed percentage which varied from institution to institution. These results confirm our impression that there is no clear consensus on whether ethnic adjustments are necessary, which ethnic groups require some sort of adjustment, and how adjustment should be approached if it is necessary. Ethnic differences in pulmonary function parameters are best documented in blacks and Asians,^{20,26} but studies of ethnic differences in lung function are frequently confounded when the different ethnic groups are not studied with the same equipment and techniques. Interlaboratory variability in lung function measurements due to technical factors is large in comparison to the magnitude of ethnic differences and could mask or accentuate ethnic differences. However, comparisons among blacks, Asians and whites have generally shown whites to have the largest lung volumes, blacks to have the smallest, and Asians to have intermediate lung volumes, after adjustment for body size.^{20,26,27,31} People of mixed race have been found to have intermediate values. Flow rates have usually been found to be about the same in all three ethnic groups. Studies differ on whether or not proportional adjustments of white equations are an acceptable method of dealing with the differences.^{28,31} At the moment, it is acceptable to use either proportional differences or population specific equations to deal with ethnic differences. It is

Table 5—Summary of Institutions Citing Reference Equations in the Prediction of Airways Resistance*

	RAW
Dubois et al ²⁰	12
Briscoe and DuBois ²⁴	13
Clausen and Zarins ²⁵	7
Other equations	16

*Nine institutions used a numerical range for normal values rather than a prediction equation.

not, however, acceptable to ignore them.

Reference equations from studies done in Europe are not used frequently in the United States or Canada. The summary equations reported by the standardization project of the European Community for Coal and Steel² were rarely cited in this survey. The pattern of the prediction equations in use has changed from that reported from a similar survey conducted in 1968.²² Equations from larger studies using current standardized methods and newer technology are now more frequently cited.

The replies to our survey suggest the availability of automated systems—and manufacturers' default settings—may also influence the choice of equations. Forty-seven institutions responding to our survey returned manufacturer-supplied computer sheets listing the equations used. Three institutions replied they used software provided by the manufacturer and did not know what equations it was based on. These responses raise the possibility that the delay between the publication of good reference equations and their use in practice is, in part, a function of the time it takes for such information to find its way into manufacturers' computer software.

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