Correct measurement of height is important when assessing lung function values

Sidsel Bendixen Holm Renstrøm, Christian Skjoldvang Andersen, Camilla Helene Borup Pedersen & Flemming F. Madsen

ORIGINAL ARTICLE

Allergy and Lung Clinic Helsingør

Dan Med J 2012;59(2):A4376

ABSTRACT

INTRODUCTION: Measurement of stature is a prerequisite for determination of the normal lung function since reference equations are based on stature (standing height). We investigated the optimal method for measuring stature and for testing the current practice.

MATERIAL AND METHODS: We measured the stature of 87 subjects using a digital-counter stadiometer and a wall-mounted bench rule. Stature was also estimated based on finger-reach measurement, and self-reported stature was recorded. Results were compared using Altman-Bland plots. An email survey asking about written instruction on the practice for measuring stature was performed.

RESULTS: The Harpenden stadiometer delivered results reproducible within ± 0.29 cm and the bench rule compared with the Harpenden stadiometer yielded results within ± 0.59 cm. The Harpenden stadiometer was the faster of the two methods. With two exceptions, Danish lung function laboratories did not use a written instruction on measurement of stature in our sample.

CONCLUSION: It is necessary to focus on correct measurement of stature. Measurement of stature can be performed accurately with stadiometers with either digital or analogue counters. The digital stadiometer was the faster of the two.

FUNDING: not relevant.

TRIAL REGISTRATION: not relevant.

The interpretation of pulmonary function tests is flawed if the reference value is not accurate. Stature (standing height) is the most critical factor defining normal lung function.

From our review of the literature on standards for pulmonary function testing [1, 2] and principal auxological (study of growth) literature [3, 4] and from our visits to national and international respiratory physiology laboratories we have the impression that, with few exceptions, measurement of stature is a forgotten discipline in adult medicine and in many departments of pulmonary medicine, the instruments are not state-of the art [5]. In the study of children's grows, the methods used for measuring stature are more often described [6].

We describe how to correctly measure stature using a dedicated stadiometer with a digital counter and an analogue bench rule and we report the accuracy and speed of the measurements deploying the correct terminology adopted from Tanner and Hrdlicka [3, 4]. The vocabulary [7, 8] used to describe metrological quality is summarized in **Figure 1**.

MATERIAL AND METHODS

Subjects and study design

The primary study was a randomized, single-visit, quality-assurance study performed from June 2006 to December 2007 at the Allergy and Lung Clinic in Elsinore (Helsingør), Denmark. All subjects gave informed consent prior to their participation.

Study enrolment was sporadic because it was dependent on the workload of the study team which consisted of four medical students whose primary task was to assist two nurses in performing skin prick tests and bronchial challenges.

Patients were recruited for the study only when a team member had extra time available to perform the study procedures (e.g., after an appointment had been cancelled).

The study procedures consisted of measurements of finger-reach and stature. Immediately before the measurements, the patients were asked about their stature.

For each subject, stature was measured by two distinct methods: a counter-recording instrument stadiometer and a class-III EEC bench rule. The order of the stature measurements was determined using a random number table [9]. The individuals on the study team had all received written instruction and specific training on the operation of the instruments.

In a separate, secondary study, pairs of the study team determined the precision of measurement and the minimal time required to stature. Study subjects were selected from among patients who had participated in the primary study and who returned at later dates for routine follow-up visits. In the secondary study, the two study team members who performed the measurements in the primary study were not eligible to perform the measurements on the same patient in the secondary study; they were replaced by the other two study team members.

Ethics: In Denmark, quality assurance studies like the present require no approval from the local research ethics board.

FIGURE 1

Summary of vocabulary describing metrological quality and measurement procedures.
Accuracy: Closeness of the agreement between the results of a measurement and a true value of the "measurerand" = "particular quantity subject to measurement".
Precision: Closeness of agreement between independent results of measurements obtained under prescribed conditions.

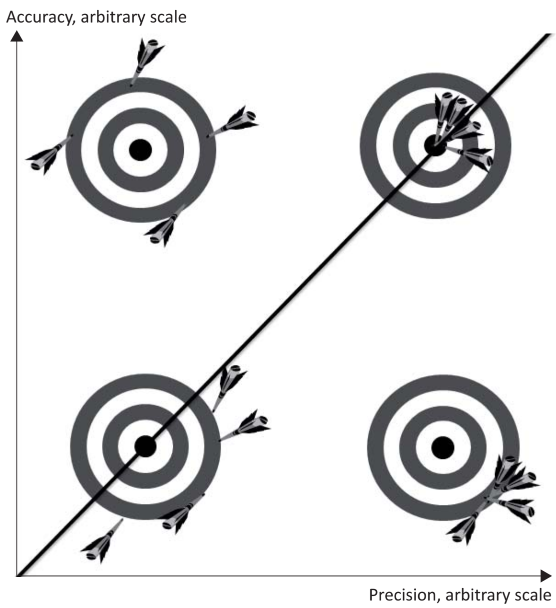
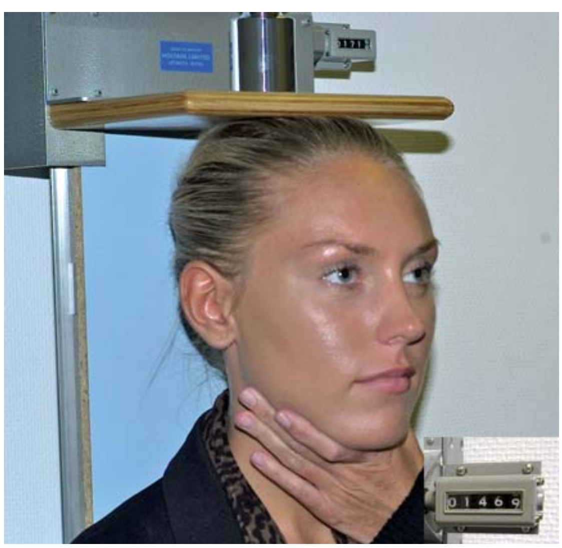


FIGURE 2

Harpenden stadiometer with mechanical counter-type indicator.



Instrumentation

Stature was measured using a stadiometer and a wall-mounted bench rule. The stadiometer used was a "Harpenden stadiometer" equipped with a standard mechanical counter and assembled with a heel block mounted on the floor (Holtain Ltd. Crosswell, Crymyh, Pembs U.K) (**Figure 2**). The instrument provides a direct digital reading that is accurate to the nearest millimetre over a range of 600-2,100 mm. The main frame of this instrument is rigid and made of light alloy mechanics mounted on a wooden plate and provided with a 600 mm spacing rod for mounting and calibration and adjustable wall brackets for mounting. The head-block operates via miniature ball-bearing rollers to ensure free movement without cross-play. Accuracy of the stadiometer and bench rule at 100.0, 150.0 and 200.0 cm was checked by comparison with bench rules before and after the study.

All bench rules were a Hultafors model SLM 100 (Hultafors AB Bollaryd, Sweeden). The bench rule was operated together with an engineer's square (Moore & Wright, Bordon, Hampshire England) weighing 1,602 g.

Finger-reach which was measured with a wall-mounted horizontal bench rule.

In the study of the time needed to perform the measurements, a phantom replaced the patients because we were interested in comparing only the time needed to perform the measurement with either the Harpenden stadiometer or the bench rule and not the time needed to remove shoes and to position the patient. For this purpose, we used a Messtronic telescopic measuring stick with a digital counter (Nedo GmbH & Co. KG Dornstetten, Germany) and an electronic stop watch.

Measurements of stature and finger-reach

We adopted the method described by Hrdlicka and Cameron [3, 4].

Preparation: Shoes were removed and hair loosened if tied up. Thin socks were allowed.

Positioning: The subject to be measured was placed with the back and buttocks in contact with the wooden plate on the Harpenden stadiometer or the wall. The palms were directed medially. The feet were placed with the medial malleoles in contact and the heels in contact with the Harpenden heel plate. The subject was instructed to relax the shoulders and the subject's head was placed in the Frankfurt plane, which is the position where the line passing through the inferior margin of the left orbit and the upper margin of the left external auditory meatus is horizontal. The stadiometer head block was moved down to touch the head and was secured so that it rested on the head with only a few layers of hair between the head block and the head. The subject was instructed "to take a deep breath and stand tall". Stretching of the spine was assisted by application of a gentle upward pressure beneath the mastoid process. The subject was instructed as follows: "relax your shoulders and stretch up as much as you can – keep your heels on the ground".

Measurement: The head plate was pressed against the head and the measurement was read from the digital counter in millimetres. If the last digit on the counter was between two values, the lower value was recorded.

Measurement with the bench rule was performed with exactly the same placement and instruction of the subject. The only differences from the Harpenden measurement were the following: the heels were placed as close to the wall as possible, an engineer's square was used instead of the Harpenden head block, results were read from a horizontal bench rule (analogue reading) and the heel block was omitted.

The engineer's square was placed in contact with the wall and carefully lowered until it was in contact with the head. The operator's eyes had to be at the same horizontal level as the square when reading the stature. If the operator was much shorter than the subject, the operator used a footstool in order to read the engineer's square at eye level to avoid parallax error.

For measurement of finger-reach, the subject stood with his back to the wall and the fingertip of the middle finger in contact with a plate indicating the zero point. The distance to the longest fingertip on the other hand was measured using a pendulum in equilibration position.

The time study was recorded with the Messtronic telescopic measuring stick with a digital counter. One operator telescoped the Messtronic to a random length, placed vertically simulating a patent and measured the distance with either the Harpenden stadiometer or the bench ruler. When the Messtronic was placed correctly, the operator gave the signal "go" and a stopwatch was started by a second operator. A third operator performed the measurement as quickly as possible. As soon as the result was recorded, the signal "stop" was given and the time was recorded. First then, the length of the Messtronic was read and recorded.

In 2011 we obtained n sample on stature measurement practice among selected Danish and international departments of pulmonary medicine, Danish departments of clinical physiology and the main Danish centres of respiratory physiology and epidemiology. Five international centres were selected according to their reputation as centres of excellence in the field of respiratory physiology. The head of the department was asked "do you have an instruction for the measurement of stature" and, if so, we asked for a copy.

Statistics

Agreement between the methods was analyzed using the Altman-Bland [10] by plotting the paired difference between measurements against the mean of the two measurements. Agreement of the results obtained with the different methods and the results obtained with the stadiometer was performed by calculating the mean difference for paired observations and the corresponding 95 % confidence interval for the differences. A p value < 0.05 was considered significant. All statistical analyses were performed using SPSS Statistics, version 19.0.

Trial registration: not relevant.

RESULTS

A total of 87 subjects participated in the study including 60 males and 27 females with a mean age of 45 years (range 18-82 years). Ten of the subjects returned to the clinic for routine follow-up visits within three month and were measured again in the secondary study.

Table 1 shows mean differences between stature measurements using the stadiometer compared with measurements using the bench ruler. The mean self-reported stature had only a small error, but 44 patients reported a stature that deviated more than 1.25 cm from the value measured with the Harpenden stadiometer which corresponds to an error in the predicted [11] forced expiratory volume in the first second (FEV_1) of more than 50 ml (**Figure 3**) which is the maximal allowable error for a spirometer [12].

The mean time needed to perform a measurement of stature after the "phantom" patient (Messtronic) had been placed correctly and until the measurement was recorded was 9.9 seconds (range 6.2-22.7) for the Harpenden and 14.3 seconds (range 10.1-29.0) for the bench rule.

The mean numeric difference between the "phantom" height and the recorded value was 0.01 cm (n = 25, range 0-0.1) for the Harpenden and 0.05 cm (n = 25, range 0-0.02) for the bench ruler.

Linear regression analysis showed a high correlation ($r^2 = 0.86$) between finger-reach and stadiometer-determined stature for 87 subjects, but underestimated stature by 3 cm in subjects measuring 140 cm and overestimated stature by 1.5 cm in subjects measuring more than 191 cm (**Figure 4**).

Three out of the five international departments we asked about their use of an instruction on how to measure stature answered our question and two answered affirmatively. Three out of five Danish respiratory epidemiological centres answered our question and two presented an instruction. Nineteen out of nineteen Danish departments answered our question and none used an instruction.

TABLE 1

Agreement between methods in measurement of stature.

	n	Mean difference,[a] cm	95% confidence interval for difference,[b] cm	
			lower	upper
Difference Harpenden – Harpenden	10	−0.29	−0.60	−0.02
Difference Harpenden – bench rule	87	−0.59	−0.70	−0.49
Difference Harpenden – finger-reach	87	0.45	−0.48	1.38
Difference Harpenden – interview	86	−1.12	−1.58	−0.67

a) Mean difference is an estimate of "trueness".
b) The 95% confidence interval for the difference between individual measurements is an estimate of "precision".

FIGURE 3

Differences between measurements performed with the bench rule and the Harpenden stadiometer plotted versus the mean of the two measurements. Dotted lines are the linear regression line and the 95% confidence interval for the individual differences. The intercept indicates bias.

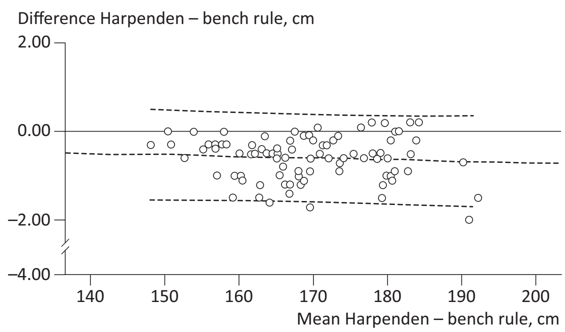
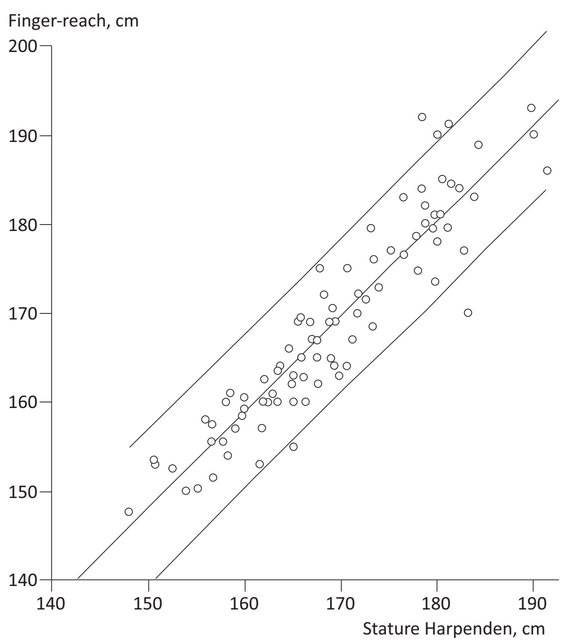


FIGURE 4

Linear regression of finger-reach versus stature measured with the Harpenden stadiometer. $r^2 = 0.86$. Regression line is shown with the 95% prediction interval.



DISCUSSION

The most important result of our study was the almost complete lack of focus on measurement of the stature of adults in Danish epidemiological centres, pulmonary function laboratories as well as in the international standards on pulmonary function testing and in most scientific papers.

We confirmed that a dedicated digital counter stadiometer offered a quicker reading in practice than an analogue bench rule with a carpenters square, but found that the accuracy was the same for the two methods.

Our comparison of the literature on the study of growth (auxology) with the literature on pulmonary function testing disclosed many examples of flawed terminology (Frankfort plane instead of Frankfurt plane (named after Frankfurt am Main), armspan instead of finger-reach and height instead of stature or standing height).

We were unable to identify studies where a sample of laboratories were asked about their practice on measurement of stature or studies where a standard bench rule was compared with a stadiometer with digital counter. In one study, the accuracy of repeated measurements with the Harpenden stadiometer was tested and the authors found the accuracy of measurement comparable to ours, but they found a slightly better precision for the Harpenden stadiometer [13].

Our study corroborates previous studies [14-16] in finding self-reported stature and finger-reach as surrogate markers for stature to be too inaccurate for use in the pulmonary function laboratory.

We were unable to identify studies that evaluated the time needed to perform the different types of measurements.

In the literature by Tanner and Whitehouse, who constructed the Harpenden digital stadiometer, we found no indications that there should be an improvement in accuracy when going from analogue to digital readings. The advantage was expected to be found in improved practicality of the measurement and the minimized risk of misreading the results, as indicated by the large technical literature on the use of digital counters instead of analogue instruments [17].

The practicality of a measurement is not easily quantitated, but Whitehouse, who performed anthropological measurements eight hours a day for years, constructed the Harpenden range of anthropometres with the specific aim of improving practicality [3]. We have only indirect evidence that the Harpenden stadiometer is more practical to use as judged from the increased speed of measurement which is primarily a result of the ease with which the digital counter can be read.

The major strength of our study is the high degree of standardization of the methods and that the study was performed in a busy pulmonary function laboratory which means that the results can easily be extrapolated to other clinical laboratories.

It may be considered a weakness of our study that we did not standardize the load on the head plate of the stadiometer when the counter was read. According to Tanner, a weight of approximately one kg should be placed on the head plate to minimize the effect of the hair. We put pressure on the head plate with one hand while reading the counter and varied the pressure depending on the amount of hair. We did not take pathologic compression of vertebrae between first and second measurement with the Harpenden stadiometer into consideration, but since the second measurement was the tallest, compression fractures of the vertebrae have not biased the results.

The lack of focus on measurement of stature in adult pulmonary medicine is probably due to a lack of knowledge about auxological methods and equipment. Although many stadiometers are commercially available, we have only been able to identify three with a digital counter. Besides the Harpenden stadiometer, the 235A Heightronic digital stadiometer and the Seca digital stadiometer 242 have digital counters (price 750-1,050 GBP).

It is of clinical relevance for patients that both the stature on which the reference material is based and the stature on the basis of which the predicted lung function is measured are accurate. An error of ≥ 1.25 cm in the measurement of stature implies an error ≥ 50 ml in predicted FEV_1 [11]. Even though decisions of importance to a patient should not be based on marginal results only, some widely used classification systems are based on rigid FEV_1 limits stated as a percentage of the predicted value, e.g. the GOLD classification where FEV_1 as a percentage of the predicted value is used as a severity scoring system [18, 19]. Even a small error in FEV_1 as a percentage of the predicted value may therefore result in misclassification of the severity grade. This is also the case in many clinical trials where patients with asthma and chronic obstructive pulmonary disease are included on the basis of their FEV_1 as a percentage of the predicted value.

If self-reported stature was used instead of measured stature errors, up to 473 ml in predicted FEV_1 would be introduced and therefore self-reported stature should be avoided.

CONCLUSION

Accurate and precise measurement of stature needs attention in international standards on pulmonary function testing, papers reporting reference values and in the respiratory function laboratory. Cameron and Hrdlicka have described how to correctly measure stature and since digital instruments are available correct measurement of stature should become the standard in pulmonary function laboratories.

CORRESPONDENCE: *Flemming F. Madsen,* Allergy and Lung Clinic Helsingør, Sct. Olai Gade 39, 3000 Helsingør, Denmark. E-mail: flem-mad@dadlnet.dk

ACCEPTED: 30 November 2011

CONFLICTS OF INTEREST: none

ACKNOWLEDGEMENTS: The authors wish to thank *Barbara Rutledge* for English-language editing and for helpful advice.

LITERATURE

1. Miller MR, Crapo R, Hankinson J et al. General considerations for lung function testing. Eur Resp J 2005;26:153-61.
2. Pellegrino R, Viegi G, Brusasco V et al. Interpretative strategies for lung function tests. Eur Respir J 2005;26:948-68.
3. Cameron N. The methods of auxological anthropometry. In: Faulkner F, Tanner JM, eds., Human growth 2. Postnatal period. London: Balliere and Tidall, 1978:35-61.
4. Hrdlicka A. Hrdlicka's practical anthropometry. Philadelphia: The Wistar Institute, 1947.
5. Tanner JM. A history of the study of human growth. Cambridge: Cambridge University Press, 1981.
6. Thomsen J, Evald P, Skieller V et al. A comparative study of two different methods of measuring stature and the velocity of growth in children and adults. Eur J Orthod 1990;12:166-73.
7. Dybkaer R. Vocabulary for use in measurement procedures and description of reference materials in laboratory medicine. Eur J Clin Chem Clin Biochem 1997;35:141-73.
8. DS/ISO 5725-1. Nøjagtighed (korrekthed og præcision) af målemetoder og resultater. Del 1 Generelle principper og definitioner. Geneva: DS/ISO, 1995.
9. Diem K, Lentner C. Scientific tables. Basel: J.R. Geigy S.A., 1970.
10. Altman DG, Bland JM. Measurement in medicine: the analysis of method comparison studies. Statistician 1983;32:307-17.
11. Quanjer PH, Tammeling GJ, Cotes JE et al. Lung volumes and forced ventilatory flows 1993 update. Eur Respir J 1993;6 suppl 16:5-40.
12. Miller MR, Hankinson J, Brusasco V et al. Standardisation of spirometry. Eur Respir J 2005;26:319-38.
13. Coles RJ, Clements DG, Evans WD. Measurement of height: practical considerations for the study of osteoporosis. Osteoporos Int 1994;4:353-6.
14. Roberts RJ. Can self-reported data accurately describe the prevalence of overweight? Public Health 1995;109:275-84.
15. Parker JM, Dillard TA, Phillips YY. Impact of using stated instead of measured height upon screening spirometry. Am J Respir Crit Care Med 1994; 150:1705-8.
16. Hoilund-Carlsen PF, Schlichting P, Quaade F. Subjective and objective height and weight estimates of men and women. Ugeskr Læger 1980; 142:2611-3.
17. Lipták BG. Instrument engineers' handbook. Boca Raton: CRC Press, 2006.
18. Rabe KF, Hurd S, Anzueto A et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. Am J Respir Crit Care Med 2007;176:532-55.
19. Global Initiative on Chronic Obstructive Pulmonary Disease. GOLD. www.goldcopd.com (11 Dec 2007).