EUROPEAN JOURNAL OF PHYSICAL AND REHABILITATION MEDICINE
EDIZIONI MINERVA MEDICA

Hump height in idiopathic scoliosis measured using a humpmeter in growing subjects: the relationship between the hump height and the Cobb angle and the effect of age on the hump height

Claudio FERRARO, Stefano MASIERO, andrea VENTURIN, Marco FERRARO, Daniele FABRIS MONTERUMICI

Eur J Phys Rehabil Med 2016 Nov 08 [Epub ahead of print]

EUROPEAN JOURNAL OF PHYSICAL AND REHABILITATION MEDICINE
Rivista di Medicina Fisica e Riabilitativa dopo Eventi Patologici
pISSN 1973-9087 - eISSN 1973-9095
Article type: Original Article

Hump height in idiopathic scoliosis measured using a humpmeter in growing subjects: the relationship between the hump height and the Cobb angle and the effect of age on the hump height

Claudio Ferraro [1*], Andrea Venturin [2], Marco Ferraro [3], Daniele Fabris Monterumici [4], Stefano Masiero [2]

[1]Senior Scholar at the Studium Patavinum, formerly Professor of Physical and Rehabilitation Medicine, University of Padova, Padova (Italy); [2]Orthopedic Rehabilitation Unit, General Hospital-University of Padova Medical Center, Padova (Italy); [3]Physical and Rehabilitation Unit, Local Health Unit 13 of Mirano, Mirano (Venice, Italy); [4]Sandro Agostini Spinal Surgery Unit, General Hospital-University of Padova Medical Center, Padova (Italy).

*Corresponding author: Claudio Ferraro, MD, via Francesco De Lazara 3/A, 35124 Padova, Italy. E-mail: claudio.ferraro@unipd.it

Conflict of interest—None.

BACKGROUND: The comparison between Cobb angle and hump height measured using a humpmeter in idiopathic scoliosis have produced contradictory findings concerning the association between the two variables in growing subjects.

AIM: To analyze the relationship between the hump height and the Cobb angle and the effect of age on the first.

DESIGN: Cross-sectional, descriptive analytical study.

SETTING: A tertiary university hospital.

POPULATION: One thousand two-hundred forty-five subjects with diagnosed idiopathic scoliosis or with a hump without spine deformity, aged between 3-21.

METHODS: The hump was measured with subjects in a forward-bending position using a pocket humpmeter; the Cobb angle was determined on a traditional radiograph. A linear regression estimated the Cobb angle in relation to the hump height, and a multiple regression based on standardized regression coefficients (ß) and coefficients of determination (R^2) assessed the contribution of age and the Cobb angle to hump variations.

RESULTS AND CONCLUSIONS: The hump height was between 0–50 mm and the Cobb angle was between 0–78°. Based on regression coefficients, every unit (1 mm) increase in the thoracic/thoracolumbar and lumbar humps corresponded to an average increase in the Cobb angle of 1.542° (SE 0.037°; P=0.000) and 1.857° (SE 0.095°; P=0.000), respectively. The 95% confidence intervals for the estimated mean Cobb angles and those for the individual angles with respect to a given hump height lead to various hypotheses regarding the interconnection between the two entities. ß values for age were low with respect to ß values for the Cobb angle both at the thoracic level (0.095 *vs.* 0.807) and at the lumbar one (0.138 *vs.* 0.651), and R^2, after the age-variable was excluded, decreased slightly from 70.3% to 69.4% and from 48.5% to 46.7%, respectively. Humpmeter measurements can thus be considered reliable in diagnosed idiopathic scoliosis and in asymmetric children – having a hump without deformity in spine – regardless of age.

CLINICAL REHABILITATION IMPACT: Hump severity can be considered the balance needle when children with idiopathic scoliosis and asymmetric children are being treated and/or monitored. The humpmeter technique, coupled with Cobb angle measurement, can facilitate the clinical evaluation.

Key words: Scoliosis – Diagnosis – Radiography – Surface metrics – Growth.

The hump deformity that alters the back surface of patients is a posterior subcutaneous salience of the rib cage or the lumbar paraspinal muscles that determines a contralateral depression. The detection of a hump is at least in part related to axial vertebrae rotation in subjects with scoliosis,[1, 2] while in subjects without scoliosis may be determined by rib cage deformity that could precede spine deformity.[3-5]

Actually, screening and follow-up for early signs of idiopathic scoliosis are essentially based on assessing the hump,[6] while the size of the hump is one of the most critical clinical elements under consideration when therapeutic programs are being prescribed and treatment outcomes are being monitored.[2, 7-9]

It thus appears opportune both in clinical practice as well as in the research setting not only to simply note the presence of the hump deformity but also to quantify its severity in some objective (numerical) way. While modern non-invasive systems investigating the surface topography of spine and trunk deformities are not always available given their cost and dimension, less sophisticated hand held devices with lower detection capability are characterized by small dimensions and ease of use.

The most representative of these devices are especially specific-designed altimeters currently called hump-meters (humpmeters) and inclinometers. Placing the humpmeter across the back of the subject bending forward horizontally, the clinician measures the difference in height between the peak of the prominence and the site on the depressed contralateral part, at the same distance from the spinous process line. The inclinometer measures the lateral inclination of a tangent line to the transversal contour of the hump with respect to the horizontal plane or, in other words, the angular deformity of the hump, also called the angle of trunk rotation [10] or the angle of trunk inclination.[11]

The forerunner of humpmeters was first described by Lavermicocca [12] in 1921; actually, the instrument prevalently used [11,13-18] is a modified version of the bubble level instrument presented by Vinchon [19] in 1965. Alternative techniques consist in transferring the transversal profile of the hump first on paper in order to measure its height,[20-22] or assessing it radiologically.[8] Another radiological method is represented by the Rib Index, which is defined as the ratio of two distances (d1/d2). The first (d1) is the distance between the posterior margin of the vertebral body and the most extended point of the most projecting rib contour, while the second (d2) is the distance between the posterior margin of the same vertebral body and the most protruding point of the least projecting rib contour.[5]

Researchers have investigated the relationship between the size of the hump deformity and the Cobb angle on radiographs essentially to predict the latter on the basis of the former. Studies in the literature using the humpmeter method are, nevertheless, even today relatively rare and their results have proven to be inconclusive or contradictory. In recent years, moreover, the method seems to be going out of use in clinical practice and in research settings where the inclinometer (the Bunnell scoliometer, in particular) is generally preferred. This can probably be explained by the fact that the humpmeter is a relatively difficult instrument to use. But even more importantly, many investigators consider the measurement achieved unreliable, since it is affected by the trunk dimensions.[10, 11, 14, 21, 23] In fact, the Authors prefer to use standardized measures of the hump such as, for example, the ratio between its height and width or between its height and trunk width,[14, 21] or even inclinometer measurements since these are dimensionless and thus unaffected by the trunk dimension.

The aim of the current study is then to analyze (a) the correlation between the Cobb angle and the height of humps located in the principal regions of the back and (b) the hump height variations in relation to age in growing subjects.

The humpmeter measuring technique

Designed by one of the authors (CF),[17] the humpmeter (Figure 1A) is assembled by an horizontal rod with a spirit level and three vertical sliding rods, attached to the horizontal rod, of which one rod is central and 2 are lateral. It is a handheld tool that is commonly used in clinical practice. During the Adams' forward bending test (used to detect hump deformity with the naked eye), the patient who is in a standing position is instructed to bend forward until the back reaches a horizontal plane, with feet spread apart resting ideally below the shoulders, knees in extension, shoulders, arms, and hands hanging loosely. In the authors' experience, the examiner may stand or sit directly in front of the subject (Figure 1B). To correctly reach the measurement, it is crucial to maintain the device horizontally – by looking at the level bubble – and to point the central vertical rod to the spinous process line. Then, one lateral rod is placed in contact with the apex of the hump and the other lateral vertical rod is placed equidistant on the opposite side, to reach the depression.

The difference in height between the lateral rods indicates the height of the hump deformity expressed in millimeters, according to the standard model [8, 11, 13-16, 19] (Figures 1C, D).

Subjects and methods

The present study was conducted at the Orthopedic Rehabilitation Unit and the Spinal Surgery Unit of the University of Padova Medical Center between 1984 and 2011. One of the authors (CF) personally measured the hump height and the Cobb angle in 1235 young patients. Untreated patients or patients prior to being treated surgically or with spinal braces were assessed. The diagnosis of idiopathic scoliosis was achieved when other demonstrable causes of scoliosis had been excluded on the basis of clinical and radiological findings. Subjects were considered eligible for the study until they reached skeletal maturity, which was confirmed by the radiological detection of grade 4-5 on the Risser Classification (United States grading system).

Radiographs of the spine were prescribed, in some cases by the authors themselves, because of back asymmetry and in any case not in function of this study. Several children were addressed to our Department following a scholastic screening program. The majority of the subjects lived in the Veneto region (Italy) and nearly all were Caucasian. Some of the subjects had been included in a precedent study.[17]

Spine lateral curves of any entity were measured in traditional upright standing frontal radiographs using the Cobb method.[24] The curves were classified, depending on the apical vertebra level, as thoracic, thoracolumbar, or lumbar; those curves with an apex between the T11 vertebral body and the T12/L1 disc space were considered thoracolumbar. The curves were considered structural whenever a corresponding hump was visible during the Adams’ test. Even if minimal, as long as it was visible at the test, the hump was measured and, depending on the level of its apex along the trunk axis, it was classified as thoracic, thoracolumbar, or lumbar. If there were two or more humps (397 cases; 31.9%), the largest was considered the main one, and the second largest was considered the secondary one. If the humps were the same size (19 cases out of 397; 4.8%) the hump with the largest Cobb angle was considered the main one; in the 3 cases of a double thoracic and lumbar hump with the same angle size, the lumbar hump was, by common agreement, considered the main one.

Lower limbs discrepancy was evaluated clinically and on the upright standing radiographs for scoliosis. Patients affected by detectable leg length discrepancy, the height of the hump was measured with the subject wearing shoe lifts between 0.5-2 cm. Although shoe lifts were used in order to obtain values as close as possible to the subject’s real hump height, it is important to remember that the minimal thickness of lifts that was used may only modify the outcome partially: on the average 1 mm and 2 mm for a thickness, respectively, of 0.5 cm and 1 cm (authors’ data).

In the rare cases in which the subject was unable to assume a standing forward-bending position, the hump was measured with the patient in a sitting bending position. Usually, radiographs were taken within three months since hump measurement.

Each subject was evaluated for the study only once. In accordance with current clinical practice, the hump and the Cobb angle were measured only one time.

As far as the author (CF) was concerned, the intra-observer casual (statistical) errors in measuring the hump and the Cobb angle, that were expressed in accordance with the graphic technique proposed by Bland and Altman, as ± 2 standard deviations (2 SDs) of the differences between two consecutive independent measurements (taken on an average of three weeks time from one another) were found to be, respectively, 2.9 mm and 3.1°.[25] Measurement differences had a normal (Gaussian) distribution and were not influenced by the amplitude or the site of the entities.

Pearson's r correlation coefficient and multiple and simple linear regression analysis were used. The level of statistical significance was set at a P value <0.05. The SYSTAT program package for the Macintosh, version 5.2. (Evanston, IL: SYSTAT, Inc., 1992) was utilized.

Results

Data and population assessment

The ages of the 1245 subjects ranged between 3 and 21 years (mean 12.7 years; SD 2.1 years) and the female: male ratio was 2.9:1. The height of the single or main hump varied between 0 and 50 mm (mean 8.4 mm; SD 6.4 mm) and the Cobb angle of the relative curve between 0 and 78° (mean 17.0°; SD 12.7°). The linear relationship of these variables (Pearson’s r) was 0.788 (Figure 2).

In the majority of cases, the radiologic site of the curve appeared almost at the same point in the trunk (along its axis) where the hump was located; it was rarely located at a more cranial or caudal level. Idiopathic scoliosis (≥10°) was found in thoracic region in 74% of subjects examinated, while in thoracolumbar and lumbar regions in 49% and 66% of subjects respectively. The remaining patients presented only surface deformities without or with minimal spinal deformity (Cobb angle ≤9°).

Four percent of the subjects (50 cases) presented an atypical hump (*i.e.*, the apex of the hump was located on the concave side of the curve) having a humpmeter reading of 1 to 12 mm (mean 5.4 mm; SD 2.3 mm) and the corresponding Cobb angle of 1 to 19° (mean 8.0°; SD 3.4°). In 48 cases the atypical hump was single, while in 2 cases the atypical hump were coupled to a typical hump. In these 2 patients was chosen the atypical hump, that was characterized by a larger Cobb angle. The association between Cobb angle and atypical hump measurement was not significant (r=0.107: P=0.460). However, all patients of this group were included in the statistical analysis.

In the subjects with a double hump (N.=397) was found a greater association between the main hump height and its Cobb angle in comparison to the height of the secondary hump and its angle (r=0.787 *vs.* r=0.656; P=0.024). On the average, the Cobb angle linked to the main hump was greater in comparison to the secondary hump, regardless the main hump was thoracic (24.3° *vs.* 21.4°; P=0.000; N.=273), thoracolumbar (19.9° *vs.* 15.8°; P=0.003; N.=11), or lumbar (22.3° *vs.* 20.2°; P=0.001; N.=113).

The demographic and clinical characteristics of the subjects studied, who were divided into groups based on the location of the single or main hump, are outlined in Table I.

The variation in the Cobb angle with respect to the height of the single/main hump

Multiple linear regression analysis was performed to evaluate the Cobb angle with respect to the hump height and the interaction between the hump height and the region in which it was located. The latter variable was introduced into the model to verify if the variation in the Cobb angle in function of the hump height was the same in the thoracic, thoracolumbar, and lumbar regions.

The analysis showed that both the regression coefficient for the hump height as well as the interaction were significant (P=0.000 and P=0.000 for each of the variables). When pairwise comparisons for the regions were made separately, it was found that while the coefficient values for the thoracic and thoracolumbar regions did not differ significantly (P=0.064), both were lower with respect to the coefficient for the lumbar region (P=0.000 and P=0.000 for each of the comparisons).

It thus seemed best to determine two distinct regression coefficients for the Cobb angle values in function of the hump height: one of 1.542° with reference to the thoracic and thoracolumbar (thoracic/thoracolumbar) region and another of 1.857° with reference to the lumbar one (Tables II and III).

The respective regression equations were:

$$y = 3.517 + 1.542x$$

$$y = 3.182 + 1.857x$$

where y = estimated mean Cobb angle and x = hump height in millimeters. The relative regression lines, with 95% confidence intervals for the estimated mean Cobb angle values are shown in Figure 3.

The variation in the Cobb angle explained by the linear relationship of the angle with the hump height according to the coefficient of determination R^2 was 0.681 or 68.1% for the thoracic/thoracolumbar region and 46.7% for the lumbar one.

The quantity $1 - R^2$ represent the percent change of Cobb angles due to accidental causes (random measurement error) and other systemic causes not included in the models (other independent variables, effects nonlinear interaction factors) and were 31.9% and 53.3% respectively.

In Figure 4, the 68% and 95% confidence intervals of the residual Cobb angle values for every hump height registered are plotted as confidence bands around the regression lines. The size of the bands is given by the SD of the residual values, that is, the measure of the variation in the Cobb angle not explained by the linear relationship of the angle with the hump height.

As 2 SDs of residuals are equal to 15° (that is 7.61° x 2) for the thoracic/thoracolumbar region and 16° (7.99° x 2) for the lumbar region, it can be deduced that 95% confidence bands for the Cobb angle of a future individual with a hump height of a given x value will be respectively, y ± 15° and y ± 16°, where y is the estimated mean angle value for that hump value. Figure 5 shows the graphics of the confidence bands.

Age-related variations in hump height

In the subjects with a single/main hump in the thoracic region (N.=541) and in those whose single/main hump was in the lumbar region (N.=438) a multiple linear regression analysis was performed separately for the hump height (dependent variable) with respect to age and the Cobb angle (independent variables). This analysis allow to evaluate the variation in hump height in dependence to the patient’s age (and thus the trunk dimension) maintaining the Cobb curve and vice versa under control.

As can be observed in Table IV, the results of the analysis indicated that there was a mean increase in the thoracic hump of 0.343 mm for every unit (1 year) of age and of 0.429 mm for every grade (1° Cobb) in the curve. The comparison of the standardized regression coefficients ß – beta – (which determines the contribution linked to various independent variables expressed in different measurement scales) showed that while the Cobb angle produced an important contribution (ß=0.807) to the estimated hump increase, age provided a minimum one (ß=0.095) as it was 8 times lower with respect to the Cobb angle (0.807/0.095).

As can be observed in Table V, there was an increase in the lumbar hump of 0.278 mm for every year of growth and 0.239 mm for every grade of the Cobb angle. The ß value for age with respect to the ß value for the Cobb angle (0.138 *vs.* 0.651) showed that the contribution of the former was 5 times lower with respect to the latter.

Excluding the age variable from the regression models, the coefficient of determination R^2 dropped from 70.3% to 69.4% (a variation of 0.9%) as far as the thoracic hump was concerned and from 48.5% to 46.7% (1.8%) with regard to the lumbar hump. The slight reduction in R^2 was further evidence that the age variable was much lower with respect to the Cobb angle in contributing to the goodness of fit of the models.

Discussion

Statistical errors using the humpmeter to measure humps

As far as the author (CF) is concerned, the intra-observer error was 2.9 mm (2 SDs).[25] Thus, assuming that the single measurement of the hump deformity is 10 mm, it should be interpreted that with a probability of approximately 95%, it is between 7.1 mm and 12.9 mm (*i.e.*, 10 ± 2 SDs) rounded off between 7 mm and 13. It can be deduced that two consecutive, independent measurements of the deformity will indicate a real increase or decrease in its height, probably because of ≥4 mm (>2 SDs) differences in the absolute value.

The inter-observer error (2 SDs) between two of the authors of the present study (CF vs. AV) was found to be nearly the same as the intra-observer value of one of the two (CF).[27]

Other investigators have described a hump measurement variability that is generally between 2 mm and 4 mm.[14, 28, 29]

Relationship/prediction of the Cobb angle depending on hump height

Since it has been demonstrated that in patients with more than one hump, the main one is generally correlated with a larger Cobb angle, the present study was limited to evaluate the correlation/regression to the main hump in those cases.

The strength of the linear relation of the Cobb angle with the height of the single/main hump was in general very good (r=0.788); particularly, it was excellent (r=0.825) in the thoracic/thoracolumbar curves and good (r=0.683) in the lumbar curves.

The humpmeter as the Bunnell scoliometer,[10, 30] allows to uncover the associations between the variables and to carry out a regression analysis.

The statistical analysis estimates that mean Cobb angles increase linearly with the hump depending on the region of the back affected (Tables II, III and Figure 3).

In fact, each increase of 1 mm in the hump, correspond to 1.542° in the thoracic/thoracolumbar region and to 1.857° in the lumbar region of the Cobb angle value.

The discrepancy may be partially explained by a linear correlation between trunk axial longitudinal rotation and the apical vertebral rotation, as confirmed by other Authors.[1, 2, 21]

We could speculate that the trunk and the apical vertebra represent a single rotated anatomical entity.

Thus, the difference may be attributed to the role of the rib cage that determines a leverage effect on the hump in the thoracic region. Consequently, in the lumbar region, it is necessary greater grade of rotation to obtain an equal hump (Figure 6). It will also have a greater Cobb angle that is positively correlated to the angle of the trunk rotation.[10, 30]

The finding that the regression coefficient for the Cobb angle linked to the thoracolumbar hump does not significantly differ from that linked to the thoracic hump is probably due to the leverage effect of the last caudal ribs of the rib cage inclined in a downward direction. The so-called "rib" hump mentioned in the literature can thus be generally considered inclusive of the thoracolumbar region.

From a clinical perspective, these findings show that when the severity of the curve is estimated on the basis of a humpmeter measurement, the larger the hump, the more attention should be directed towards the lumbar region with respect to the thoracic and thoracolumbar ones.

Specialists unanimously agree that some degrees of the Cobb angle define scoliosis severity and that these are indispensable in order to make decisions about treatment. It may be interesting to know, given the regression analysis, the hump heights that those angles estimate. The hump severity can in turn be defined by those heights without ever losing sight of the corresponding estimated mean Cobb angle. For example, if the diagnosis of a scoliotic deformity of the spine is made for angles ≥11°, [21, 31] that for a hump deformity can be made for heights ≥5 mm as far as the thoracic/thoracolumbar region is concerned and ≥4 mm for the lumbar region (5 mm and 4 mm estimate in fact 11.2° and 10.6°, respectively). Numerous Authors, by the way, consider 5 mm of height as the threshold value for screening scoliosis and for radiograph assessment.[17, 18, 32, 33]

In general, the hump deformity can be defined in increasing classes for every 5 mm of height: $0 \text{ mm} \le x < 5 \text{ mm}$, $5 \text{ mm} \le x < 10 \text{ mm}$, $10 \text{ mm} \le x < 15 \text{ mm}$ etc, bearing in mind that there is an estimated mean Cobb angle behind every number.

The examiner may nevertheless be interested in knowing the “real” Cobb angle for a single individual. It is necessary in this case to refer to the 95% confidence intervals or bands for a single individual (Figure 5). For example, if the hump in the thoracic/thoracolumbar region of an individual is 11 mm, the Cobb angle, with a 95% probability, is between 5° and 35° (20° ± 15°); if it is in the lumbar region and it is 5 mm, the angle is between -4° (in practice 0°) and 28° (12° ± 16°).

Overly wide limits, a clear identification is not feaseble.

Furthermore, analogous difficulties are revealed when the scoliometer is used in view of the dispersion of hump angles as compared to the Cobb angle and vice versa.[10, 30]

On the basis of the 95% confidence bands (Figure 5), the assessment of the individual Cobb angles that can define what is “typical” at progressively higher hump heights lead to interesting developments in clinical practice. We can foresee, that when the curve of the spine progresses as the hump height increases, it is bound for the entire period of time during which it progresses to remain within the area of the confidence band with its typical angle values. It is then to be expected that, since it is synchronized with that of the hump, the progression of the curve takes place following pathways that appear to be more or less parallel to the regression line, as, in fact, is shown in Figure 7A. Worsening of the hump in these cases will signal the simultaneous radiologic progression of the curve, just as the absence of worsening will underline its stationariness. These conditions will aid the clinician to verify when it is necessary to prescribe radiographs, thus reducing as much as possible exposing young patients to ionizing radiation.[34, 35]

Not infrequently, however, the scoliotic curve follows pathways on a diagram that do not appear straight or parallel to the regression line, as can be seen in Figure 7B. It can worsen, for a certain period of time, without any real modification in the hump height or, on the contrary, as has been demonstrated also by a longitudinal study,[17] it can remain stationary while hump deformity increases. At times when there is a worsening of one or the other of these entities, this can alternate with a synchronic progression of the two, thus suggesting pathways that appear, overall, of a curvilinear rather than a rectilinear type (cases a, b, c in Figure).

The non linear variations of Cobb angle may be included in the 31.9% “unexplained” cases of the thoracic/thoracolumbar regions.

However, from a clinical perspective, we can speculate that there are basically two different asynchronous worsening pathways that are possible in the natural history of children affected or at least in those with a mild thoracic curve: a radiological pattern, as far as the angle of the curve is concerned and a referred to surface pattern, as far as the height of the hump is concerned. Assuming that, we could deduce that the stationariness of a hump may not always guarantee the radiological stationariness, nor the worsening may always represent a real threat of a worsening curve.

More extensive longitudinal studies are needed to verify the real utility in daily clinical practice of these observations.

Interestingly, in female patients that presented a thoracic hump ≥7°, Grivas *et al.*[4] founded the absence of a correlation between Cobb angle and Rib-Index in the younger subjects, while noticed the presence of a positive correlation in the older subjects. Therefore, the Authors concluded that surface deformity may precede spinal deformities in the pathogenesis of idiopathic scoliosis.

In any case, the specialist can monitor the hump-height deformity itself (*i.e.*, regardless of the curve dimension) in order to identify not only its worsening or stationariness but also its improvement in patients undergoing therapy.[25, 36]

The Influence of age

To the authors' knowledge, this is the first study demonstrating that the hump height increases in idiopathic scoliosis subjects simply due to body growth. This was demonstrated only indirectly as neither the perimeters and/or the trunk diameters, nor the differences in constitution and sex were evaluated. In addition, the study's cross-sectional design and the linear nature of the regression models flattened the peak effect of the pubertal growth spurt.

Our findings show that the degree of association between the hump height and the Cobb angle was not seriously compromised despite the wide age range of the subjects examined and the trunk dimension, that was consequently variable. The age seems to play a relatively unimportant role even from a clinical viewpoint. If, for example, in a generic scoliosis subject the thoracic curve increases 10° in a year (a foreseeable event in clinical practice) then the hump as a result of thoracic growth and worsening of the curve, on the basis of regression coefficients (Table IV), respectively increases 0.34 mm and 4.3 mm. In this case then growth affects the hump deformity 12 times less than the scoliotic deformity of the spine.

In short, we can affirm that even at present many specialists continue to use the classic humpmeter to measure the raw hump height, that it can be considered a reliable method regardless of the trunk dimension, and that standardized measures devised by some investigators to exclude the trunk effect do not appear indispensable. Conversely, a study by Takemitsu [13] demonstrated that the measures produced by the ratio between two linear dimensions of the hump deformity and of the trunk paradoxically led to worse results with regard to the degree of the Cobb correlation, which, it could be hypothesized, might be due to an accumulation of measurement errors introduced while matching the height of the deformity with other aspects that are more difficult to precisely measure.

Further clinical studies comparing this measurement procedure with the Bunnell scoliometer method or that of other inclinometers are needed. The two methods, may, in fact, be able to compensate one another thus justifying their combined use, as suggested by other Authors.[37, 38]

Conclusions

The clinical use of the classic humpmeter method in this sample of subjects has clearly demonstrated the linear relationship between the Cobb angle and the hump height in all three (thoracic, thoracolumbar, and lumbar) regions of the back. Two mathematical formulas, one for the thoracic/thoracolumbar region and the other for the lumbar region, make it possible to estimate the mean Cobb angles of the curve using humpmeter measurements and to predict the severity classes of the hump deformity linked to the angles.

Confirming previous findings, the formulas may not, however, permit us to exactly predict the Cobb angle of a future individual given the dispersion of angle values when compared with the humps.

Knowing the 95% confidence bands for single Cobb angles at progressive hump heights lead to interesting hypotheses from both theoretical and clinical points of view with regard to the interconnection and the progression of these variables over time.

The humpmeter method was found to be a valid tool to assess the hump height; the impact of the trunk dimension and age on hump height values do not appear to be substantial. Humpmeter measurements can thus be considered reliable in already diagnosed idiopathic scoliosis children and in asymmetric children – having a hump without o minimal deformity in spine – regardless of age.

Acknowledgements

The Autors would like to acknowledge Dr Filippo Vittadini for his help in the English translation and revision of the manuscript.

References

1. Aaro S, Dahlborn M. The longitudinal axis rotation of the apical vertebra, the vertebral, spinal, and rib cage deformity in idiopathic scoliosis studied by computer tomography. Spine 1981;6:567-72.

2. Kuklo TR, Potter BK, Lenke LG. Vertebral rotation and thoracic torsion in adolescent idiopathic scoliosis. What is the best radiographic correlate? J Spinal Disord Tech 2005;18:139-47.

3. Normelli H, Sevastik J, Akrivos J. The length and ash weight of the ribs of normal and scoliotic persons. Spine 1985;10:590-2.

4. Grivas TB, Vasiliadis ES, Mihas C, Savvidou O. The effect of growth on the correlation between the spinal and rib cage deformity: implications on idiopathic scoliosis pathogenesis. Scoliosis 2007;2:11.

5. Grivas TB. Rib index. Scoliosis 2014;9:20.

6. Bunnell WP. Selective screening for scoliosis. Clin Orthop 2005;434:40-5.

7. van Ooy A, Guekers ChWGM. Results of CD operation in idiopathic scoliosis. Acta Orthop Belg 1992;58(Suppl 1):129-33.

8. Harding IJ, Chopin D, Charosky S, Vialle R, Carrizo D, Delecourt C. Long-term results of Schollner costoplasty in patients with idiopathic scoliosis. Spine 2005; 14:1627-31.

9. Min K, Waelchli B, Hahn F. Primary thoracoplasty and pedicle screw instrumentation in thoracic idiopathic scoliosis. Eur Spine J 2005;14:777-82.

10. Bunnell WP. An objective criterion for scoliosis screening. J Bone Joint Surg 1984;66-A:1381-7.

11. Burwell RG, Dangerfield PH. Anthropometry. In: Findlay G, Owen R, editors. Surgery of the spine, volume 1. Oxford: Blackwell Scientific Publications; 1992. p. 191-227.

12. Lavermicocca A. L'ileocoxometro in funzione di livellatore. Archivio di Ortopedia 1921;37:281-310.

13. Takemitsu Y. Scoliosis: screening methods and the subsequent management. J Jpn Orthop Ass 1981;55:243-57 (in Japanese).

14. Götze HG. Der Rotationsindex bei idiopathischen Thorakalscoliosen. Z Orthop Ihre Grenzgeb 1973;111:737-43.

15. Vercauteren M, van Beneden M, Verplaetse R, Croene Ph, Uyttendaele D, Verdonk R. Trunk asymmetries in a Belgian school population. Spine 1982;7:555-62.

16. Pruijs JEH, Keessen W, van der Meer R, van Wieringen JC. School screening for scoliosis: the value of quantitative measurement. Eur Spine J 1995;4:226-30.

17. Ferraro C, Gottardo A. La misurazione del gibbo. Studio critico mediante un dispositivo tascabile. Minerva Ortop Traumatol 1993;44:637-43.

18. Catanzariti JF, Salomez E, Bruandet JM, Thevenon A. Visual deficiency and scoliosis. Spine 2001;26:48-52.

19. Vinchon B. Présentation d’un appareil permettant la mesure des gibbosités scoliotiques. Rev Chir Orthop Réparatrice Appar Mot 1965;51:643-4.

20. Thulbourne T, Gillespie R. The rib hump in idiopathic scoliosis. Measurement, analysis and response to treatment. J Bone Jt Surg 1976;58-B:64-7.

21. Burwell RG, James NJ, Johnson F, Webb JK, Wilson YG. Standardized trunk asymmetry scores. A study of back contour in healthy schoolchildren. J Bone Jt Surg 1983;65-B:452-63.

22. Pun WK, Luk KDK, Lee W, Leong JCY. A simple method to estimate the rip hump in scoliosis. Spine 1987;12:342-5.

23. Huang SC. Cut-off point of the scoliometer in school scoliosis screening. Spine 1997;22:1985-9.

24. Cobb JR. Outline for study of scoliosis. The American Academy of Orthopaedic Surgeons. In: Instructional Course Lectures 1948;5:261-75.

25. Ferraro C, Masiero S, Venturin A, Pigatto M, Migliorino N. Effect of exercise therapy on mild idiopathic scoliosis. Preliminary results. Eur Medicophys 1998;34:25-31.

26. Altman DG. Practical statistics for medical research. London: Chapman and Hall; 1991.

27. Zanovello L. Studio comparativo interpersonale tra due metodi non invasivi di misurazione del gibbo nella scoliosi idiopatica. Tesi di Laurea in Medicina e Chirurgia, Università degli Studi di Padova; A.A. 1995-1996.

28. Pruijs JEH, Keessen W, van der Meer R, van Wieringen JC, Hageman MAPE. School screening for scoliosis: methodologic considerations. 1. External measurements. Spine 1992;17:431-6.

29. Duval-Beaupere G. Rib hump and supine angle as prognostic factors for mild scoliosis. Spine 1992;17:103-7.

30. Korovessis PG, Stamatakis MV. Prediction of scoliosis Cobb angle with the use of the scoliometer. Spine 1996;21:1661-6.

31. Weinstein SL. Natural history. Spine 1999;24:2592-600.

32. Negrini S, Aulisa AG, Aulisa L, Circo AB, de Mauroy JC, Durmala J *et al.* 2011 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis 2012;7:3.

33. Aulisa AG, Guzzanti V, Falciglia F, Giordano M, Peruzzi M, Aulisa L. Is the screening able to lower morbidity in the territory? Scoliosis 2013;8(Suppl 2):O5.

34. Theologis TN, Fairbank JC, Turner-Smith AR, Pantazopoulos T. Early detection of progression in adolescent idiopathic scoliosis by measurement of changes in back shape with the Integrated Shape Imaging System scanner. Spine 1997;22:1223-8.

35. Liu XC, Thometz JG, Lyon RM, Klein J. Functional classification of patients with idiopathic scoliosis assessed by Quantec System. Spine 2001;26:1274-9.

36. Aulisa AG, Guzzanti V, Perisano C, Marzetti E, Menghi A, Giordano M, Aulisa L. Correlation between hump dimensions and curve severity in idiopathic scoliosis before and after conservative treatment. Spine (Phila Pa 1976). 2011 Jan 8.

37. Zaina F, Atanasio S, Negrini S. Clinical evaluation of scoliosis during growth: description and reliability. In: Grivas TB, editor. The conservative scoliosis treatment. Stud Health Technol Inform 2008;135:125-38.

38. Suk SI, Kim JH, Kim SS, Lee JJ, Han YT. Thoracoplasty in thoracic adolescent idiopathic scoliosis. Spine 2008;33:1061-7.

Titles of Tables

Table I—*Demographic and clinical features of the scoliotic subjects (Cobb ≥10°) and the asymmetric subjects – having a hump without o minimal deformity in the spine (≤9°), classified according to the back region where the single/main hump was located.*

Table II—*Linear regression analysis of the Cobb angle with respect to the height of single/main hump located in the thoracic/thoracolumbar region. Number of subjects = 807.*

Table III—*Linear regression analysis of the Cobb angle with respect to the height of single/main hump located in the lumbar region. Number of subjects = 438*.

Table IV—*Multiple linear regression analysis of the height of single/main hump located in the thoracic region with respect to the age (years) and the Cobb angle. Number of subjects = 541.*

Table V—Multiple linear regression analysis of the height of single/main hump located in the lumbar region with respect to the age (years) and the Cobb angle. Number of subjects = 438.

Legends of Figures

Figure 1.—A) The latest version of the pocket humpmeter is entirely in plastic. There is a spirit level bubble attached to the central horizontal rod. Three vertical sliding rods, are attached to the horizontal rod through a rail. The lateral vertical rods slide in both vertical and horizontal directions, while the central vertical rod slides only vertically. Each rod has impressed a graduated scale in which the point 0 is on the inferior extremity; in the present study, the central vertical rod is used by the physician only to point at the spinal line. B) The examiner sits directly in front of the subject who is bent forward, to facilitate the use the humpmeter, especially in the lumbar or thoracolumbar regions; C, D) Examples of measuring a right thoracic hump (C) and a left lumbar hump (D). The humpmeter is basically held with the last three fingers flexed in such a way that the thumb and index finger are both free to maneuver the vertical rods. While the device has been adjusted so that the bubble is centered and with the central rod indicating the line of the spinous apophyses (which can also be traced with a dermographic pencil), one lateral rod is placed in contact with the apex of the hump (reset to zero on the extremity of its rail) and the other lateral vertical bar is placed equidistant on the opposite side, to reach the depression. The difference in height between the lateral rods indicates the height of the hump deformity expressed in millimeters (rounded up or down) on the vertical lateral rod pointed on the depression, on the extremity of the rail.

Figure 2.—Relationship between the Cobb angle and the height of the single/main hump in 1245 subjects having untreated idiopathic scoliosis and subjects having a hump without or minimal spine deformity (Cobb ≤9°). – The circles, which represent the individuals assessed, have been shifted slightly and randomly to partly avoid overlapping.

Figure 3.—Linear regression lines with 95% confidence bands (grey areas) for the estimated mean Cobb angle for the height of the single/main hump located in the thoracic/thoracolumbar and

lumbar regions. The estimates are valid within the sample amplitudes; extrapolating them is, however, hazardous and can lead to false conclusions.[26]

Figure 4.—Linear regression lines (solid lines) for the Cobb angle values referring to the height of the single/main humps in the thoracic/thoracolumbar (A) and lumbar (B) regions. The dotted lines – parallel to each regression line at a vertical distance equal to 1 SD and 2 SDs on each side – circumscribe the 68% and 95% confidence bands of the residual angle values for every subject evaluated (circles). The SD of residuals is 7.61° and 7.99° which respectively refer to the thoracic/thoracolumbar and lumbar regions. Assumptions of homogeneity and normality of residuals around the regression lines do not appear to be seriously violated upon direct observation of the diagrams.

Figure 5.—95% confidence bands to predict the Cobb angle values (or all possible values) of a future individual whose single/main hump is located in the thoracic/thoracolumbar (A) and lumbar (B) region. The bands – at a vertical distance equal to 2 SDs on both sides of each regression line (central line) – correspond to the grey shadowed areas. They are in (A) and (B), respectively, $y \pm 15°$ (15.22° to by precise) and $y \pm 16°$ (15.98°), (y= estimated mean Cobb value).

Figure 6.—Schematic drawing showing the possible relationship in idiopathic scoliosis between humps of the same height in the thoracic and lumbar regions and the axial rotation of the trunk and the apical vertebra. A) The height of the thoracic hump (h_T) connected to the thorax and the vertebral rotation (α_T) is amplified by the costal lever (W_T); B) The lumbar hump height (h_L) is amplified through the paravertebral muscles by a lever (W_L) which is smaller with respect to the costal arm (W_T); in order for it to be equal to the thoracic one (h_T) it has the rotation of the lumbar trunk and vertebra (α_L) which is wider with respect to (α_T).

Figure 7.—Examples of variations over time, within the shaded area of the 95% confidence band of the Cobb angle of the right thoracic curves (arrows in the diagrams), with respect to variations in the height of single or main humps in individual untreated subjects. Worsening of one and/or the other entity defines the increases that are greater than the author's (CF) intra-observer error with respect to each previous examination. The age of the subjects at the time of each examination is indicated in the diagrams. A) Worsening of the curve and of the hump in 4 females and 1 male (indicated as "M"). The oblique direction of the arrows, more or less parallel to the regression line, emphasizes the synchronic progression of the entities; B) Variations of the Cobb curves non-parallel to the regression line in 4 females and in a male "M" (the only case present in Figures A and B). Vertical arrows indicate worsening of the curve despite the fact that the hump is stationary; horizontal ones indicate stationariness despite the fact that the hump was more pronounced. Broken line arrows (a, b, and c in the Figure) obtained from 3-4 serial examinations of the same subjects exhibit oblique as well as vertical and horizontal lines. They are indicative of the worsening of the scoliotic curve according to a temporal pattern of a curved rather than a straight nature, as erroneously one could be induced to think considering, as in the case of the male "M" in Figure A, only the first and last examinations.

Table I—*Demographic and clinical features of the scoliotic subjects (Cobb ≥10°) and the asymmetric subjects – having a hump without o minimal deformity in the spine (≤9°), classified according to the back region where the single/main hump was located.*

	T	TL	L	T + TL
Subjects number (%)	541 (43.4)	266 (21.4)	438 (35.2)	807 (64.8)
Mean age, in years (standard deviation; range)	12.9 (2.1; 2.8-21.0)	12.2 (2.2; 4.8-18.0)	12.9 (2.0; 6.3-18.6)	12.6 (2.2; 2.8-21.0)
Female:male ratio	2.8:1	2.5:1	3.3:1	2.7:1
Subjects with right curve (%)	88.2	49.2	33.1	75.3
Mean Cobb angle, in degrees (standard deviation; range)	20.9 (14.6; 0-78)	12.0 (8.0; 0-60)	15.3 (10.9; 0-75)	18.0 (13.4; 0-78)
Mean hump heigth, in millimetres (standard deviation; range)	11.2 (7.7; 0-50)	5.6 (3.7; 0-22)	6.5 (4.0; 0-26)	9.4 (7.2; 0-50)
Pearson's r between Cobb angle and hump heigth	0.833*	0.585*	0.683*	0.825*

T: Thoracic; TL: Thoracolumbar; L: Lumbar; T/TL: Thoracic + Thoracolumbar.

*P = 0.000

Table II—*Linear regression analysis of the Cobb angle with respect to the height of single/main hump located in the thoracic/thoracolumbar region. Number of subjects = 807.*

Variable	Regression coefficient	Standard error	t	P
Hump height	1.542	0.037	41.82	0.000
(Constant)	3.517	0.440	7.99	0.000

$R^2 = 0.681$. Residual SD = 7.61°. F test (ANOVA) = 1715.42 (P = 0.000).

Table III—*Linear regression analysis of the Cobb angle with respect to the height of single/main hump located in the lumbar region. Number of subjects = 438.*

Variable	Regression coefficient	Standard error	t	P
Hump height	1.857	0.095	19.55	0.000
(Constant)	3.182	0.730	4.36	0.000

$R^2 = 0.467$. Residual SD = 7.99°. F test (ANOVA) = 381.68 (P = 0.000).

Table IV—*Multiple linear regression analysis of the height of single/main hump located in the thoracic region with respect to the age (years) and the Cobb angle. Number of subjects = 541.*

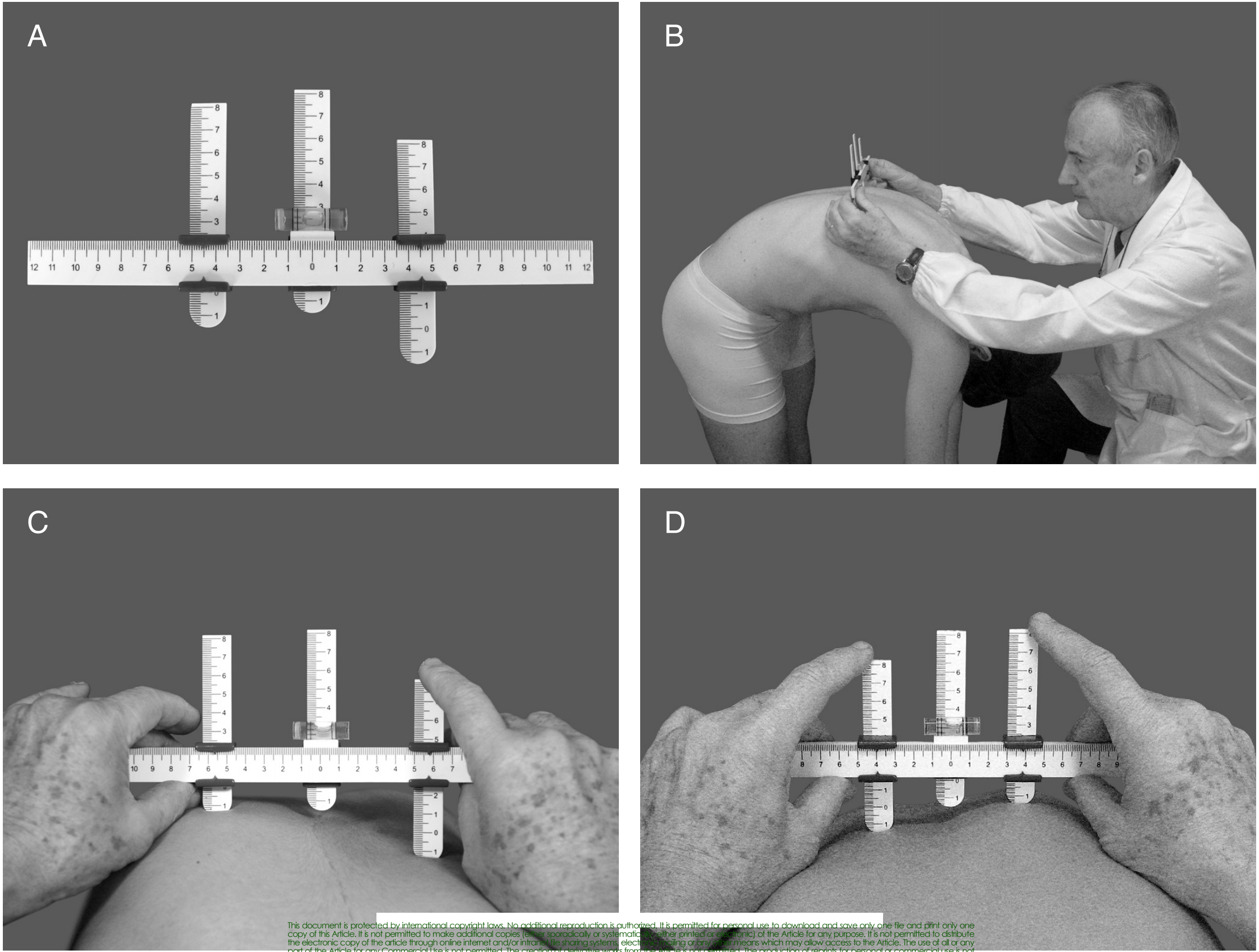
Variable	Regression coefficient	Standard error	Standardized coefficient β	t	P
Age	0.343	0.089	0.095	3.87	0.000
Cobb angle	0.429	0.013	0.807	33.02	0.000
(Intercept)	-2.166	1.133			

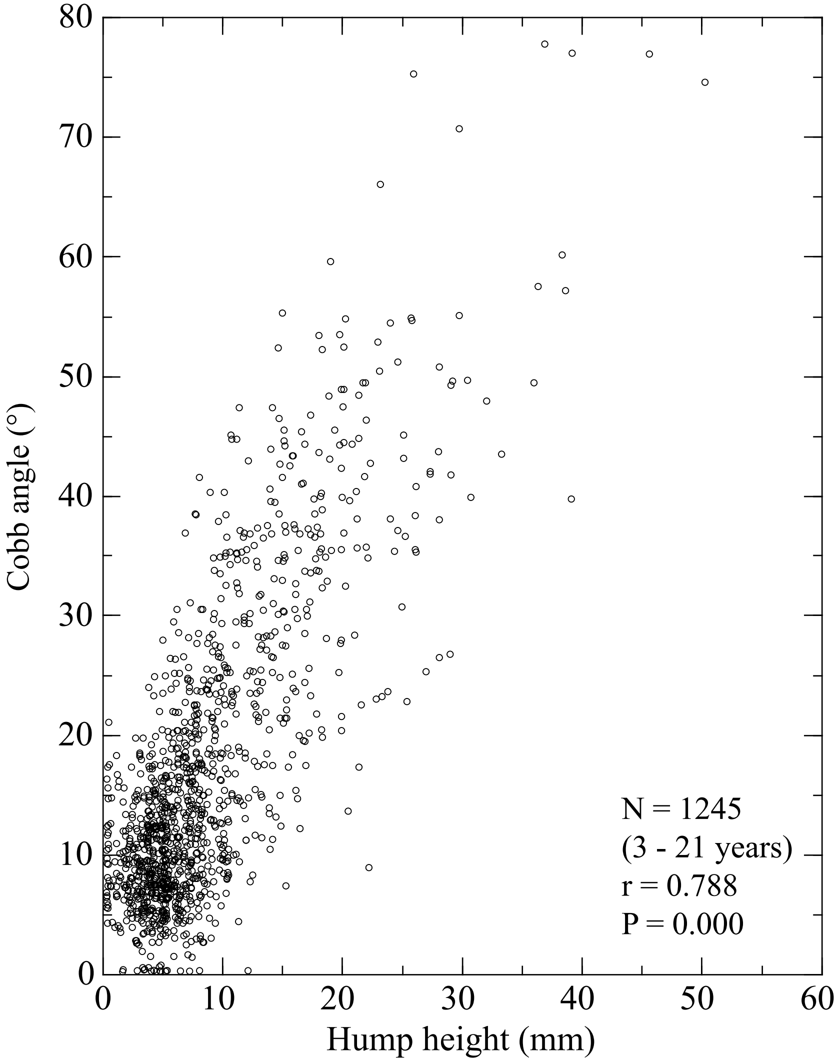
R^2 = 0.703. Residual SD = 4.24 mm. F test (ANOVA) = 635.42 (P = 0.000).

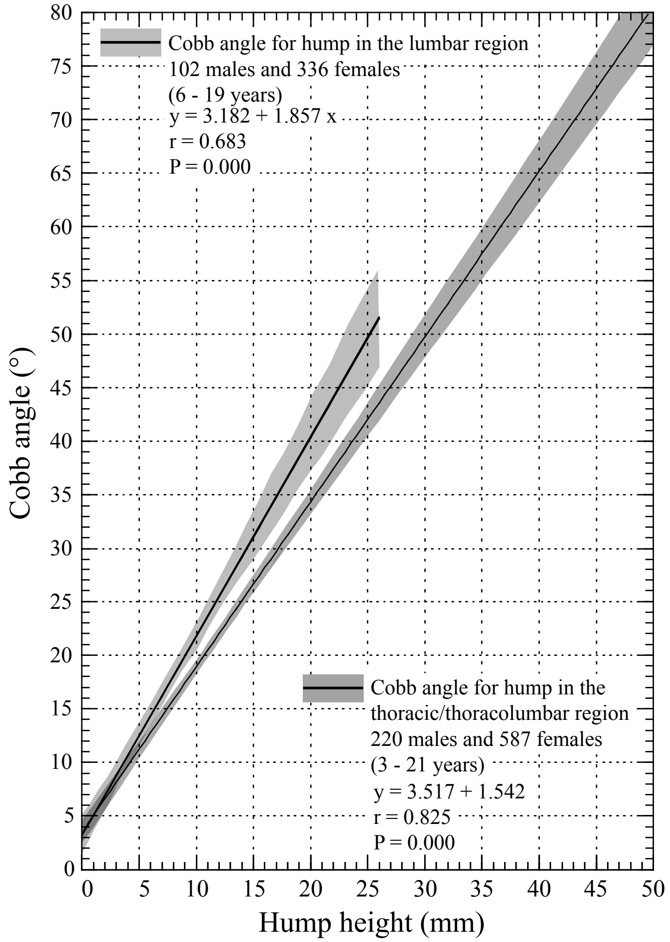
Table V—*Multiple linear regression analysis of the height of single/main hump located in the lumbar region with respect to the age (years) and the Cobb angle. Number of subjects = 438.*

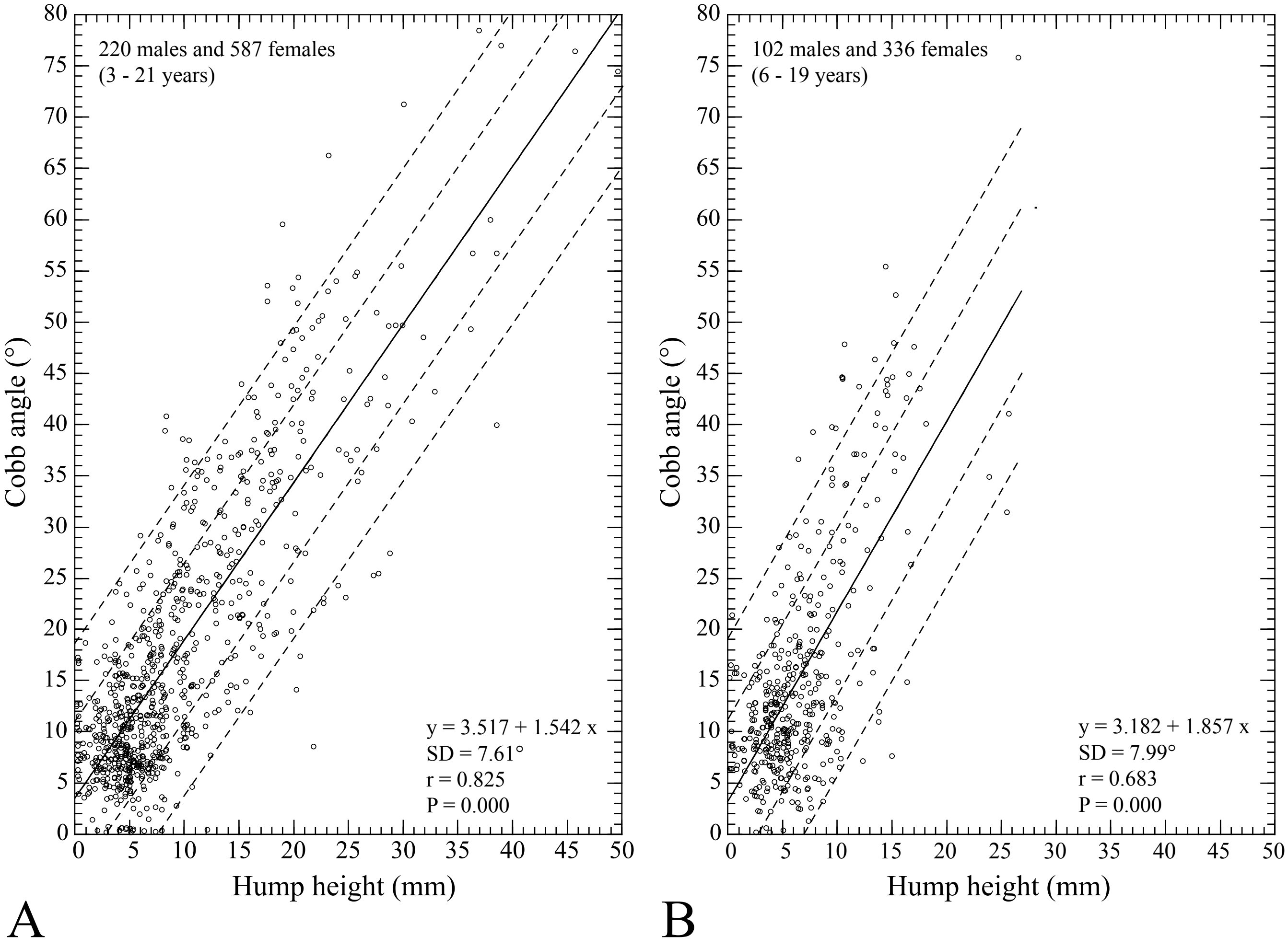
Variable	Regression coefficient	Standard error	Standardized coefficient β	t	P
Age	0.278	0.071	0.138	3.89	0.000
Cobb angle	0.239	0.013	0.651	18.37	0.000
(Intercept)	-0.698	0.902			

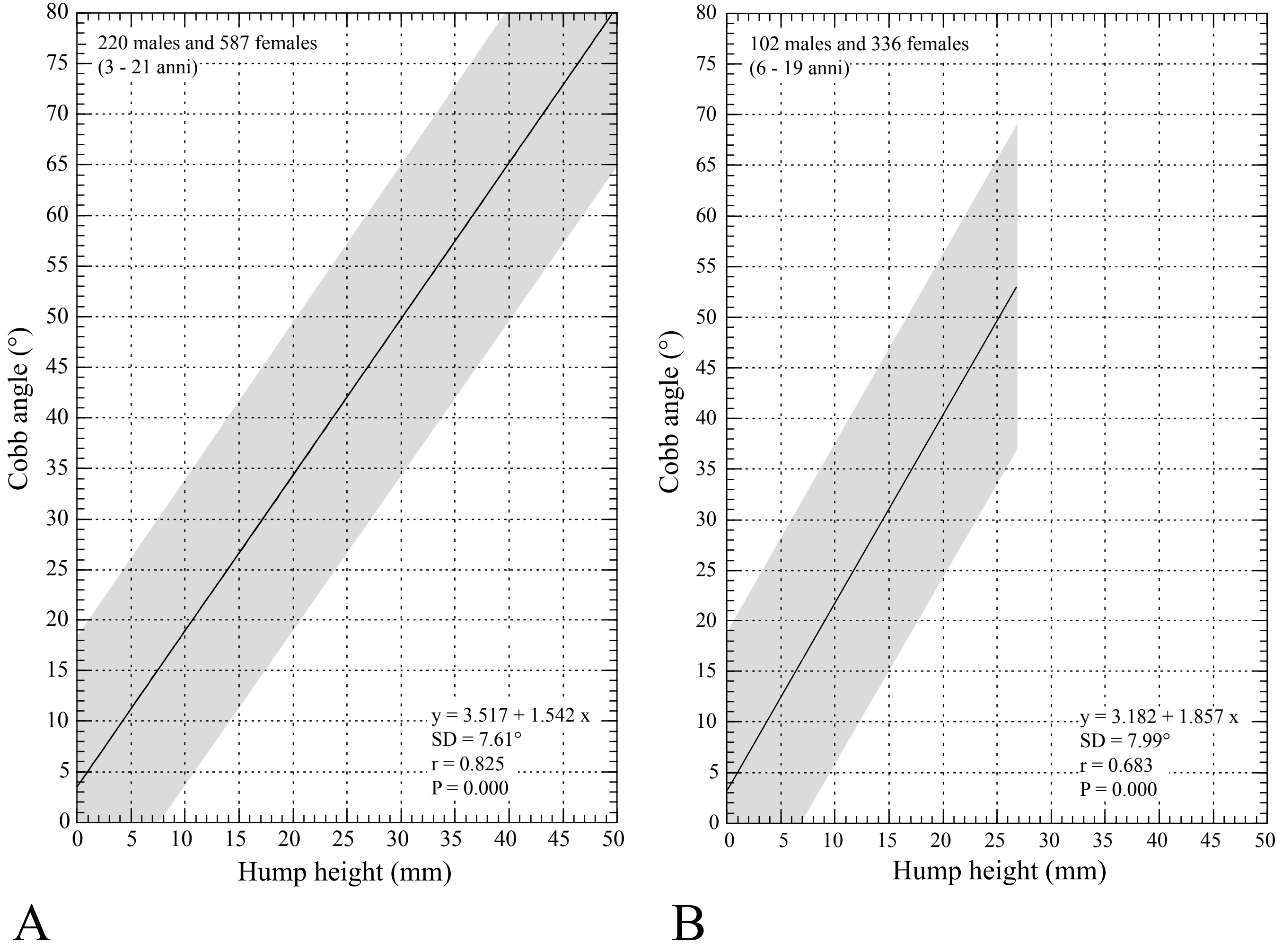
R^2 = 0.485. Residual SD = 2.89 mm. F test (ANOVA) = 204.61 (P = 0.000).

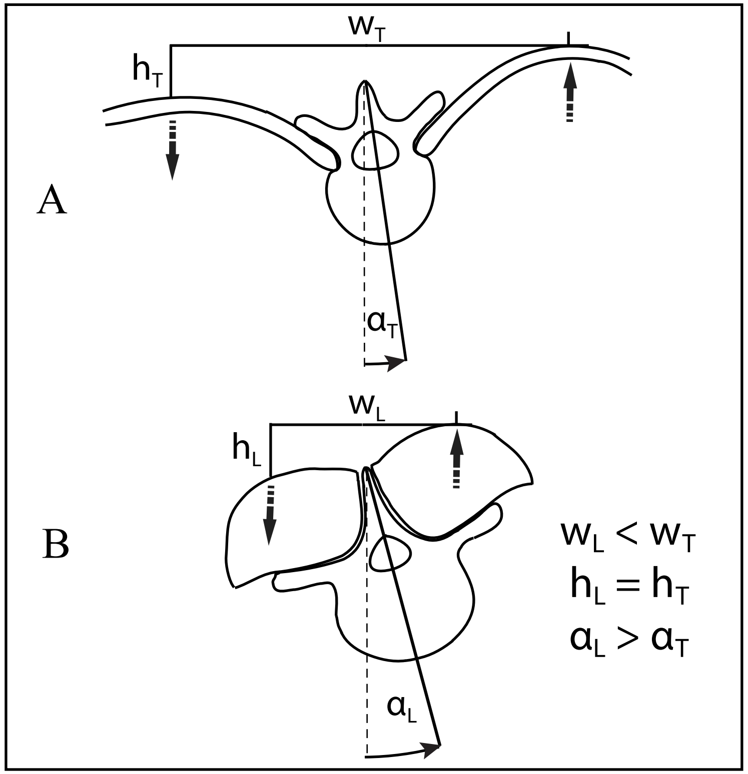

A
B
C
D

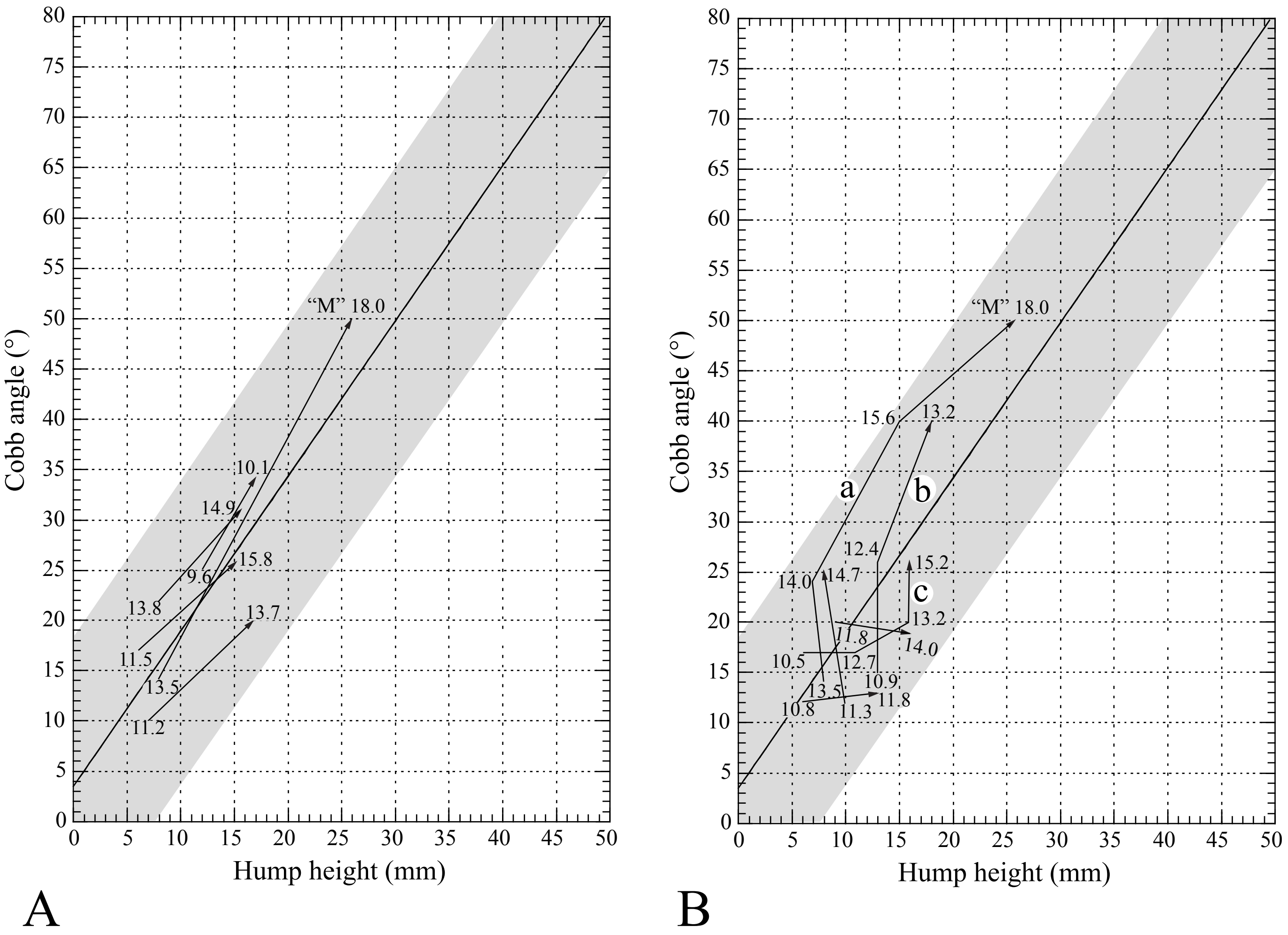

80
70
60
50
40
30
20
10
0
Cobb angle (°)
0
10
20
30
40
50
60
Hump height (mm)
N = 1245
(3 - 21 years)
r = 0.788
P = 0.000


Cobb angle for hump in the lumbar region
102 males and 336 females
(6 - 19 years)
y = 3.182 + 1.857 x
r = 0.683
P = 0.000
Cobb angle for hump in the
thoracic/thoracolumbar region
220 males and 587 females
(3 - 21 years)
y = 3.517 + 1.542
r = 0.825
P = 0.000
Cobb angle (°)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Hump height (mm)
0
5
10
15
20
25
30
35
40
45
50


220 males and 587 females
(3 - 21 years)
y = 3.517 + 1.542 x
SD = 7.61°
r = 0.825
P = 0.000
Cobb angle (°)
Hump height (mm)
A
102 males and 336 females
(6 - 19 years)
y = 3.182 + 1.857 x
SD = 7.99°
r = 0.683
P = 0.000
Cobb angle (°)
Hump height (mm)
B
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80


220 males and 587 females
(3 - 21 anni)
y = 3.517 + 1.542 x
SD = 7.61°
r = 0.825
P = 0.000
Cobb angle (°)
Hump height (mm)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
A
102 males and 336 females
(6 - 19 anni)
y = 3.182 + 1.857 x
SD = 7.99°
r = 0.683
P = 0.000
Cobb angle (°)
Hump height (mm)
B


A
w_T
h_T
α_T
B
w_L
h_L
α_L
$w_L < w_T$
$h_L = h_T$
$\alpha_L > \alpha_T$


Cobb angle (°)
Hump height (mm)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
"M" 18.0
10.1
14.9
9.6
15.8
13.8
13.7
11.5
13.5
11.2
A
15.6
13.2
a
b
12.4
15.2
14.0
14.7
c
13.2
11.8
14.0
10.5
12.7
10.9
13.5
10.8
11.3
11.8
B