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Comparison of usual and alternative methods to measure height in mechanically ventilated patients: potential impact on protective ventilation

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Abstract

Background: Protective ventilation implementation requires the calculation of predicted body weight, determined by a formula based on gender and patient height. Consequently, height inaccuracy may be a limiting factor to correctly set tidal volumes. The objective of this study was to evaluate the accuracy of different methods in measuring heights in mechanically ventilated patients.

Methods: Before cardiac surgery, actual height was measured with a height gauge while subjects were standing upright (gold standard) and also estimated with alternative methods based on lower leg and forearm measurements. After cardiac surgery, upon ICU admission, patients' heights were visually estimated by a clinician and then measured with a measuring tape while patient was supine undergoing mechanical ventilation.

Results: 100 subjects (75 men, 25 women) were prospectively included. Mean predicted body weight was 61.0 ± 9.6 kg and mean actual weight was 30.3% higher. In comparison with the reference method, visually estimated height and the tape measuring method were less accurate than both lower leg and forearm measurements. Errors above 10% in calculating the predicted body weight were present in 25 and 40 subjects when the tape measure or visual estimation of height was used in the formula, respectively. With lower leg and forearm measurements, 15 subjects had errors above 10% ($P<0.001$).

Conclusions: Our results demonstrate that significant variability exists between the different methods of measuring height in bedridden patients on mechanical ventilation. Alternative methods based on lower leg and forearm measurements are potentially interesting solutions to facilitate the accurate application of protective ventilation.

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Key words: Protective Mechanical Ventilation; Tidal volume; Predicted Body Weight; Height; Ventilator induced lung injury; Acute Lung Injury; Measure

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Introduction

In patients with acute respiratory distress syndrome (ARDS), ventilation with high tidal volumes increases mortality and protective ventilation with lower tidal volumes is now widely recommended [1-4]. Several studies suggest that prophylactic protective ventilation should be used in most mechanically ventilated critically ill patients to avoid acquired ARDS [5-7] and to improve outcome [6, 8].

It is well established that patients' lung volumes are well correlated to their height [9] and this important physiological value cannot be overlooked in mechanically ventilated patients. Indeed, protective ventilation implementation requires the calculation of predicted body weight (PBW), based on gender and patients' height [1]. Consequently, height inaccuracy may be a limiting factor to adequately reduce the tidal volumes. In this regard, it should be underscored that predicted body weight rather than actual body weight must be used to calculate the prescribed tidal volume [8, 10]. The utilization of actual body weight can lead to large errors in tidal volume settings [11], especially in women and obese patients [8, 12]. Visual estimation of the patient's height is frequently used in mechanically ventilated patients [13, 14]. However, visual estimation of height and even more of the predicted body weight are inaccurate [15-18].

In addition, despite strong evidence and recommendations, protective mechanical ventilation is not optimally implemented [19-23] ; unavailability of the height may be an additional barrier[11].

Considering the central role of the physiological value of the patient's height and its impact on mechanical ventilation settings we conducted the present study to evaluate the accuracy of usual measurements of height in mechanically ventilated patients and to assess alternative measurements.

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Material and Methods

From July 2010 to December 2011, we conducted a prospective study to evaluate height measurement accuracy in patients requiring cardiac surgery at the Institut Universitaire de Cardiologie et de Pneumologie de Québec. Study approval was obtained from the local ethics committee and informed consent was obtained from all subjects before surgery.

Subjects

The research coordinator screened patients before the surgery. The exclusion criteria were the inability for the patient to stand up for initial measurement including emergent surgeries and patients already on mechanical ventilation before the surgery.

Study measurements (Figure 1)

Pre-operatively

The gold standard used for comparison was the subjects' actual height, measured with a height gauge while subjects were standing up. We also measured the lower leg size to calculate patients' heights by using the Chumlea method [24-26]. We measured the lower leg size with a special caliper while the patient was sitting with the knee at a 90-degree angle. The size from the top of the knee (patella) to the bottom of the heel was measured. The patient's height was calculated by using previously described equations [26]. In addition, we measured the patient's forearm with a measuring tape between the olecranon process of the elbow and the midpoint of the prominent styloid process of the radius. We then calculated the height based on a previously described chart [27]. Each measurement was performed only once for each patient, and two different investigators were involved in these measurements.

Post-operatively

Within the first minutes after ICU arrival, while subjects were on mechanical ventilation, other data were recorded. First, patients' heights were visually estimated by a nurse or a respiratory therapist and then subsequently measured by a nurse with a measuring tape while the patient was supine in bed. Nurses were not aware of the patient's pre-operative height [Figure 1]. The predicted body weight was calculated using the previously validated equations [1].

Statistical analysis

The data values are presented as means ± standard deviation. Categorical variables are presented as counts. The agreement between the results was expressed by the Bland and Altman method [28] and all of the data are presented using Bland-Altman plots. Estimated bias (average of the differences between the reference height (gauge) and the different measuring methods) and 95% of limits of agreement (bias ± 1.96*standard deviation) were calculated. For errors of measurement, we calculated the mean of absolute difference between the reference and the different measuring methods. A generalized linear mixed model was performed using the normality or the binary model according to the data distribution. A compound symmetric structure was used to take into account the dependency among measurements. Posteriori comparisons were performed using the Tukey's technique. Relationships between the reference and the other methods of measurement were analyzed using the Pearson's correlation coefficients. All report p-values were declared significant at 0.05 level. Data were analyzed using statistical package SAS v9.3 (SAS Institute Inc, Cary, NC).

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Results

Subjects

One hundred subjects were studied (75 men and 25 women) with a mean age of 66.0 ± 9.3 years. A total of 500 measures of patients' heights were obtained (five measurements per patient). The mean actual weight was 79.5 ± 17.6 kg while the mean predicted body weight was 61.0 ± 9.6 kg. The median (interquartile) height measured by height gauge before the surgery was 167 (159-174) cm. Data on height obtained with the different measuring methods and errors in comparison with the reference measure are shown in table 1.

Differences between actual height, measuring tape method and visual estimation

Measuring tape and visual estimation were well correlated with the reference, height gauge (Figure 2). Compared with the reference, bias with measuring tape was -3.7±5.0 cm with 95% limits of agreement between 6.2 and -13.5 cm and bias with visual estimation was -4.0±7.0 cm with 95% limits of agreement between 9.7 and -17.7 cm (Figure 3). Maximum errors with measuring tape and visual estimation were 19.0 cm and 20.5 cm respectively.

Error of the visual estimation was inversely correlated to the patient's height ($r=0.52$, $P<0.0001$) (Fig. E2). Mean error with visual estimation was significantly greater with shorter subjects (those with height below or equal to the median value of 167 cm) (7.3±6.7 vs. 0.4±5.5 cm, $P<0.0001$).

Alternative methods (height derived from the lower leg (Chumlea method) and forearm size)

Height derived from lower leg and forearm correlated well with height gauge (Figure 2). Compared with the reference, bias with lower leg was -2.4±3.9 cm with 95% limits of

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agreement between 5.2 and -10.0 cm and bias with forearm was -1.3±5.0 cm with 95% limits of agreement between 8.6 and -10.8 cm (Figure 3). Maximum error with lower leg and forearm methods were 11.9 cm and 20.0 cm respectively.

Potential impact on protective mechanical ventilation

Mean actual body weight was 25% higher than the PBW, and differences in the calculation of tidal volumes with actual body weight vs. PBW were of similar amplitude. The errors for predicted body weight were higher when the calculation of PBW was based on visually estimated heights and lower when the Chumlea method was used (Table 2). PBW errors greater than 10% were present in 15% of subjects when using the lower leg or forearm methods, 25% when using measuring tape and 40% when relying on the visual estimation (Table 2). As expected, the error on tidal volume settings was marked when actual weight rather than PBW was used (Table 3). We compared the impact of the errors for shorter patients and taller patients based on the median height of the patients (i.e. 167 cm). Actual weight was higher than PBW, from +21% (in patients >167 cm) to +35% (in patients ≤ 167 cm) (Table 3). In comparison with tidal volume set with PBW based on the reference height, overestimation of tidal volume settings in short subjects went from 296 ml with actual weight to 82 and 73 ml with lower leg and forearm methods respectively (Table 3). Among shorter patients (≤167 cm), the proportion of women was 45.1% (23/51), while in the subgroup of taller patients (>167 cm), the proportion of women was only 4.1% (2/49) (P<0.001) (Table 3). Ninety-two percent of the women measured less than the median height.

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Discussion

Predicted rather than actual body weight should be used to determine the tidal volume required for mechanically ventilated patients[1, 8, 10]. However, patient's height is required to calculate predicted body weight[1] . We compared different direct and alternative methods to measure height in one hundred beddriden mechanically ventilated patients. We showed that significant differences exist between these methods (tape measure, visual estimation, patients' height delivered from lower leg size, and forearm-measuring method) and the reference standard (gauge measurement). We found that the visual estimation to determine height was an inaccurate method with large potential errors. The alternative methods based on lower leg and forearm length were close to the gold standard method and at least as efficient as the measuring tape method. This study represents the largest evaluation of different methods to evaluate height in bedridden patients and demonstrates the potential impact on protective ventilation implementation.

Despite the paucity of data, several studies suggest that height is not used to set the tidal volume [11, 14], or that height is unknown, as up to 40% of ARDS patients had no height in their medical record [29] and consequently the visual estimation of height or weight is frequently used [13, 14, 30]. In surgical units, patients are frequently measured preoperatively. In a recent study, patients' heights measured before surgery were available in 3763 patients and missing in only 6 patients (0.16%) [8]. Although few data are available, it is likely that the tape measurement of beddriden patients is also frequently used in medical patients when height is not known. In a survey in the UK, 15 intensive care units out of 20 measured patients with tape and 5 estimated heights [13]. Our results show that visual estimation and the tape measuring method while

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patients are supine in bed are not accurate, with maximal errors around 20 cm with these methods. These errors were associated with large errors in tidal volume settings. Our results are in agreement with previous data that showed inaccuracy of visual estimations in different populations [15-18, 31, 32]. To our knowledge, there is no study evaluating accuracy of the tape measuring method in beddriden patients in comparison with the reference method with a height gauge when patients are standing upright.

Several methods have been described to obtain patient's height indirectly, among which lower leg measurement (knee-heel length, Chumlea method) [24-26], patients' forearm (from elbow to the wrist) and demi-span (distance from the middle of the sternal notch to the tip of the middle finger in the coronal plane) are the most frequently evaluated [27, 33]. These alternative methods are potentially useful for bedridden patients or mobility-impaired patients [24]. For these patients, the utilization of the tape measuring method to measure height directly may be difficult (the patient's position in bed or the utilization of short tape measures are potential sources of errors) and may not be accurate as we describe in the present study. The use of flexible tape to measure lower leg is a potentially interesting solution [34].

The Chumlea method which allows height estimation from knee-heel length has been validated in large cohorts [24-26, 35]. In elderly patients, who represent the majority of mechanically ventilated patients, this method was accurate in determining patient height [25, 26]. Our study evaluated two indirect methods (based on lower leg and forearm measurements) and we showed that these methods were well correlated with the reference method and were at least as accurate as the measure with tape in beddriden patients. Maximum errors were equivalent (with forearm measure) or lower (with lower leg measure) in comparison with tape measuring.

Potential impact on implementation of protective ventilation

In this study, tidal volumes were much higher when actual rather than predicted body weight were considered, which is in line with previous reports [11]. It is now recommended to set tidal volume based on predicted rather than on actual body weight [1, 8, 10]. However, errors in the measurement or estimates of patient's height are responsible for errors when calculating PBW and consequently on tidal volume settings. It is likely that visual estimation is frequently used in mechanically ventilated patients. In the present study, the error on height estimation was greater in short patients. Importantly, in this subgroup of shorter patients, almost all were women. Consequently, the impact on tidal volume setting was greater in this subgroup. Patients of shorter height were less likely to receive protective ventilation in previous studies [36, 37].

The tape measuring method was also associated with potentially high errors on tidal volume settings. Overestimation of the tidal volume almost attained 150 mls when tape measuring was used to calculate PBW rather than the reference height. With alternative methods (lower leg and forearm measurements), maximal errors on tidal volume were limited between 73 to 87 mls. In addition, owing to the formula for the PBW calculation, an error on height measurement or estimation leads to higher errors on tidal volume settings in women in comparison with men (Figure E1). Our data helps explain in part why women frequently receive higher tidal volumes as compared to men [7, 8, 11, 12, 30, 36].

These data highlight the importance of height in effectively reducing tidal volumes, which may be difficult when accurate height measurements are not available. Consequently, finding an accurate and easy method to obtain height in bedridden patients is of great importance.

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Limitation of our study

Our study has several limitations. The Chumlea method (based on lower leg measurement) in this study was not recorded directly in bedridden subjects, but preoperatively, in subjects sitting in a chair with the knee at a 90-degree angle, which limits the chance of errors. The results may therefore not be directly transposable to the situation of mechanically ventilated supine patients. The present study is to be considered as a first step to assess this method as a potential alternative method of measurement. In a subsequent study, we have evaluated a modified Chumlea method, using lower leg measurement in beddriden subjects. Preliminary evaluation of this new method showed promising results with very close correlation with the reference method [38]. In the present study we did not test the reproducibility of the measurements with different investigators and this will need to be performed in subsequent studies.

One must keep in mind that Chumlea's stature prediction equations have been made specifically for defined populations [25] and specific equations have been developed and should be used for differing populations [39, 40].

Tidal volume may not be the optimal value to consider in mechanically ventilated patients. Indeed, some authors advocate the utilization of other physiological surrogates such as transpulmonary pressure or lung volumes instead of tidal volume/PBW, given the variable effect of a unique value of tidal volume in a large population of patients [41].

Clinical relevance of our results

Protective mechanical ventilation is insufficiently implemented [19-23], due to several identified barriers and it is likely that the difficulty to accurately measure patient's height and the poor availability of derived formulas to calculate predicted body weight are additional barriers. We describe in this paper several potential indirect methods, which are at least as accurate as the tape measure method in beddriden patients and are more achievable. The data presented here also point out the inaccuracy of the visual estimation method, which can lead to large errors in tidal volume settings. Visual estimation of height should definitively be avoided as well as the use of actual body weight to determine tidal volumes [10].

The optimal tidal volume to deliver in mechanically ventilated patients to prevent [5, 42] or to treat [4] ARDS in mechanically ventilated patients is still not clearly defined. It is however well accepted that high tidal volumes increase mortality in ARDS patients [1, 4] and are associated with poor outcome in patients without ARDS [5, 6]. To this end, implementation of low tidal volume strategies requires patients' heights to calculate PBW and to choose tidal volumes based on PBW rather than on actual body weight. The formulas used in the present study have been implemented in a free smartphone application (iAnthropometer ICU) that may facilitate implementation of protective ventilation [43].

Utilization of reliable methods to measure height is also desirable to homogenise practices in the clinical field and for a research purposes. In the meta-analysis conducted by Eichaker et al. the authors showed that among the 5 randomized controlled trials evaluating different tidal volumes in ARDS patients, 4 different methods were used to determine the weight: actual weight, dry weight, ideal body weight, and predicted body weight [4]. These various surrogates of weight were acceptable when the rates of obesity (BMI > 30 kg/m^2) were approximately

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10%, but today it now approaches nearly 40 % in many countries [44] and consequently actual body weight cannot be used to set the ventilator given the risk of delivering high tidal volumes [8]. In daily practice, the alternative methods that we describe in this paper may be more accurate than visual estimation and easier to apply in comparison with the tape measure method.

Conclusion

In conclusion, we showed that the method used to obtain patient's height during mechanical ventilation might not be accurate and may have an impact on tidal volume settings. Tidal volume set according to the actual body weight leads to large errors and should not be used; PBW requiring patient's height should be used instead. The use of height measured with tape as well as visual estimation of height could also lead to large errors in tidal volume settings. When reference height is not available in patients undergoing mechanical ventilation, alternative methods to obtain patient's height based on lower leg and on forearm measurements could be useful to facilitate the application of protective mechanical ventilation to prevent [5] or to treat ARDS [1, 2]. Knowledge and accurate application of a patient's height is a low-cost therapeutic intervention based on basic physiology as the size of the lungs are closely related to height [9]. This simple yet under recognized fact should not be overlooked especially if ones consider that the only proven treatment of ARDS relies on the application of appropriate ventilator settings [1, 2].

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Figure Legend

Figure 1: Different methods to measure height
Five methods to obtain patients' height were compared. Preoperatively, patients were measured with a height gauge while patients were standing upright (1); this measure was used as the gold standard. Lower leg (2) and forearm (3) were also measured and patient height was derived from previously validated formulas [26, 27]. Formulas to predict height based on lower leg measurement are provided, based on the reference 26.
Postoperatively, patients' heights were visually estimated (4) by one clinician and patients were subsequently measured with a tape measure (5) in supine bedridden patients.

Figure 2: Pearson correlations between the reference values for height measurement and visual estimation (2a), measuring tape (2b), lower leg measure (2c) and forearm measure (2d). *Solid lines* represents linear regression (equations are provided for each correlation). The *dotted lines* show the 95% confidence interval for individual values.

Figure 3: Bland and Altman graphs comparison of the reference value for height measurement and visual estimation (2a), measuring tape (2b), lower leg measure (2c) and forearm measure (2d). *Solid horizontal line* represents the mean of the differences (bias) and the *dotted lines* represent the precision (95% confident interval = bias±1.96 standard deviations of the difference).

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	Height gauge (Reference)	Visual estimation	Tape measuring	Lower leg (Chumlea)	Forearm measure	p Value†
Height (cm) Mean±SD	165.8±9.1	169.6±8.3	169.4±9.7	168.2±9.0	167.2±7.4	<0.001
Bias (95% CI) (cm)	_	-4.0 (-17.7;9.7)	-3.7 (-13.5;6.2)	-2.4 (-10.0;5.2)	-1.3 (-10.8;8.6)	-
Error (cm) * Mean±SD	–	6.4±4.8	4.7±4.0	3.7±2.6	3.7±3.4	<0.001
Maximum error (cm) *	_	20.5	19.0	11.9	20	-
% Error * Mean±SD	–	3.9±3.1	2.9±2.5	2.3±1.6	2.3±2.0	<0.001
Number of patients with error > 5 % *	–	31	16	7	12	0.002
Number of patients with error > 10 % *	–	5	2	0	1	0.074
Number of patients with error > 20 % *	–	0	0	0	0	1.00

Table 1: Difference between the reference values and the other methods to measure patient's height.

* Errors of measurement are comparisons with the reference value of height (measure with height gauge while patient was standing upright prior to surgery)

† Statistical method: generalized linear model with repetitive measurements

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	PBW based on height gauge (Reference)	PBW based on visual estimation	PBW based on tape measuring	PBW based on lower leg (Chumlea)	PBW based on forearm measure	p Value†
Predicted Body Weight (kg) Mean±SD	61.0±9.7	64.6±8.8	64.4±10.0	63.2±9.7	62.7±8.0	<0.001
Bias (95% CI) (kg)	_	-3.5 (-15.8;8.8)	-3.2 (-12.2;5.7)	-2.1 (-9.1;4.8)	-1.2 (-10.1;7.8)	-
Error (kg) * Mean±SD	–	5.7±4.3	4.2±3.6	3.4±2.4	3.5±3.1	<0.001
Maximum error (kg) *	_	18.7	17.3	10.9	18.2	-
% Error * Mean±SD	–	10.0±8.5	7.2±6.8	5.8±4.3	6.0±5.4	<0.001
Number of patients with error > 5 % *	–	63	48	41	45	0.005
Number of patients with error > 10 % *	–	40	25	15	15	<0.001
Number of patients with error > 20 % *	–	9	7	0	1	0.027

Table 2: Difference between the predicted body weight based on the reference height and based on the other measuring methods. The number of patients with errors above 5, 10 and 20% with actual body weight compared to predicted body weight (PBW) was 88, 78 and 63 respectively.

* Errors are comparisons with the predicted body weight calculated with the reference value of height (measure with height gauge while patient was standing upright prior to surgery)

† Statistical method: generalized linear model with repetitive measurements

	Patients with height > 167 cm* (n=49)	**Patients with height ≤ 167 cm* (n=51)**
Female gender, n (%)	2 (4.1)	23 (45.0)
Age (year)	63 (57; 68)	71 (63; 75)
BMI (kg/m^2)	26.5 (22.7; 31.0)	28.4 (26.7; 30.5)
Height (cm)		
Based on height gauge (reference)	**174 (171; 176)**	**159 (153; 162)**
Based on lower leg	175 (172; 178)	163 (157; 167)
Based on forearm	173 (170; 175)	163 (158; 166)
Based on visual estimation	175 (170; 178)	165 (159; 171)
Based on measuring tape	176 (173; 180)	162 (158; 168)
Weight (kg)		
Actual weight (kg)	83.8 (73.8; 94.1)	73.2 (61.3; 81.3)
PBW based on height gauge (reference)	**69.2 (66.4; 71.5)**	**54.2 (47.2; 58.7)**
PBW based on lower leg	70.2 (68.2; 73.4)	57.4 (49.9; 63.2)
PBW based on forearm	68.7 (66.5; 70.6)	58.7 (50.6; 62.8)
PBW based on visual estimation	70.6 (66.0; 73.3)	59.7 (52.4; 66.0)
PBW based on measuring tape	71.5 (68.7; 75.1)	57.0 (52.4; 62.4)
Tidal volume 8 ml/kg (ml)		
TV based on actual weight	670 (591; 753)	585 (490; 650)
TV based on height gauge (reference)	**554 (531; 572)**	**434 (377; 470)**
TV based on lower leg	562 (546; 587)	459 (399; 506)
TV based on forearm	550 (532; 565)	470 (405; 503)
TV based on visual estimation	565 (528; 586)	478 (419; 528)
TV based on measuring tape	572 (550; 601)	456 (419; 499)
Error on tidal volume compared to reference (ml)**		
Δ TV based on actual weight	-118 (-192; -41)	-130 (-202; -94)
Δ TV based on lower leg	-12 (-24; -9)	-27 (-42; -12)
Δ TV based on forearm	7 (-5; 22)	-29 (-51; -7)
Δ TV based on visual estimation	-4 (-33; 18)	-55 (-80; -18)
Δ TV based on measuring tape	-18 (-44; 4)	-22 (-44; -7)

Table 3: Impact of the method of height measurement on tidal volume setting. Median (interquartile) values are reported in this table. Minimum and maximun differences are displayed in the online supplement.

*167 cm represents the median value for patients' height in this cohort.

**The error was calculated for a target of 8 ml/kg with the following formula: tidal volume with height reference – tidal volume with other methods. Negative values correspond to overestimation of the tidal volume.

Abbreviations: BMI: body mass index; PBW: predicted body weight; TV: tidal volume

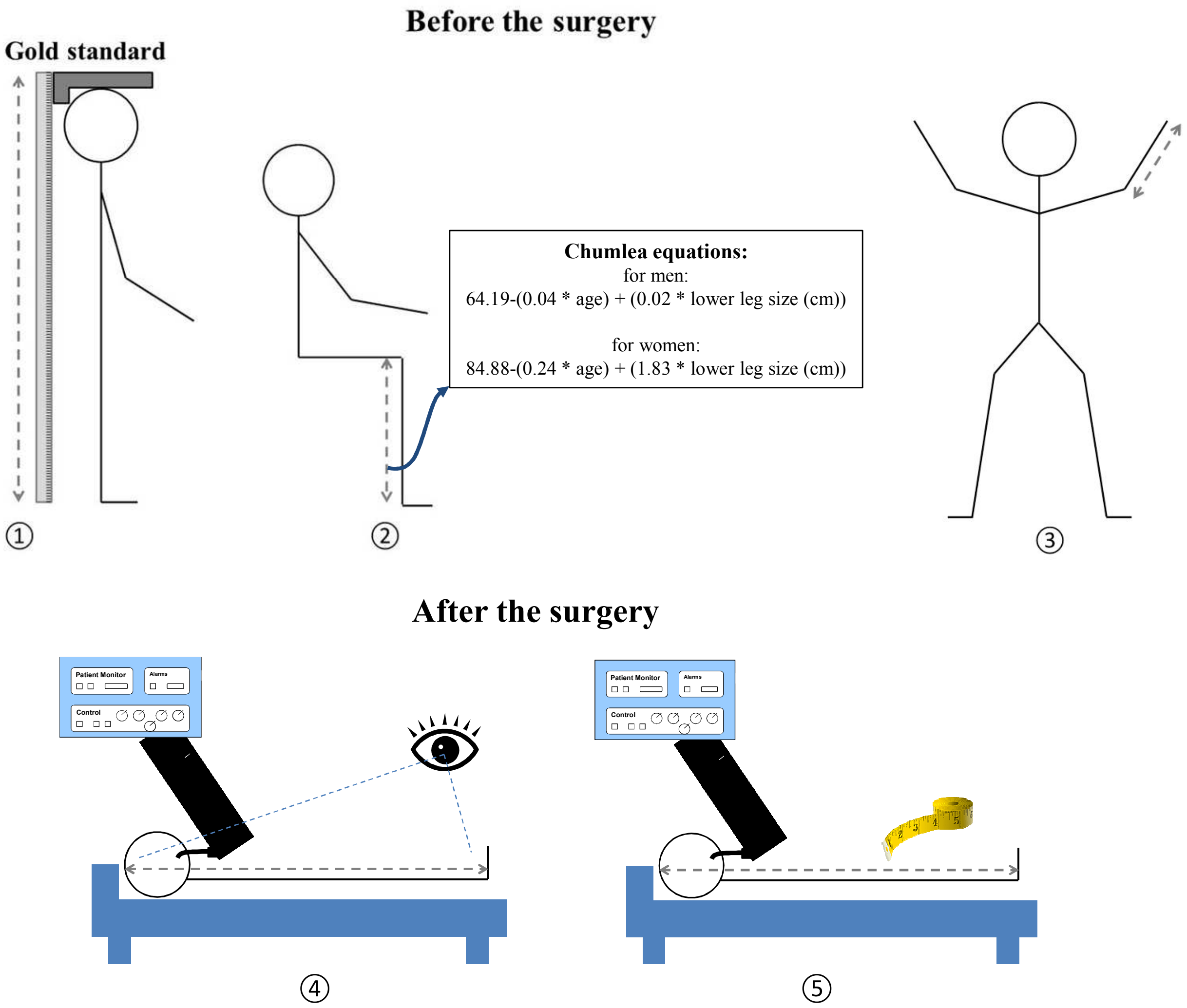

Figure 1: Different methods to measure height

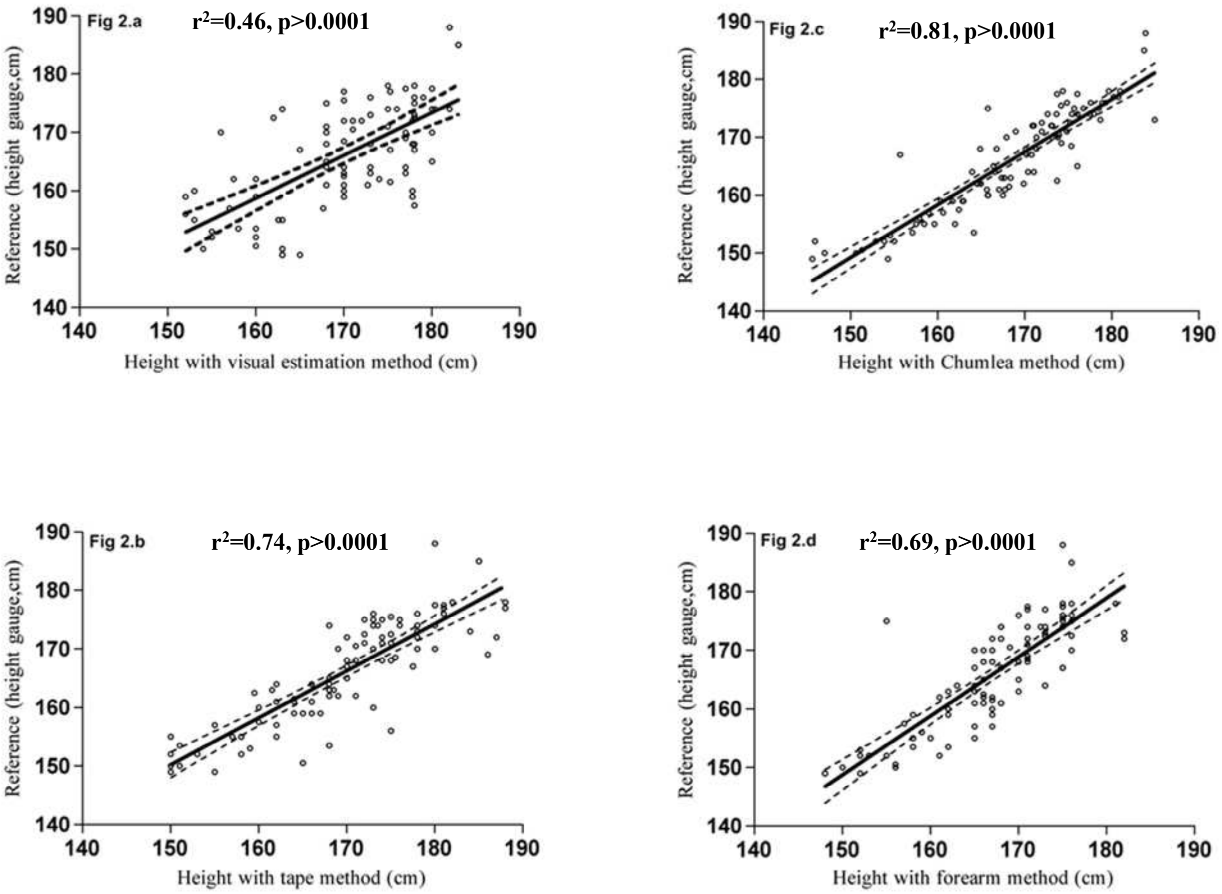

Figure 2: Scatterplots with Pearson correlations between the reference values for height measurement and visual estimation (2a), measuring tape (2b), lower leg measure (2c) and forearm measure (2d).

The solid line represents the regression line and dotted lines represent the 95% confidence interval.

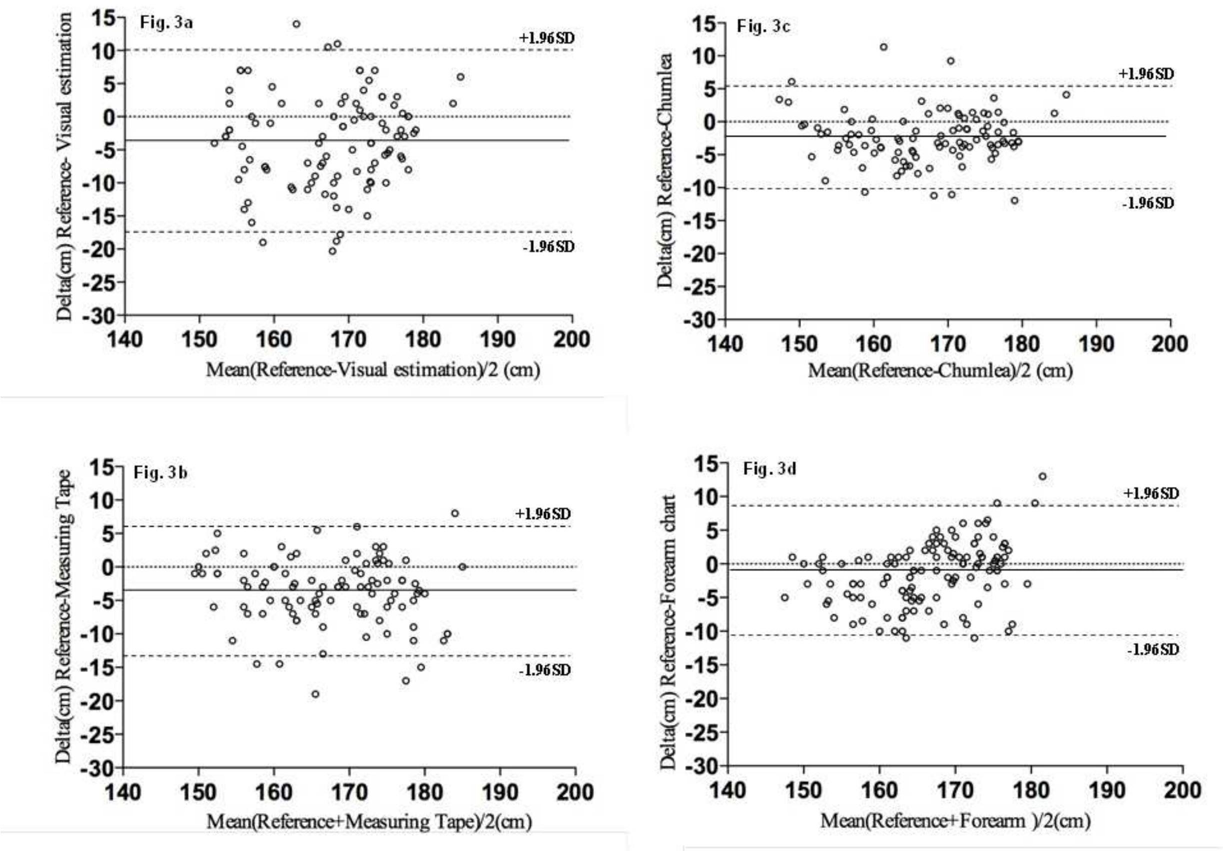

Figure 3: Bland and Altman graphs comparison of the reference value for height measurement and visual estimation (3a), measuring tape (3b), lower leg measure (3c) and forearm measure (3d).

The solid line represents the bias and dotted lines represent the 95% confidence interval.