

Can a single equation be used to predict the vital capacity of boys both before and during puberty?

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ABSTRACT: Good theoretical values for vital capacity (VCt) can be used to calculate a VC/VCt ratio which remains constant for a given individual subject throughout different growth periods. This longitudinal study on 27 boys was performed in order to determine whether a single equation was accurate throughout the growth of boys. The mean values of VC/VCt were also compared for the beginning and end of the prepubertal period in 57 boys and between the beginning and end of puberty in 40 boys. VCt was calculated from five reference equations using data from boys with average age 8-16 yrs, and from two equations using data specific to children and adolescents. The mean VC/VCt ratio was found to fall between the beginning and end of the prepubertal period and to increase very significantly between the beginning and end of the pubertal period when the reference equation used had been calculated using data from populations containing both pubertal and prepubertal subjects. When the equations established from adolescents were used, VC/VCt fell slightly between the beginning and end of the pubertal period. We conclude that data for children and adolescents should be treated separately when establishing reference values for VC.

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Vital capacity (VC) is an essential parameter for monitoring the change in ventilatory deficiency in motor-handicapped subjects. A 1978 follow-up study of VC in 69 growing children suffering from respiratory sequelae of poliomyelitis [1] showed marked changes in the ratio of VC to the theoretical vital capacity (VCt) following the onset of puberty. The reference values used to calculate VCt were taken from the studies of BJURE [2] on a population of children aged 8-16 yrs and of GEUBELLE and BRENY [3] on children aged 7-17 yrs. The two studies included both prepubertal and pubertal children. Height was the only reference variable in the equations developed in these studies, as well as in other studies by GUERINI *et al.* [4] and COTES *et al.* [5], since VC is most closely correlated with height in childhood [6]. There are other equations correlating weight and age with body height, such as that of BERNSTEIN *et al.* [7], but the specific muscular impairment in motor-handicapped patients makes the weight parameter inaccurate.

The present follow-up study of VC in a control group of healthy children was undertaken to establish the effect of puberty on the development of VC, and to define the normal development of VC during growth. Preliminary results have been published [8]. These reference data will be used in studies designed to evaluate the ventilatory deficiencies of motor-handicapped patients (muscular dystrophy, tetraplegia following traumatic or medical medullary lesions). It will also be useful in

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examinations carried out in preventive medicine and for tests of respiratory function in children suffering from bronchopulmonary disturbances.

Two studies on the growth of the respiratory system in puberty were published while this study was in progress. ENGSSTRÖM *et al.* [9] examined the relationship between VC and body height in children aged 12-21 yrs. This relationship was found to change during puberty, just after the growth spurt. DEGROODT *et al.* [10] confirmed that the relationship between VC and body height changed during the growth of pubertal subjects. They also showed that the volumes for VC predicted by their follow-up study were too high in the youngest children and too low in the oldest children if only the height was used in the regression equation, but that this trend disappeared when age was included in the equation.

This fact was pointed out by DICKMAN *et al.* [11] in 1971. These authors proposed two equations for establishing the predictive values of VC in young children and adolescents. If their height is less than 60 in, the equation takes only height into account. If it is above 60 in, both height and age are used.

By contrast, KRISTUFEK *et al.* [12] proposed a single equation which was applicable to growing, mature and senescent subjects. This mathematical model was derived from a survey of 1,024 subjects aged 6-81 yrs, and contains parameters for height, age, ageing, body weight and obesity.

The present follow-up study was specifically designed to examine the prepubertal and pubertal values of VC for a single group of children. These VC measurements were used to test the possibility that the ratio of a theoretical vital capacity (VCt), calculated from one of seven published equations [2-5, 10-12], to the measured VC (VC/VCt) remained constant throughout the prepubertal and pubertal periods.

Subjects and methods

A total of 70 boys was investigated, none of whom had a history of cardiorespiratory disease or any thoracic deformity. Some of the older subjects were occasional smokers, but this had no influence on the increase in pulmonary volumes [13]. The weight was measured. The body mass index of these subjects remained close to the normal value [14]. All of the subjects took part in a sporting activity at least once a week. The examinations were carried out during the subject's annual medical check-up.

The boys were subdivided into groups according to pubertal stage as follows:

- 1) Twenty seven subjects were examined at the beginning of the study (I), the end of prepuberty (II), the beginning of puberty (III) and at the end of the study (IV).
- 2) Thirty subjects were examined only during prepuberty, from I to II, providing data on 57 subjects for this period.
- 3) Thirteen subjects were examined only during puberty, from III to IV, providing data on 40 subjects for this period.

Overall standing height was measured on subjects standing, barefoot, with heels together and shoulders, bottom and heels in contact with the vertical part of the apparatus. In order to reduce lordosis, shoulders were

relaxed, with both arms hanging beside the body. Any influence of hair was minimized by the examiner placing a hand on the head-board. The recommendations of MARSHALL [15] were followed. The beginning of puberty was determined by establishing the growth velocity curve for each subject. Growth velocity is plotted against age [15]. The height of some subjects has been measured before VC was measured for the first time. This fact was taken into account in the growth velocity curve. This curve shows a plateau during prepuberty. The height spurt is an important indicator of the onset of puberty. This indicator allowed determination of the last measurement of VC before the onset of puberty, and the first measurement of VC after the onset of puberty.

VC was recorded using a Benedict type spirometer, calibrated by injecting a litre of air very slowly. The examiner was trained to perform pulmonary function tests on children. The recording was made in a quiet, isolated room. Children held their torsos and heads erect throughout the vital capacity measurement and used a nose-clip. The subjects were instructed to inspire maximally and then directly expire as deeply, but not as fast, as possible; after some tidal movements they expired maximally and inspired as deeply as possible. Three or more tests were performed and the best was calculated in litres body temperature, pressure and saturation (BTSP). The recommendations of TAUSSIG *et al.* [16] were followed. Only those children able to perform the VC test satisfactorily in the first examination were included in the study.

The VC measured during the growth of each subject was compared to the reference value calculated from published equations, taking into account the morphological parameters and the age of each child (table 1).

The study was designed to test whether the ratio between the measured VC and the VCt calculated from each of the above equations was approximately constant in this population.

Table 1. - Vital capacity reference values

No.	Author	Equation	Method
1	BJURE [2]	$VCt: -0.125+0.951H^3$	EVC-FVC ATPS
2	COTES <i>et al.</i> [5]	$VCt: 1.004H^{2.72}$	FVC BTSP
3	DEGROODT <i>et al.</i> [10]	$VCt: 0.5379H^{2.7} \cdot e^{0.03A}$	EVC-IVC BTSP
4	DICKMAN <i>et al.</i> [11]	VCt: (a) $94H - 3042$ (b) $174A+64H-9425$	FVC BTSP
5	GEUBELLE and BRENY [3]	$VCt: 3722 \cdot 10^{-3} H^{2.7}$	VC BTSP
6	GUERINI <i>et al.</i> [4]	$VCt: 3958 \cdot 10^{-3} H^{2.71}$	VC BTSP
7	KRISTUFEK <i>et al.</i> [12]	$VCt: e^{-3.3447} \cdot A^{0.6801} \cdot W^{0.5704} \cdot e^{0.0077H-0.0057W-0.0234A}$	VC-FVC BTSP

IVC: inspiratory vital capacity; EVC: expiratory vital capacity; FVC: forced vital capacity (ml: 4.5.6, l: 1, 2, 3, 7); A: age (yrs); W: body mass (Kg); H: height (m: 2, 3, cm: 1, 5, 6, 7, in: 4); ATPS: ambient temperature and pressure saturated with water vapour; BTSP: body temperature, pressure and saturation.

Variance analysis was used to compare VC/VCt over four periods (I-II-III-IV) of growth in 27 subjects, taking into account difference between stages and subjects. The mean ratios of VC/VCt were then compared two by two at each growth stage by the Tukey method. Student's paired t-test was used to compare the mean VC/VCt value between measurements I and II in 57 subjects and between III and IV in 40 cases.

Results

Comparison of VC/VCt between the four periods (I-II-III-IV) of growth in 27 subjects

These results are summarized in table 2. The means and standard deviation (sd) for the heights and ages of 27 subjects at the beginning of the prepubertal study (I) were age: 11.3±0.9 yrs (10–12 yrs); height: 1.41±0.07 m (1.20–1.51 m); at the end of the prepubertal period (II) were age: 12.8±0.8 yrs (11–14 yrs); height: 1.50±0.08 m (1.29–1.65 m); at the beginning of the pubertal period (III) were age: 13.9±0.9 yrs (12–15 yrs); height: 1.60±0.07 m (1.38–1.73 m); at the end of the pubertal period were age: 17.4±1.16 yrs (15–19 yrs); height: 1.72±0.07 m (1.57–1.90 m).

All of the reference equations were used (equation no. 3 was only developed for the pubertal period). There was a drop in VC/VCt in all cases during prepuberty, the difference was significant for equation no. 1. There was a significant increase (p<0.01) for equations 1, 2, 5, 6 and 7 and a drop for equations 3 and 4 during the puberty period (fig. 1).

Table 2. – Mean and standard deviation of VC/VCt at the beginning (I) and end of prepuberty (II); at beginning (III) and end of puberty (IV) for the 27 subjects examined during prepuberty and puberty

No.	I	II	III	IV
1	0.94±0.13	0.90±0.12	0.93±0.12	1.02±0.13
2	0.94±0.11	0.92±0.11	0.97±0.12	1.09±0.13
3			1.17±0.14	1.14±0.09
4	1.11±0.16	1.07±0.15	1.06±0.15	1.02±0.13
5	1.01±0.11	0.99±0.12	1.05±0.12	1.18±0.14
6	0.91±0.11	0.90±0.11	0.95±0.11	1.06±0.13
7	0.91±0.11	0.90±0.12	0.95±0.08	1.02±0.06

The reference values were calculated with each equation. VC: vital capacity; VCt: theoretical vital capacity.

Comparison of VC/VCt at the beginning (I) and end (II) of prepuberty

The mean and sd for the age and height of the 57 subjects tested at the beginning of prepuberty (I) were age: 11.1±1.0 yrs (9–13 yrs); height: 1.4±0.07 m (1.2–1.54 m). At the end of prepuberty (II) were age: 12.7±0.8 yrs (11–14 yrs); height: 1.50±0.07 m (1.30–1.65 m). They were examined 2.5±0.9 times during this period.

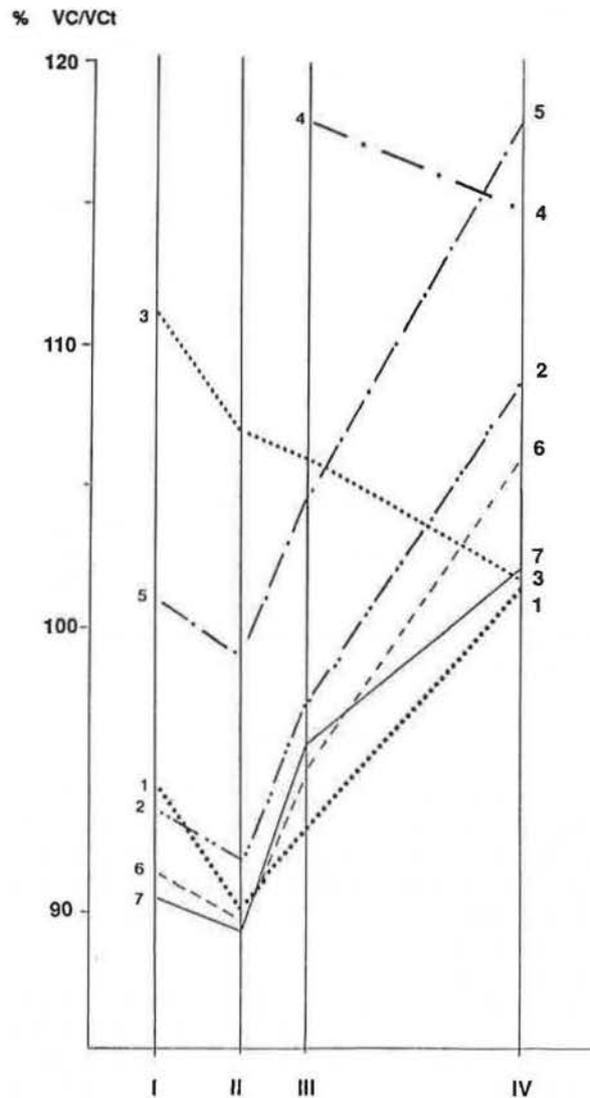


Fig. 1. – Mean values of VC/VCt calculated from each predictive equation at the beginning (I) and end (II) of prepuberty and at the beginning (III) and end (IV) of puberty for the 27 subjects examined throughout the test period. VC: vital capacity; VCt: theoretical vital capacity.

All the reference equations were used, except no. 3 which was not developed for the prepubertal period (table 3). There was a drop in VC/VCt in all cases between measurements I and II. The paired t-test showed significant differences, it was particularly clear for equation no. 1 (p<0.001).

Comparison of VC/VCt at the beginning (III) and end (IV) of puberty

The mean and sd for the 40 subjects tested at the beginning of puberty (III) were age: 13.9±0.8 yrs (12–15 yrs); height: 1.59±0.07 m (1.38–1.73 m). Their mean age was 17.6±1.8 yrs (14–19 yrs) and mean height 1.71±0.08 m (1.57–1.90 m) at the time of measurement IV. They were examined 4.2±1.4 times each.

All the reference equations were used (table 3). There was a highly significant increase ($p < 0.001$) in VC/VCt during puberty with all the reference equations except nos 3 and 4; these equations showed a significant reduction in VC/VCt ($p < 0.05$).

Table 3. — Mean and standard deviation of VC/VCt at the beginning (I) and end (II) of prepuberty period for the 57 subjects examined during prepuberty and at the beginning (III) and end (IV) of puberty for the 40 subjects examined during puberty

No.	I	II	III	IV
1	0.94±0.11	0.90±0.11	0.94±0.12	1.02±0.12
2	0.93±0.10	0.91±0.11	0.98±0.12	1.09±0.13
3			1.18±0.13	1.15±0.09
4	1.10±0.15	1.08±0.15	1.08±0.15	1.03±0.15
5	1.01±0.11	0.99±0.11	1.06±0.12	1.19±0.14
6	0.92±0.12	0.90±0.11	0.96±0.11	1.07±0.13
7	0.93±0.12	0.91±0.11	0.96±0.07	1.03±0.06

The reference values were calculated with each equation. VC: vital capacity; VCt: theoretical vital capacity.

Discussion

Body height is a predictive value for VC in children in all the reference equations used [6]. Two groups [9, 10] have documented the change in the relationship between height and VC during puberty, but there have been no published studies covering the prepubertal period.

A comparison of VC/VCt at the first and last measurement of prepuberty can indicate whether the VC/VCt remains stable during this growth period. The comparison of this ratio at the last prepubertal interview with that of the first pubertal data provides information on the influence of the onset of puberty on VC/VCt, which can then be used to verify the validity of the reference equations during growth. The onset of the growth spurt is a classical test of the onset of puberty [15]; it is particularly important in this study as it takes into account a parameter (height) which contributes to the calculation of the reference value.

The prepubertal study period was short as the children had to have a certain psychomotor maturation to ensure that they were able to correctly perform the maximum inspirations and expirations required to measure VC. The significant differences found in this study between VC/VCt ratio at the beginning and end of this period are thus more significant. The same is true for the end of the prepubertal and beginning of pubertal data.

The subjects who were 15 yrs old at the end of the study had probably not finished their puberty. However, they had begun their pubertal period at least two years before. The VC/VCt ratio varied in the same way as did the average of the group. The inclusion of these subjects explains the greater spread of age and height at stage IV than at stages I, II and III.

Comparison of the follow-up data with data derived from equations produced from survey data has been

criticized by GLINDMEYER *et al.* [17]. They showed that there is a learning effect on respiratory measurements in adults in a follow-up study. This produces results in the second and subsequent measurements which are relatively better than those of the first test. This phenomenon, if it occurs, makes the observed reduction in VC/VCt between the beginning and end of prepuberty even more significant. GLINDMEYER *et al.* [17] also showed, in a five year follow-up study of adults, that there was a drop in the maximum expired volume with age. This reduction was less marked when these data were compared to predicted values derived from survey studies. The results of GLINDMEYER *et al.* do not affect our conclusions, since the direction of the changes is reversed between the prepubertal and pubertal periods in our study. Furthermore, the differences found in our study between the beginning and end of the pubertal period are so large that they would still be clearly significant, except for equations no. 3 and 4.

All of the subjects examined took part in some sporting activity, but not in competitive sport. In most cases the nature of this activity changed as their schooling progressed. The population was, therefore, of average and uniform activity.

Each of the equations tested showed significant differences between the mean VC/VCt for different growth periods. The recently published equation of KRISTUFEK *et al.* [12] based on height, age and body weight, is not appropriate for boys aged 6–18 yrs, because there was a 12% increase in VC/VCt between the ages 12–17 yrs according to curve no. 7 (fig. 1).

Equation no. 3 is exceptional. This multiple regression of log VC with age and log body height was derived from data on adolescents. There was a moderate (3%) reduction in the VC/VCt ratio between the beginning and end of the pubertal period. It may be considered moderate if it is recalled that the measurements were made over a period of 4 yrs.

DICKMAN *et al.* [11] used both age and height in older children, and height as the only parameter in younger children. The Dickman equation was quite satisfactory for adolescents who reached a height of 60 in (1.52 m) at the beginning of puberty. In our population, all except two of the 27 subjects followed throughout their growth were over 60 in tall at stage III, and only 5 of the 40 subjects examined between the beginning and end of puberty has not reached this height by the start of puberty. All of the subjects were over 60 in tall by the end of the study. Thus, the same equation was used at stages III and IV for almost all of the subjects. The comparison of the mean VC/VCt between stage I and II of the prepubertal period is difficult to interpret. None of the subjects had reached a height of 60 in by the beginning of the study, but 10 of the 27 subjects followed throughout their growth, and 17 of the 57 examined during prepuberty were taller than this at the last measurement before entering puberty. Hence, the same equation was not used at stages I and II (tables 2 and 3). The range of heights of boys entering puberty found by SEMPÉ *et al.* [18] for a French population makes this difficult to predict. It would be better to distinguish children from

adolescents by a puberty indicator, such as the overall height gain curve, testicle size or the appearance of pubic hair. The present study confirms the results of SHRADER *et al.* [19] on the relationship between the maximum volume of air expired per second and height during adolescence. The growth in lung volumes lags behind the increase in standing height. Thus, an equation established specifically from data for adolescents, is necessary to predict VC during puberty; and this equation is different from those obtained from prepuberty data.

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Une seule équation peut elle être utilisée pour la prédiction de la capacité vitale des garçons, à la fois avant et pendant la puberté? O. Jaeger-Denavit, A. Alphonse.

RÉSUMÉ: De bonnes valeurs théoriques de la capacité vitale (CVt) permettent de calculer un rapport CV/CVt qui reste constant chez le même sujet aux différentes périodes de la croissance. Pour savoir si une seule équation est valable pendant toute la croissance chez le garçon, les auteurs ont recherché si CV/CVt varie en fonction des étapes pubertaires chez 27 garçons étudiés longitudinalement. De plus ils ont comparé la moyenne de CV/CVt entre le début de l'étude longitudinale et la fin de la période prépubertaire chez 57 garçons et entre le début et la fin de la période pubertaire chez 40 garçons. CVt a été calculée avec 5 équations de référence établies à partir des données se référant à des garçons âgés en moyenne de 8 à 16 ans et de 2 équations établies sur les données de populations distinctes d'enfants et d'adolescents. Les auteurs ont trouvé une diminution de la moyenne de CV/CVt entre le début et la fin de la période prépubertaire et une augmentation très significative entre le début et la fin de la période pubertaire lorsque l'équation de référence a été calculée à partir de données de populations qui comprennent à la fois des sujets impubères et en puberté. Avec les équations établies à partir d'adolescents CV/CVt diminue légèrement entre le début et la fin de la période pubertaire. Les auteurs ont conclu qu'il fallait traiter distinctement les données des enfants et des adolescents pour établir des valeurs de référence de CV. *Eur Respir J.*, 1990, 3, 197–201.